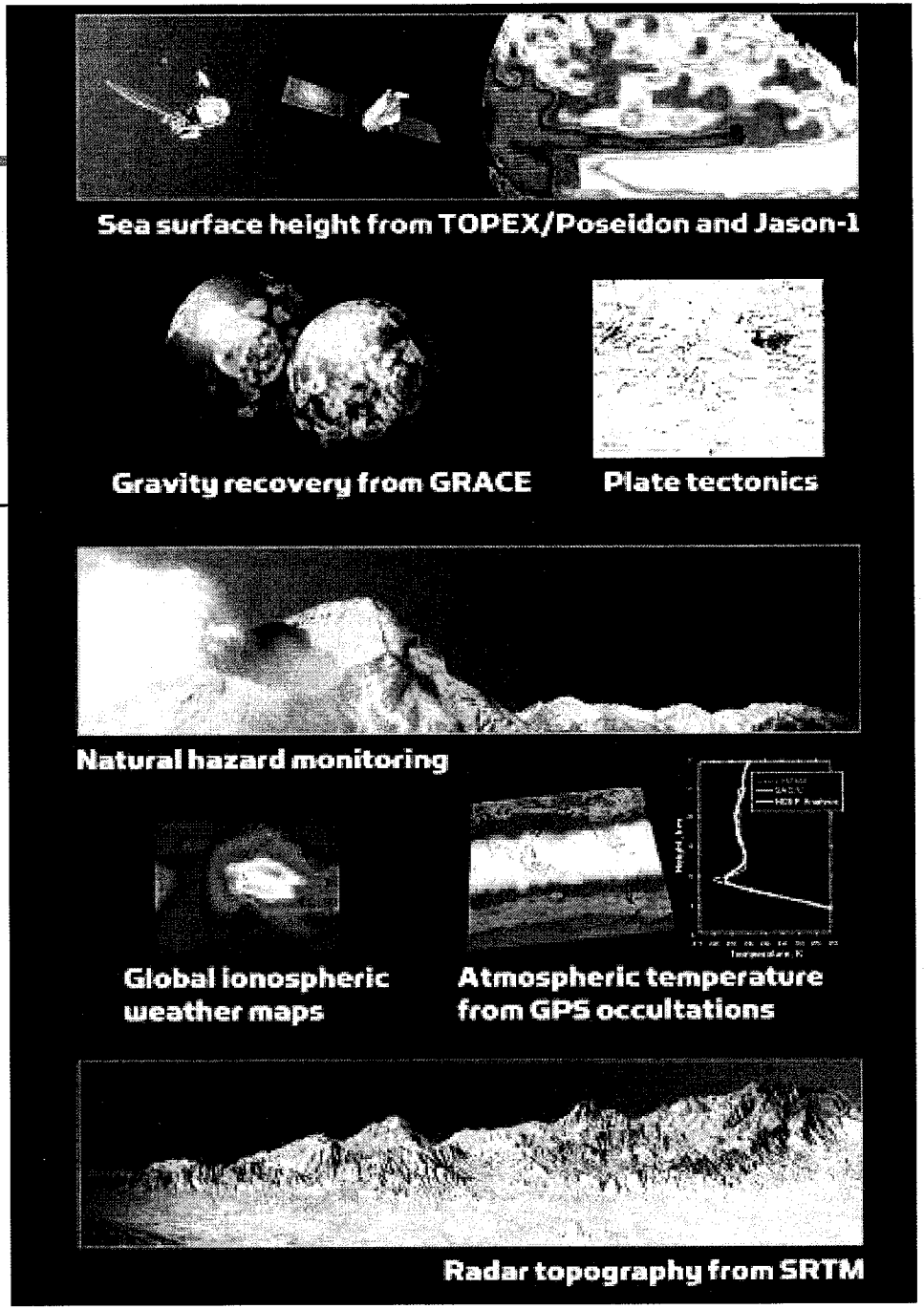
GPS at JPL: an Overview

Jim Zumberge & Yoaz Bar-Sever
Tracking Systems & Applications Section

- Receivers on the ground
  - ⇒ *plate tectonics, natural hazards, global & regional*
  - ⇒ *Critical for all precision GPS applications*
- Software
  - ⇒ *GIPSY*
  - ⇒ *RTG (real-time Gipsy)*
- Receivers in space
  - ⇒ *mission support: precision orbit determination*
  - ⇒ *science instrument: atmosphere & ionosphere*
- Global differential real-time GPS
  - ⇒ *decimeter-level real-time positioning*
  - ⇒ *on the ground and (soon) in space*



21 March 2005

TRACKING SYSTEMS AND APPLICATIONS
Section 3350

J.F. Zumberge, Manager
Y. Bar-Sever, Deputy Manager

Technical Staff
H. Abakians (PEM)
C. Dunn (PEM)
M. G. Kelsay

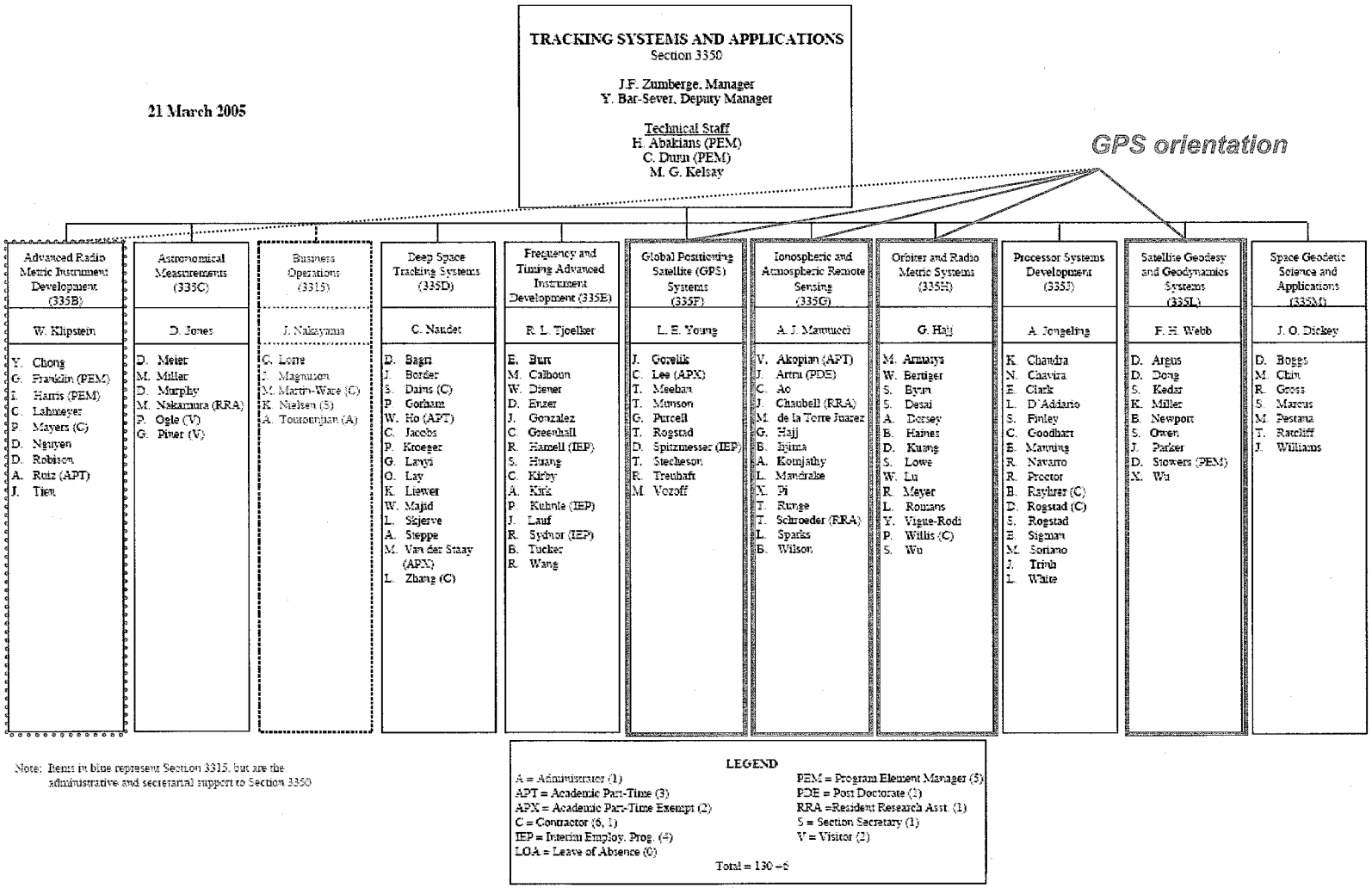
Advanced Radio Metric Instrument Development (335B)	Astronomical Measurements (335C)	Business Operations (3315)	Deep Space Tracking Systems (335D)	Frequency and Timing Advanced Instrument Development (335E)	Global Positioning Satellite (GPS) Systems (335F)	Ionospheric and Atmospheric Remote Sensing (335G)	Orbiter and Radio Metric Systems (335H)	Processor Systems Development (335J)	Satellite Geodesy and Geodynamics Systems (335L)	Space Geodetic Science and Applications (335M)
W. Klipstein	D. Jones	J. Nakayama	C. Naudet	R. L. Tjoelker	L. E. Young	A. J. Mannucci	G. Hajj	A. Jongeling	F. H. Webb	J. O. Dickey
Y. Chong	D. Meier	C. Lorre	D. Bagri	E. Burt	J. Gorelik	V. Akopian (APT)	M. Armatys	K. Chandra	D. Argus	D. Boggs
G. Franklin (PEM)	M. Miller	J. Magnuson	J. Border	M. Calhoun	C. Lee (APX)	J. Artru (PDE)	W. Bertiger	N. Chavira	D. Dong	M. Chin
I. Harris (PEM)	D. Murphy	M. Martin-Ware (C)	S. Dains (C)	W. Diener	T. Meehan	C. Ao	S. Byun	E. Clark	S. Kedar	R. Gross
C. Lahnoeyer	M. Nakamura (RRA)	K. Nielsen (S)	P. Gothard	D. Enzer	T. Munson	J. Chaubell (RRA)	S. Desai	L. D'Addario	K. Miller	S. Marcus
P. Mayers (C)	P. Ogle (V)	A. Tourtoughian (A)	W. Ho (APT)	J. Gonzalez	G. Purcell	M. de la Torre Juarez	A. Dorsey	S. Finley	B. Newport	M. Pestana
D. Nguyen	G. Piner (V)		C. Jacobs	C. Greenhall	T. Rogstad	G. Hajj	B. Haines	C. Goodhart	S. Owen	T. Ratcliff
D. Robison			P. Kroeger	R. Hamell (IEP)	D. Spitzmesser (IEP)	B. Iijima	D. Kuang	E. Marroing	J. Parker	J. Williams
A. Ruiz (APT)			G. Lanyi	S. Huang	T. Stecheson	A. Komjathy	S. Lowe	R. Navarro	D. Stowers (PEM)	
J. Tien			O. Lay	C. Kirby	R. Treuhaft	L. Mandrake	W. Lu	R. Proctor	X. Wu	
			K. Liewer	A. Kiria	M. Vozoff	X. Pi	R. Meyer	B. Rayhrer (C)		
			W. Majid	P. Kroble (IEP)		T. Runge	L. Romans	D. Rogstad (C)		
			L. Skjerve	J. Lauf		T. Schroeder (RRA)	Y. Vigue-Rodi	S. Rogstad		
			A. Steppe	R. Sydnor (IEP)		L. Sparks	P. Willis (C)	E. Sigman		
			M. Van der Staay (APX)	B. Tucker		B. Wilson	S. Wu	M. Soriano		
			L. Zhang (C)	R. Wang				J. Trinh		
								L. White		

Note: Items in blue represent Section 3315, but are the administrative and secretarial support to Section 3350

LEGEND

A = Administrator (1)
APT = Academic Part-Time (3)
APX = Academic Part-Time Exempt (2)
C = Contractor (6, 1)
IEP = Interim Employ. Prog. (4)
LOA = Leave of Absence (0)
PEM = Program Element Manager (5)
PDE = Post Doctorate (1)
RRA =Resident Research Asst. (1)
S = Section Secretary (1)
V = Visitor (2)

Total = 130 +6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GPS Capabilities in the Tracking Systems and Applications Section: Introduction

All of JPL's R&D work on GPS is carried out in the Tracking Systems and Applications Section (335)

One of the world's largest and most accomplished GPS center of excellence

5 GPS groups ~ 60 engineers/scientists

End-to-end expertise: systems, software, hardware, infrastructure, flight experiments, operations, science - complete vertical integration

Distinguished track record of leadership and innovation since inception of GPS

GPS-derived technology infuses deep space, formation flying, and other technologies

Outstanding record of technology transfer

Direct contributions to operational GPS

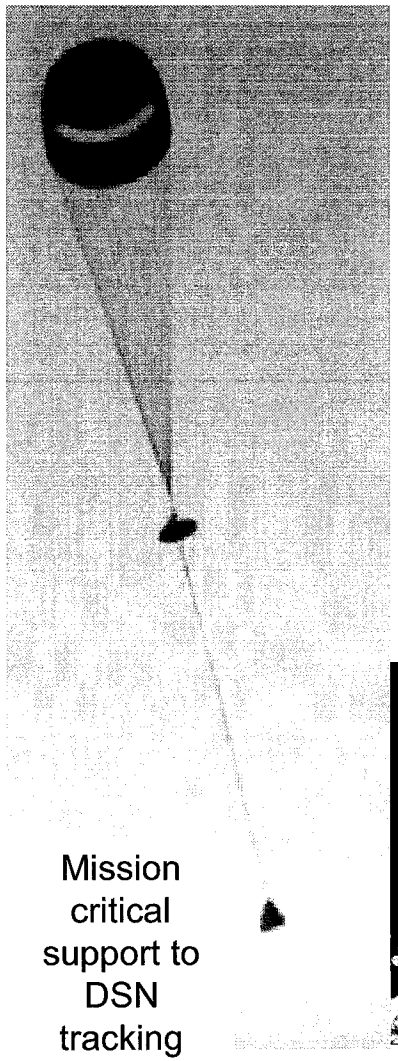
Wide Area Augmentation System (WAAS) algorithms and software to the FAA

Successful GPS technology transfer to industry, government, and academia

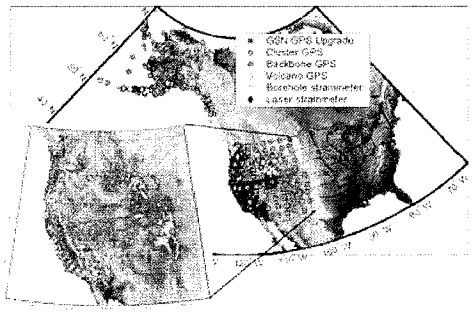
Hundreds of software licenses for GIPSY-OASIS and Real Time GIPSY

Multiple awards, including Space Technology Hall of Fame, NASA Software of the Year

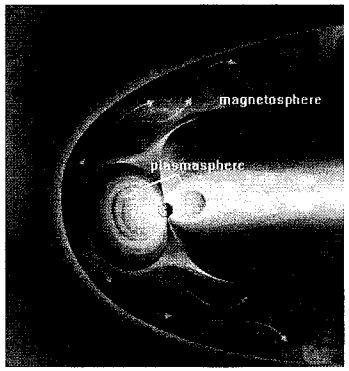
Current & Future Beneficiaries



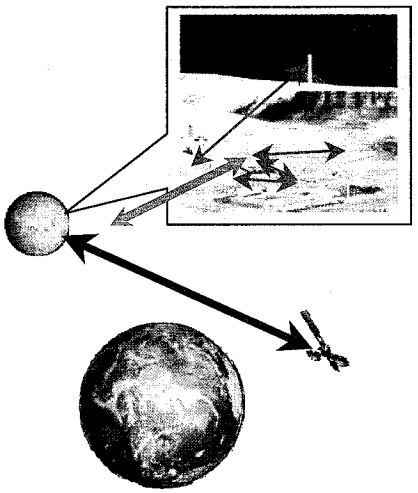
Mission critical support to DSN tracking



EarthScope

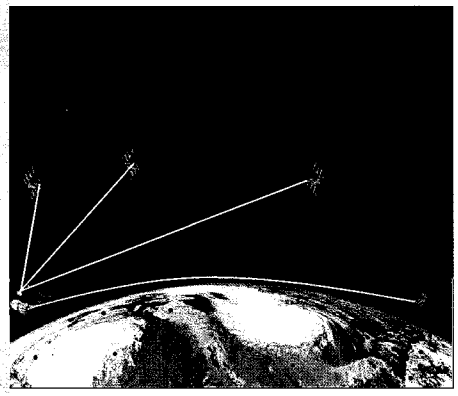


e⁻ density in space

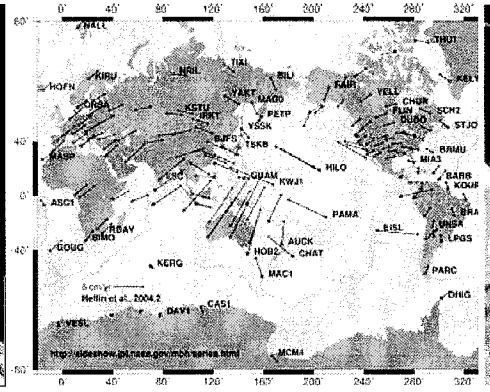


Lunar GPS & GNSS

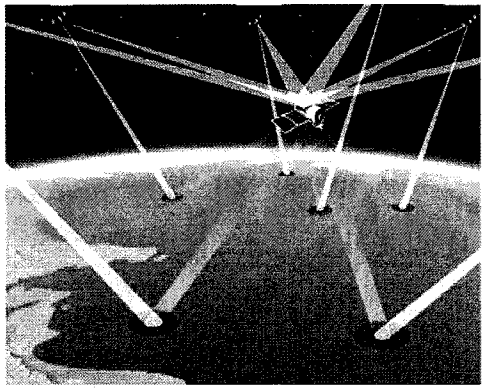
atmospheric occultations



terrestrial reference frame

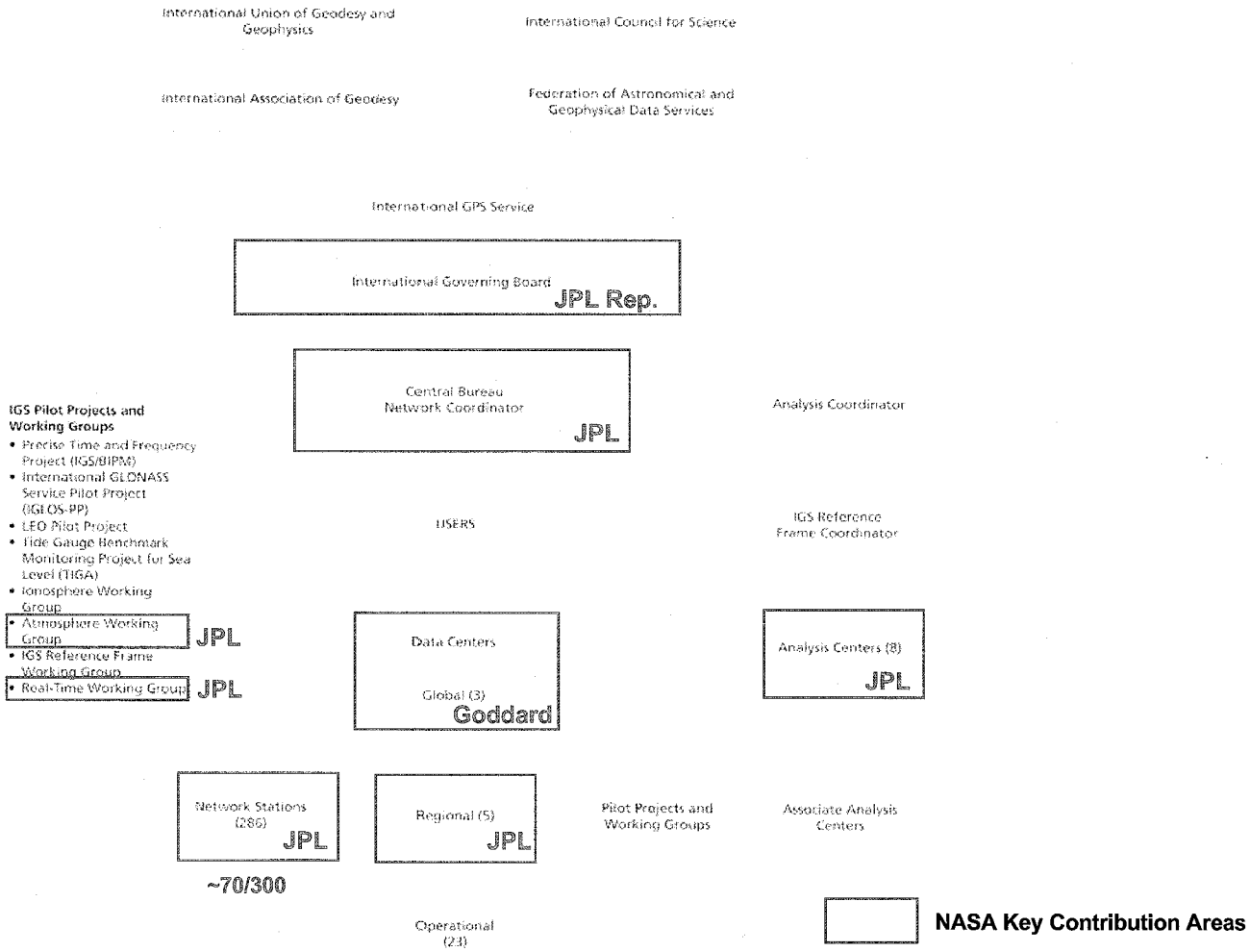


ocean surface height



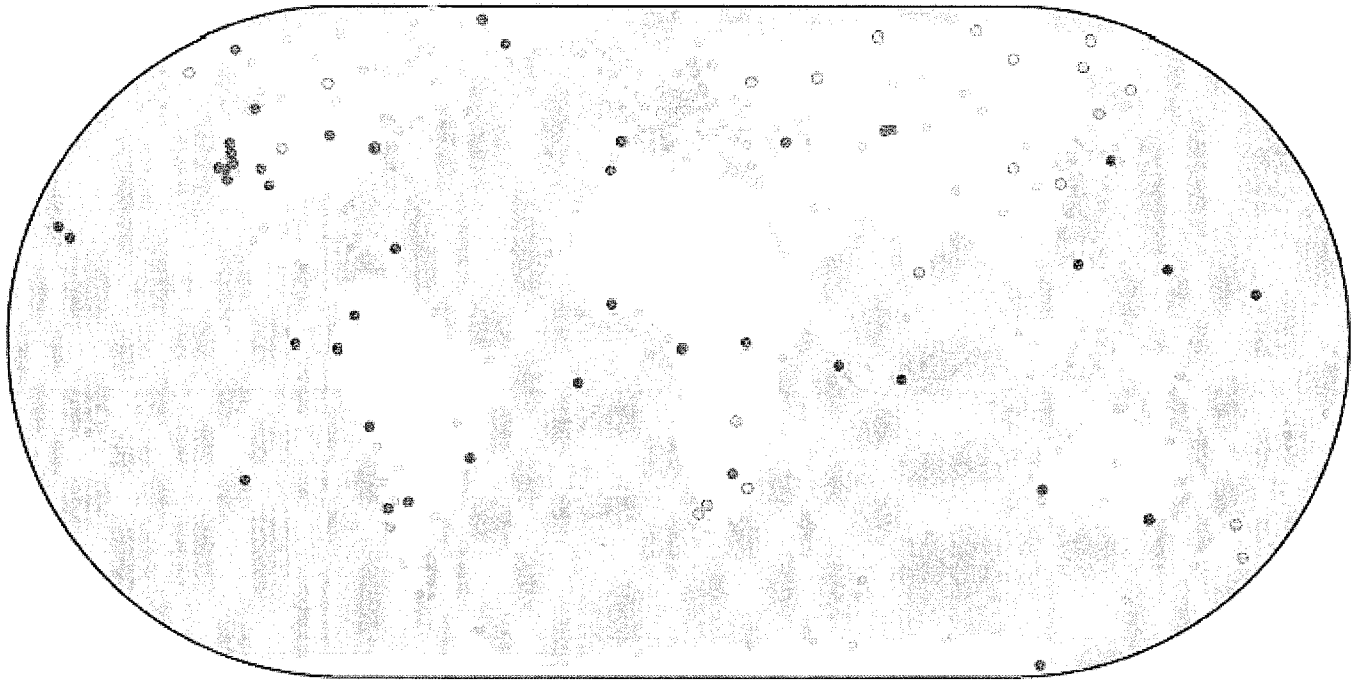
International GNSS Service (IGS)

The IGS is an international science consortium involving over 200 organizations from nearly 100 countries and is strongly supported by NASA



NASA GPS Global Network

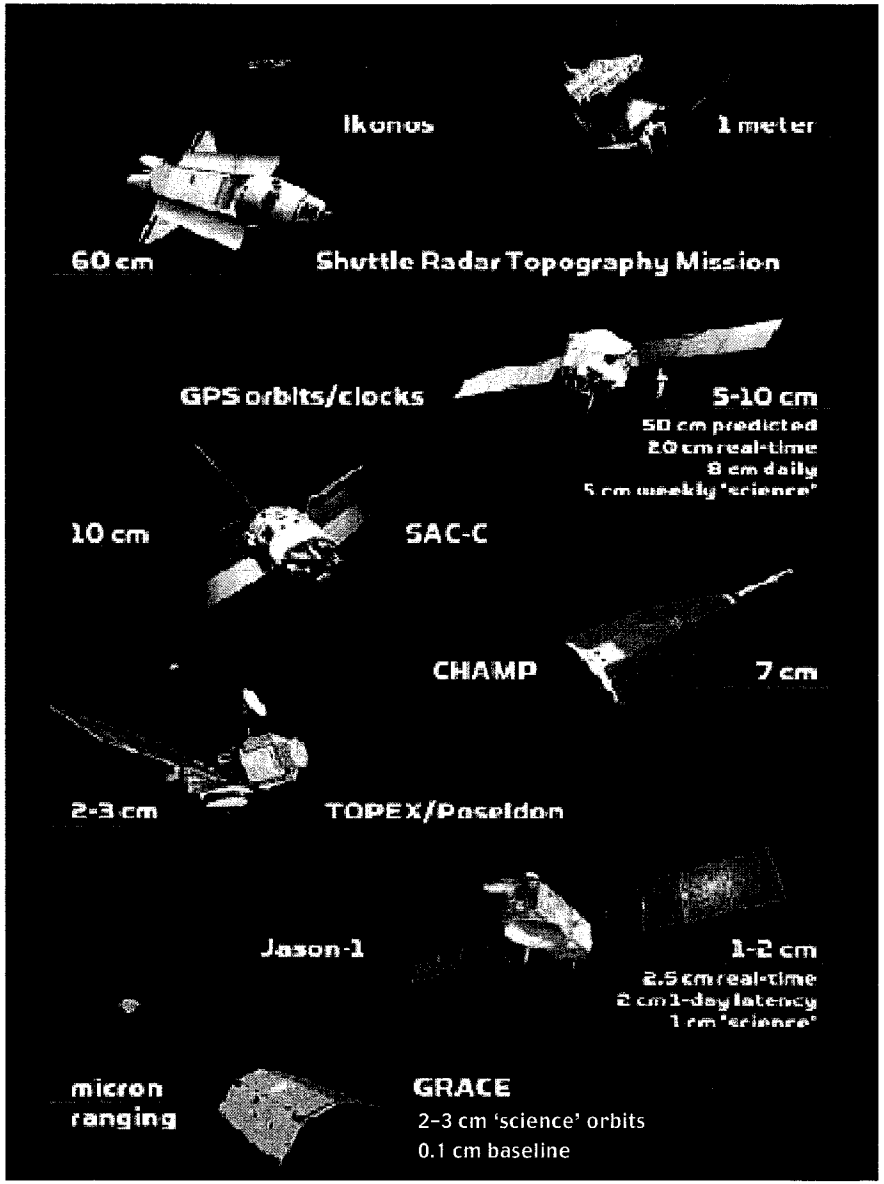
Tracking Network of the International GPS Service
Highlighting NASA's Contributions



- NASA GPS Stations
- NASA Cooperative Stations

Other Agency Stations

Precise Orbit Determination Technology and Operations



Award winning data analysis and simulation software packages

- GIPSY-OASIS, Real Time GIPSY (RTG)

Advanced spacecraft dynamic models adopted across industry

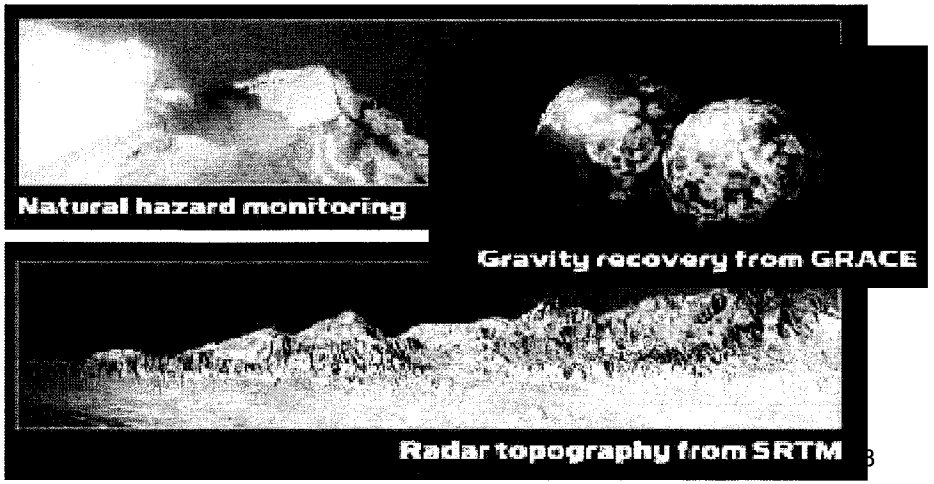
- Empirical solar pressure model
- GPS yaw attitude and signal models

Routine POD for flight projects, other customers

- GPS, Topex, Jason, GRACE, CHAMP, SAC-C…

Operational by-products from GPS POD

- Earth orientation and trop delay for DSN measurement calibration



Thumbnail History of GPS Receivers at JPL

1979 **SERIES** codeless receiver proposed

1981 ΔGPS proposed for **Topex** POD

1983 **SERIES-X** debut

1986 **Rogue** P-code receiver debut

1989 **Topex** receiver developed by Motorola

1991 **TurboRogue** debut

1992 **Topex** launched

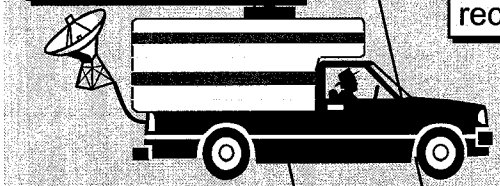
1994 **TRSR** built for GPS/MET

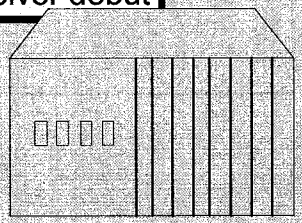
1996 **BlackJack** devt begins

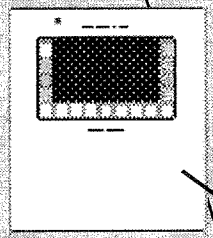
1999 **Ørsted/Sunsat** launched

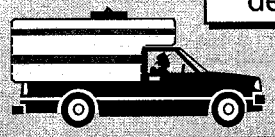
2000 **SRTM Champ SAC-C**

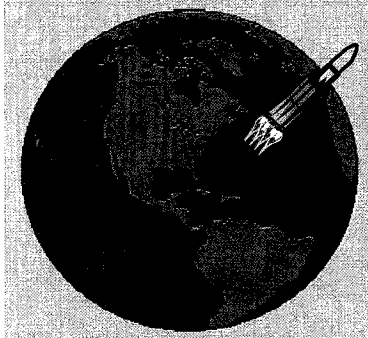
CHAMP

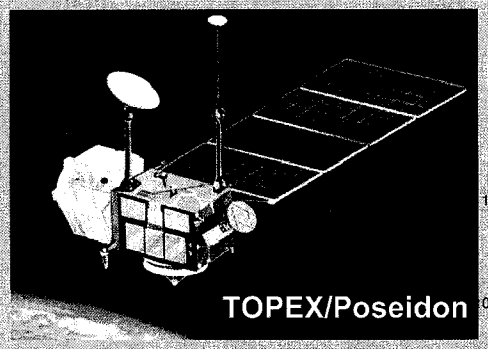


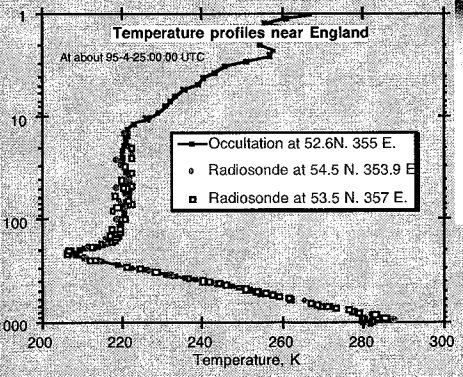


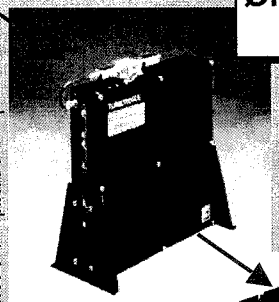


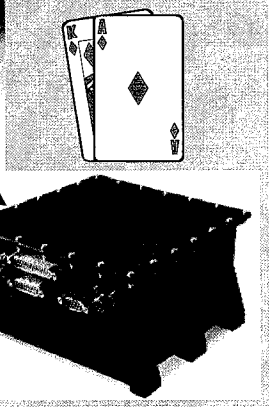






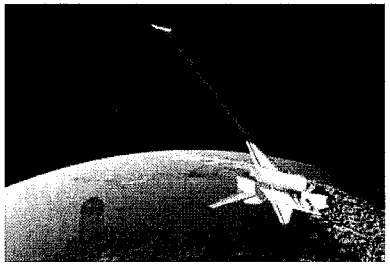






JPL/NASA BlackJack GPS Receivers: > 17 Flight Years of Successful Operations in Space

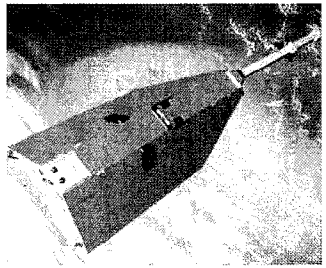
The most precise GPS receivers flown in space -- enabling new science and navigation capabilities



45-cm accuracy

SRTM

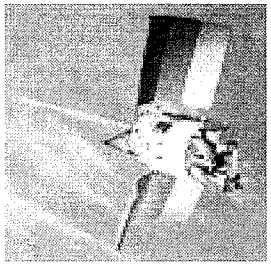
Feb 2000



4-cm accuracy

CHAMP

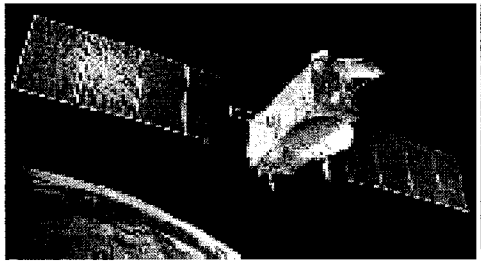
Jul 2000



4-cm accuracy
Sub-meter real-time demo

SAC-C

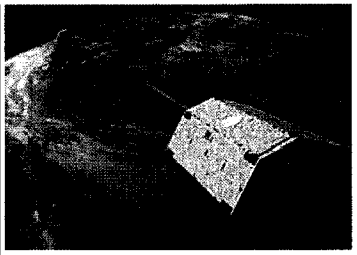
Nov 2000



1-cm accuracy

JASON-1

Dec 2001



1-cm accuracy

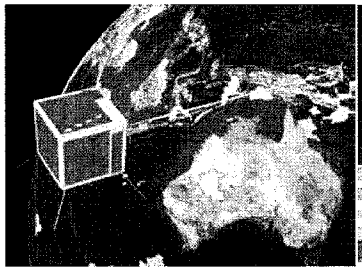
GRACE

Mar 2002

Missions In Development

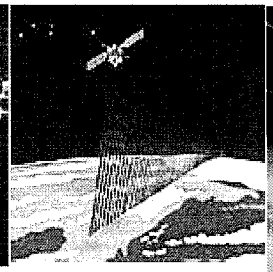
Dec 2002

FedSat



Dec 2002

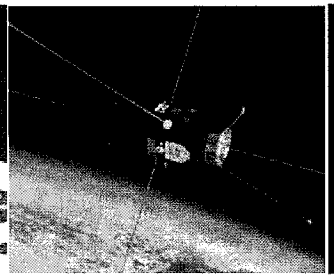
ICEsat



5-cm accuracy

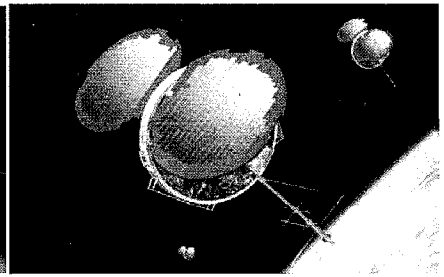
2005

C/NOFS



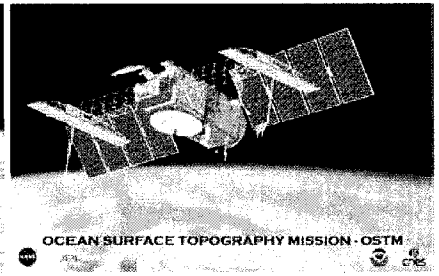
Sept 2005

COSMIC



2008

OSTM



Altimetric Missions Operations and Science Support

Broad responsibilities in nearly all aspect of ocean altimetry:

GPS receiver development and operations

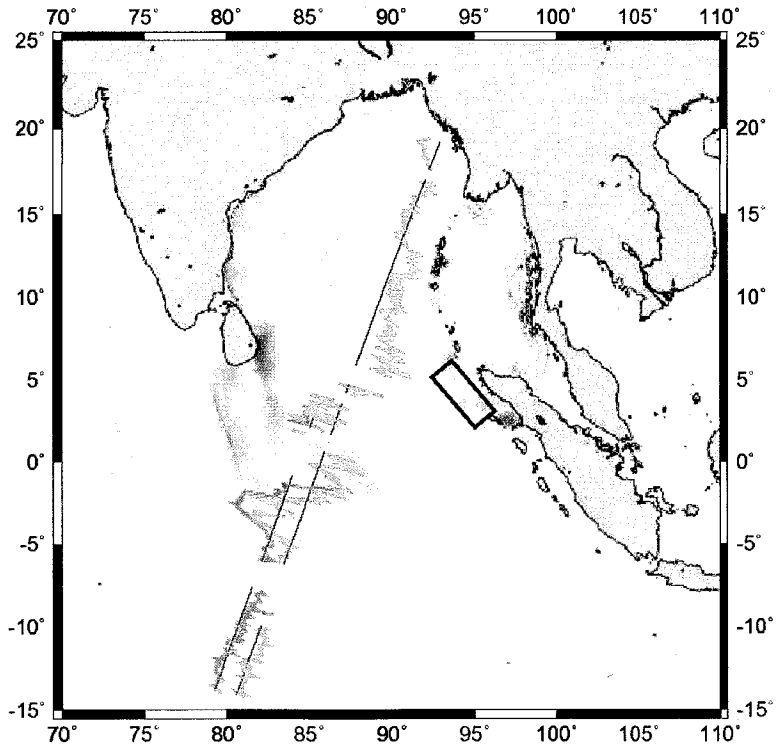
Orbit determination for Jason and Topex

- Near-real-time (3 hours, for Jason only), daily, and 'Final'
- Cutting edge technology led to consecutive 'records' in POD, presently with sub-cm RMS radial accuracy for Jason

Lead NASA component of calibration/validation for Jason, NASA Jason Measurements System Engineer

Recent Tsunami Jason (orange) and Topex (green) ocean height measurements 15 minutes after the Sumatra earthquake superimposed on a model of the tsunami (shades of red and blue)


Sea surface height from TOPEX/Poseidon and Jason-1



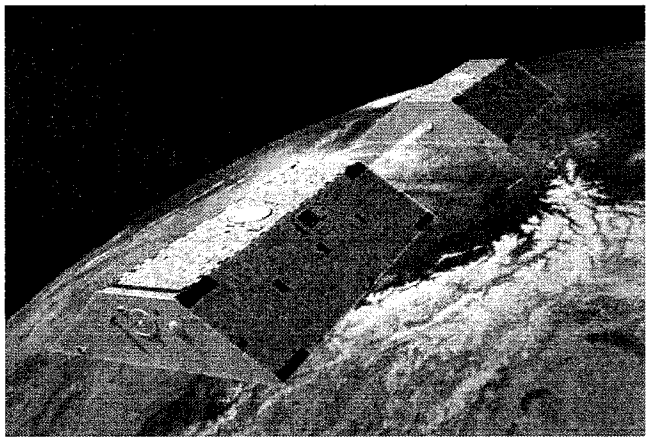
GRACE

335 designed and developed core science instrument

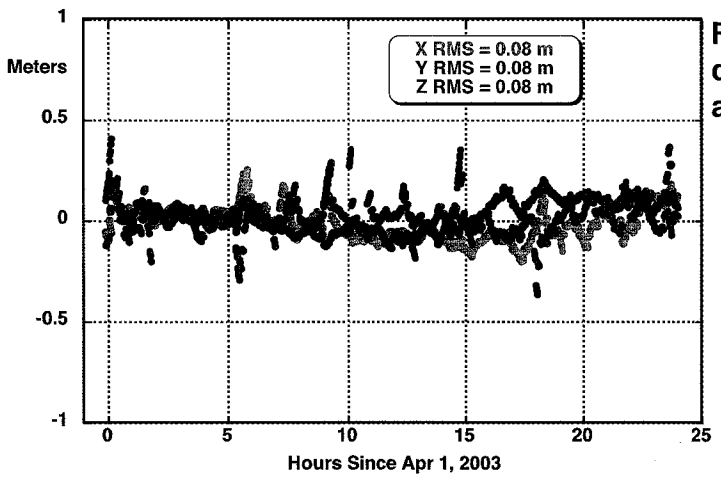
- GPS and GPS-derived technology
- End-to-end expertise in section was extremely beneficial

Critical mission support

- Orbit determination
- Level-1 science data products
- Attitude determination
- Calibration maneuvers
- Instrument support
- Gravity recovery



Ideal testbed for formation flying concepts, GPS analysis, novel POD concepts



Real time baseline determination accuracy

Precise attitude determination (PAD) using accelerometer

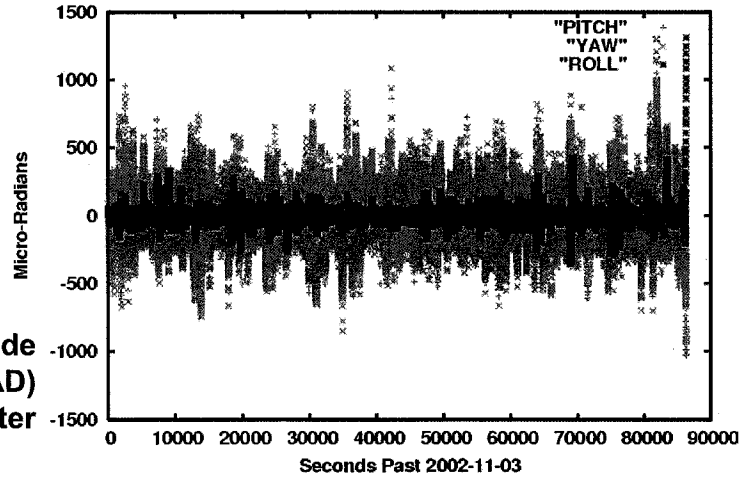
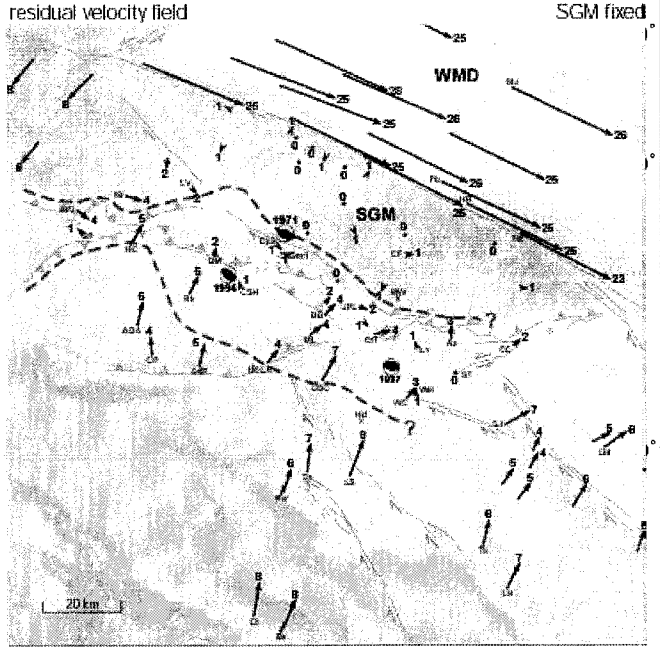


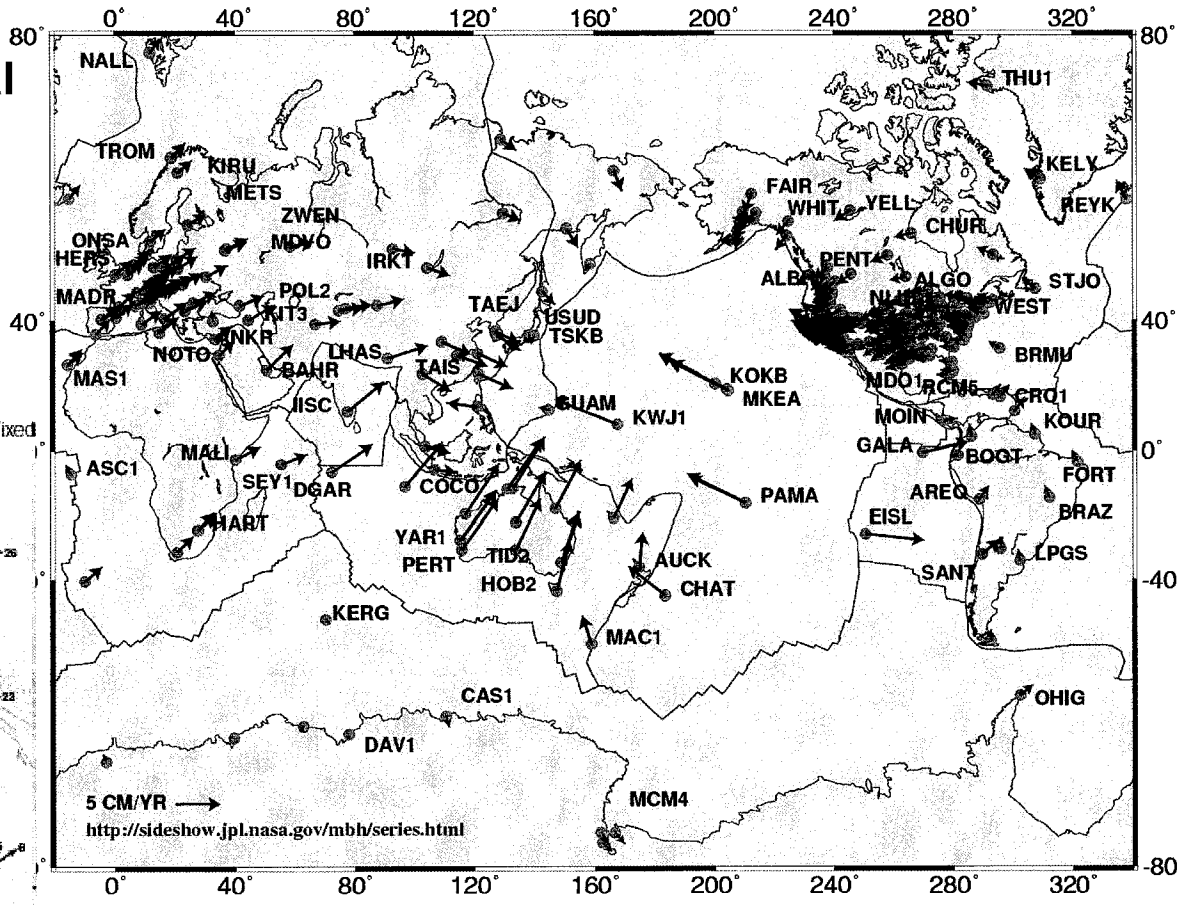
Plate Tectonics and Regional Deformations

Deploying, maintaining, and analyzing global and regional networks (GGN, SCIGN)

Deriving GPS-based definition of the terrestrial reference frame



Mojave segment, San Andreas F.
best 25 mm/yr 20 km



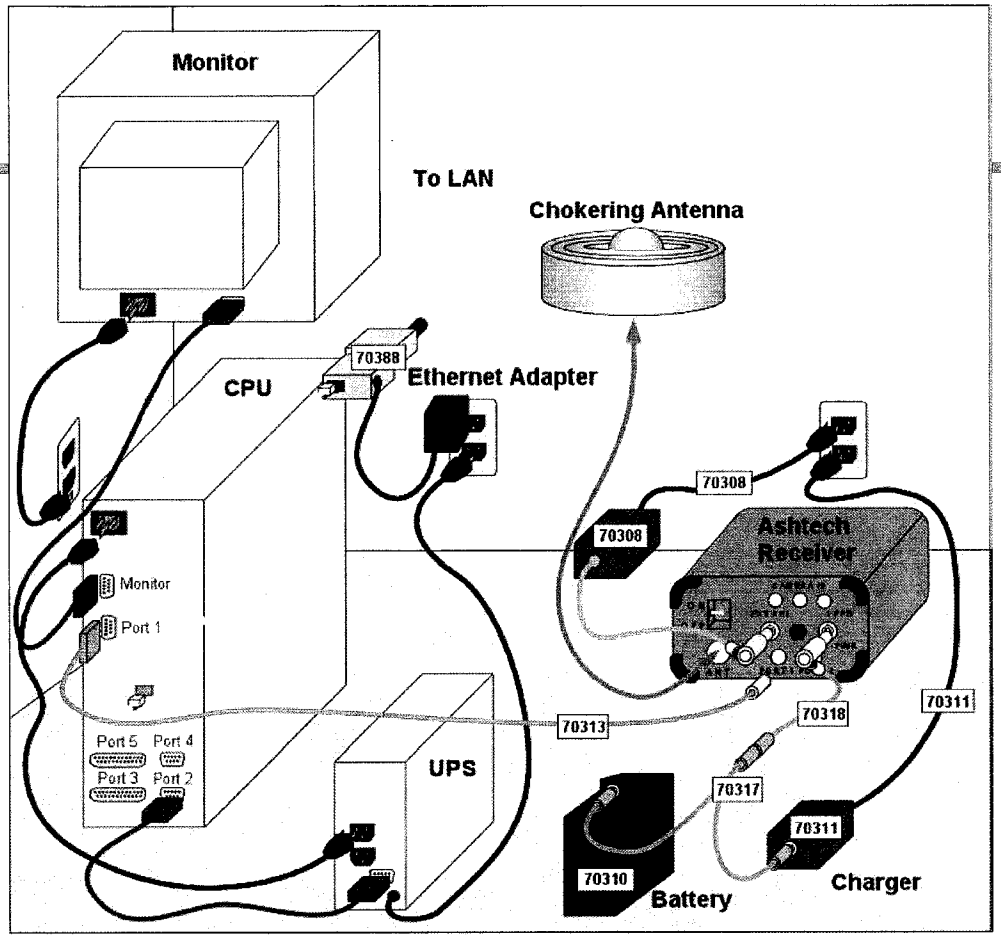
EarthScope/PBO participation

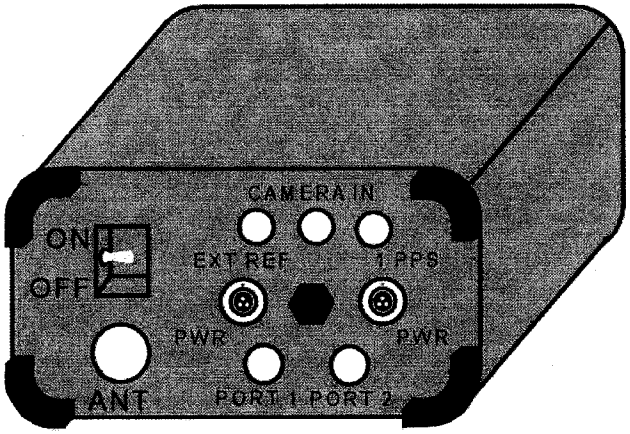
REASoN Project

Solid Earth Community Involvement

Some examples

- Relationship with Caltech
  - Collaboration with Campus on analysis of GPS component of Tectonic Observatory
- Large GPS Networks supported with GIPSY
  - GeoNET - Japan
  - GSJ - Japan
  - PANGA - Pacific Northwest
  - SWEPOS - Sweden
- UNAVCO Governance and leadership
  - Founding member of UNAVCO Inc.
  - Elected to a seat on the Board of Directors of UNAVCO Inc.
  - GGN activities are supported through a NASA grant with UNAVCO
  - Actively participate in UNAVCO working groups and committees
  - Chaired Plate Boundary Observatory (PBO) Standing Committee


Monitor
To LAN
Chokering Antenna
70388
Ethernet Adapter
CPU
70308
70308
Ashtech
Receiver
Monitor
Port 1
Port 5
Port 4
Port 3
Port 2
70313
70318
70311
UPS
70317
70311
70310
Battery
Charger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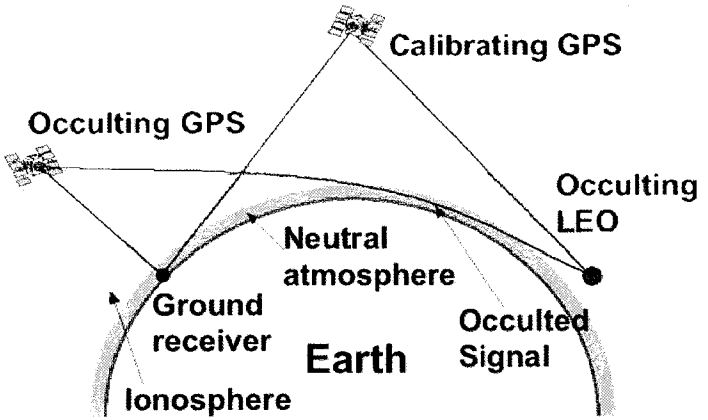
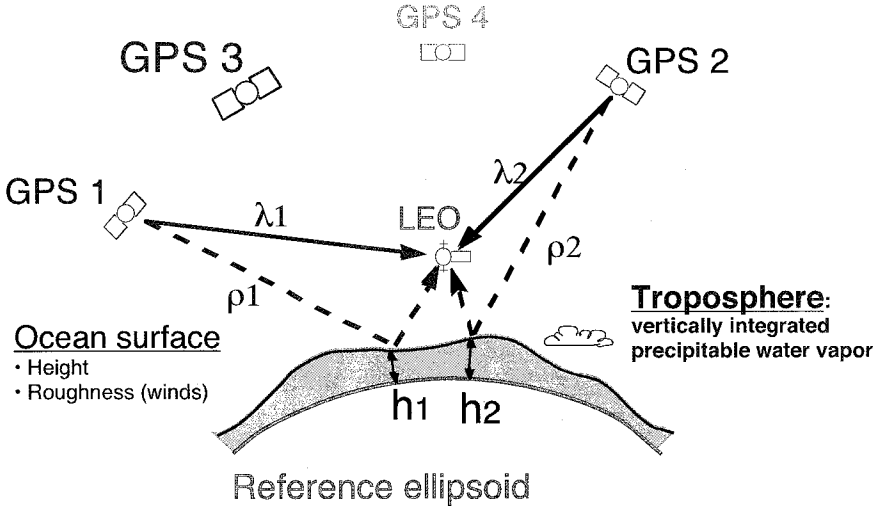
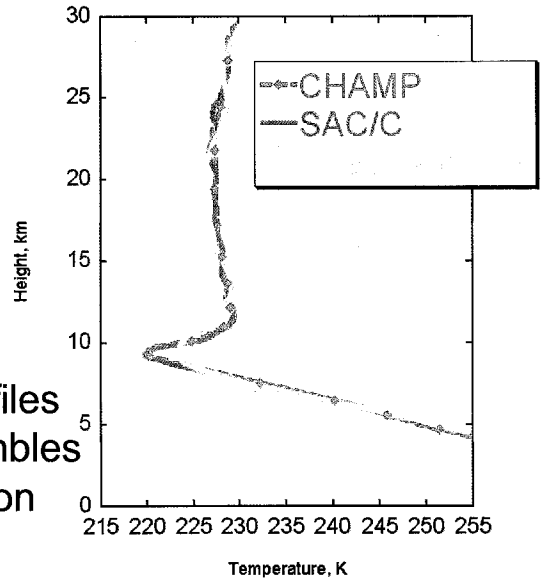
Novel Science Applications





Atmospheric and Ionospheric Remote Sensing and Science



Occultations:
0.5° K for individual profiles
0.1° K for average ensembles
100 m vertical resolution

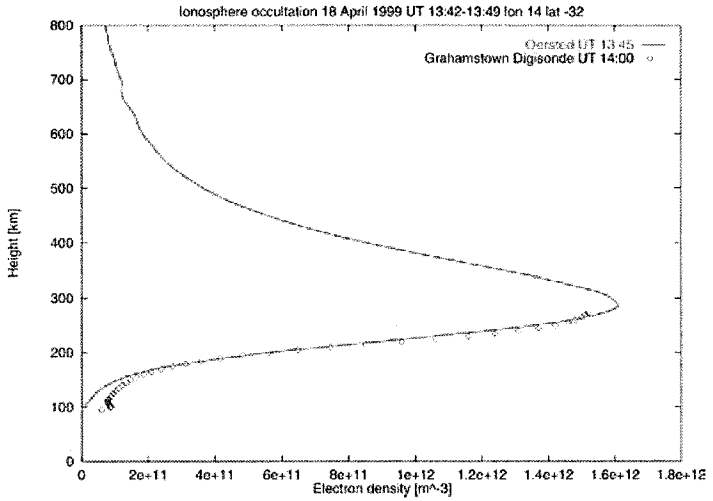
Bi-Static Ocean Reflectometry

2 cm precision altimetry in 1-sec using phase from fixed receiver (Crater Lake, OR)

Applications of GPS Remote Sensing in the Ionosphere

Capabilities:

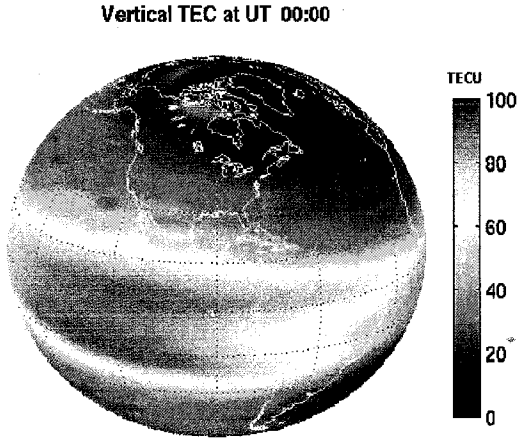
- Electron density profiles at <1km vertical resolution
- 2D global maps of vertical TEC and ionospheric response to magnetic storms
- 3D images of electron density as a function of time
- Maps of ionospheric scintillations



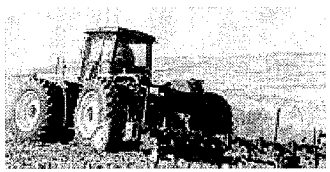
Applications:

- Excellent fit to Sun-Earth Connection science (Living With a Star)
- Key input to Navy/AF advanced space weather models
- FAA's Wide Area Augmentation System
- Mitigate effects on communications
- Improved understanding of ionospheric dynamics

Above: Example of electron density profile obtained with GPS occultations on Oersted. Below: Example of global vertical TEC maps obtained by the Global Assimilative Ionospheric Model (GAIM)



NASA's Global Differential GPS (GDGPS) System



Terrestrial and airborne users

Land lines

Iridium

Inmarsat

GDGPS Operations Center

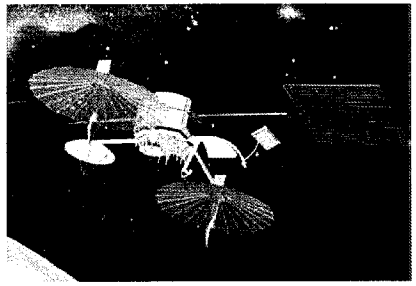
Internet

Frame

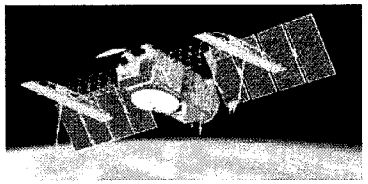
GDGPS real time network

Uplink

TDRS



Broadcast



Space users

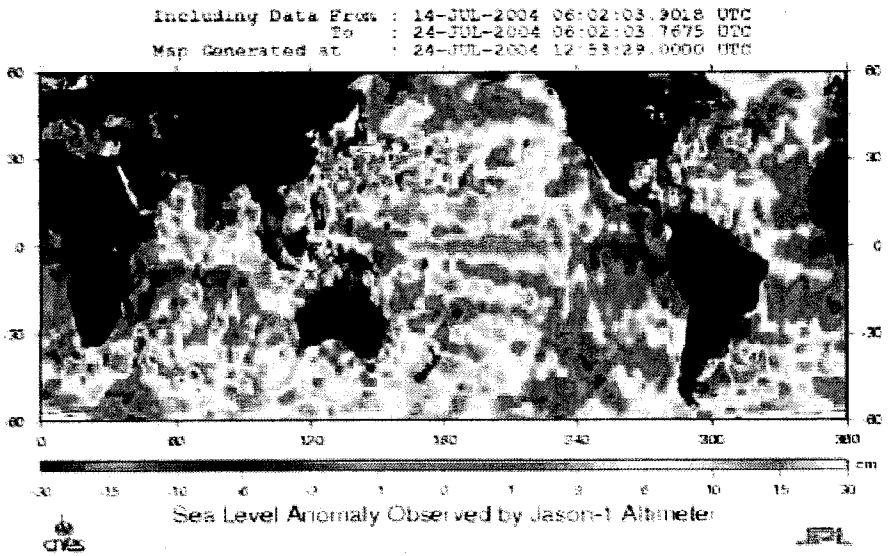
Redundant architecture: no single point of failure

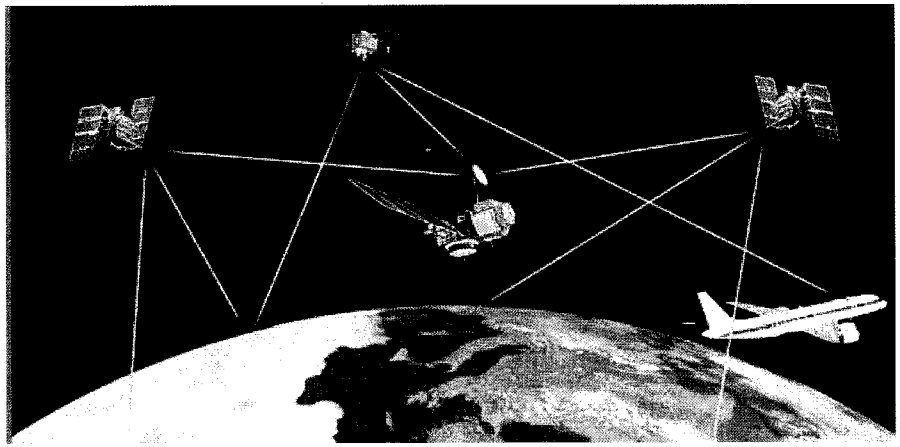
99.999% reliability since inception in early 2000

For more info see: www.gdgps.net

GDGPS 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 for LEOs**
  - GRACE, Jason, Topex
- **Post launch analysis for GRACE and SRTM**
- **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**

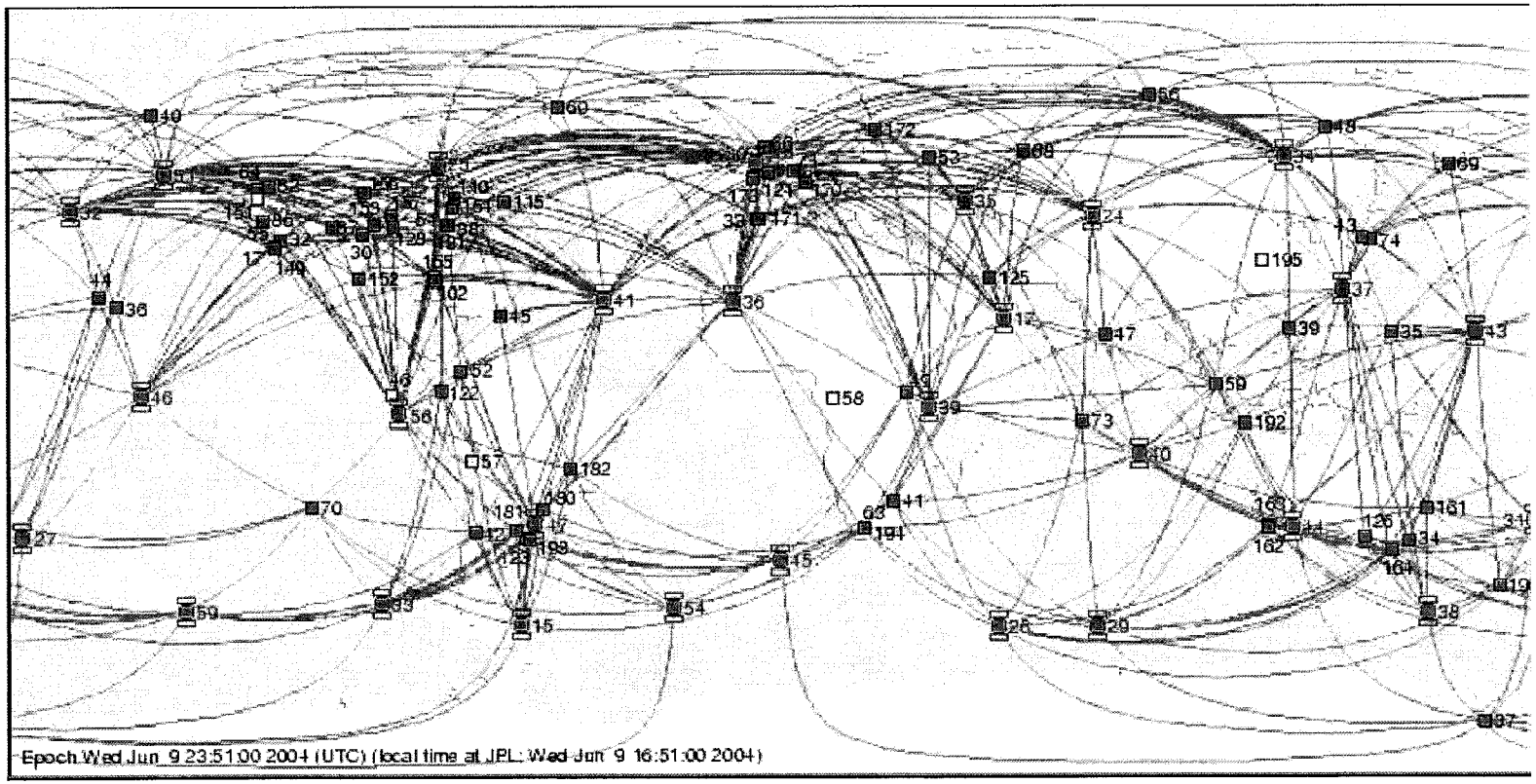




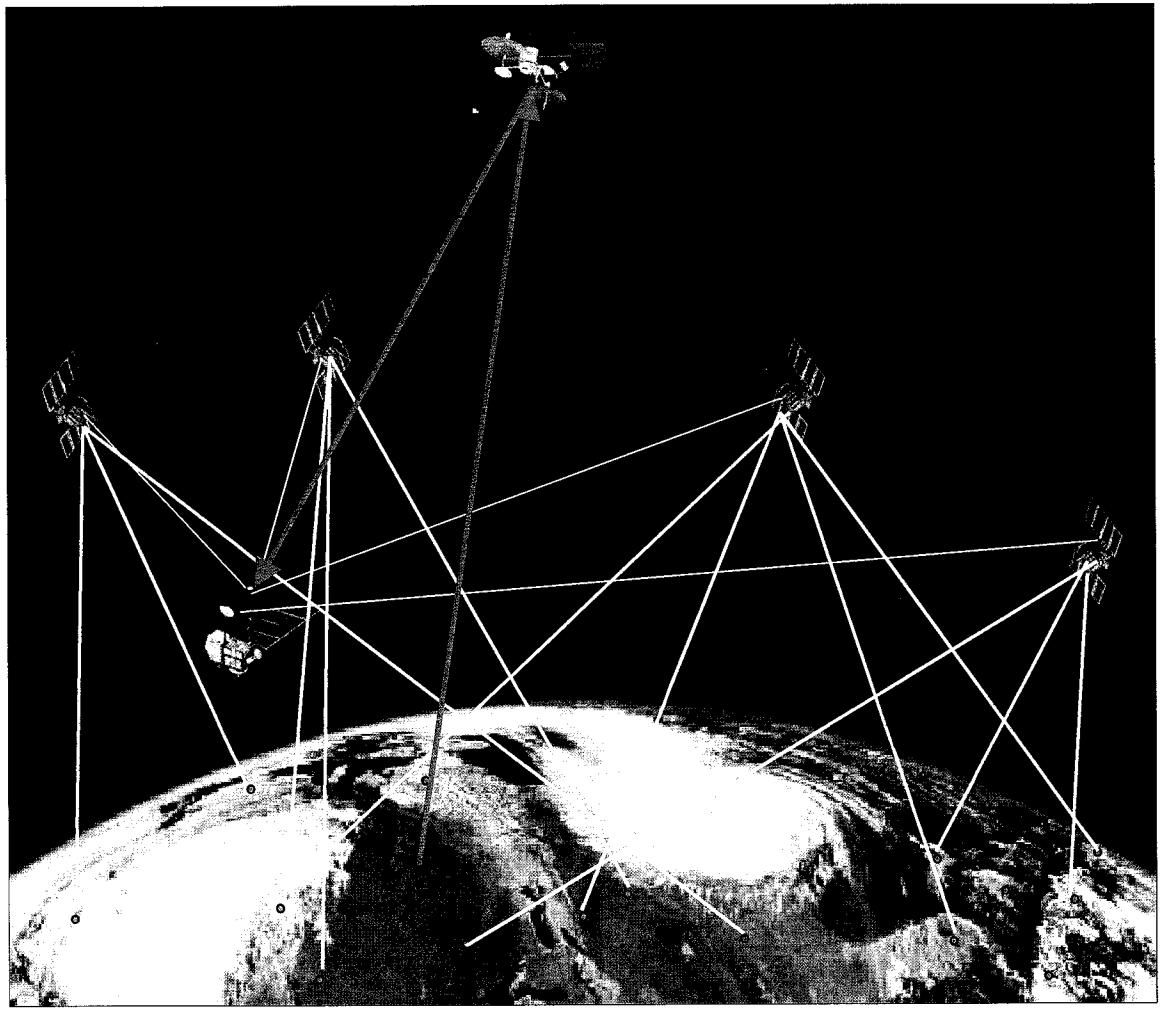
Uniquely Powerful GPS Monitoring

As a strategic national security asset and a critical global infrastructure undetected GPS failures can have enormous consequences, however, operational GPS lacks integrity monitoring due to poor tracking network

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



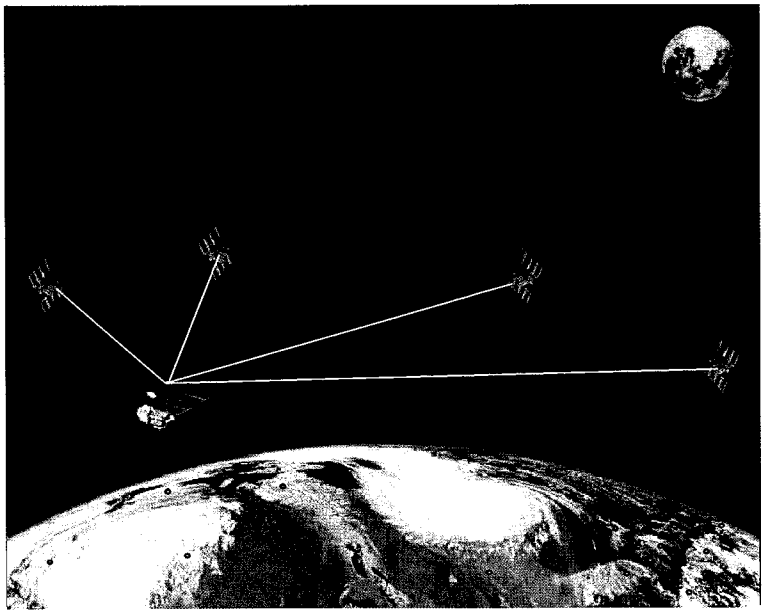
TDRSS Augmentation Service for Satellites (TASS): Integrating NASA's Ground and Space Infrastructures

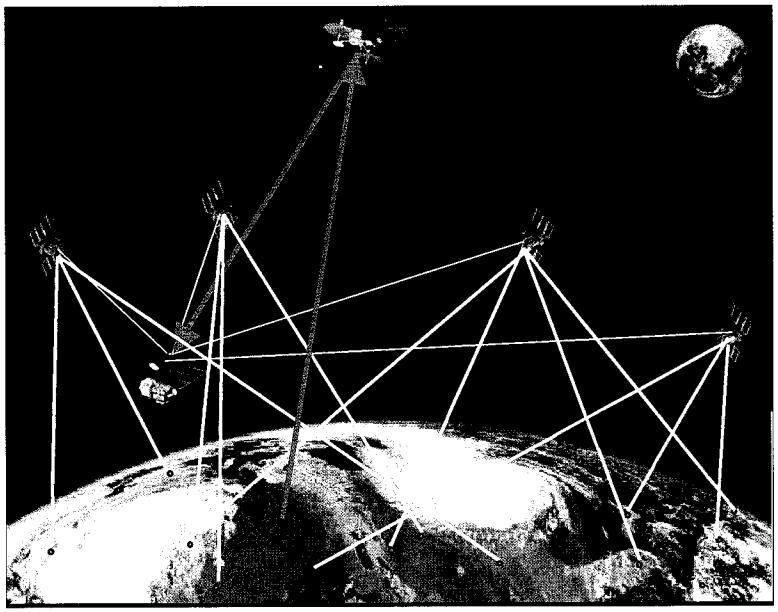


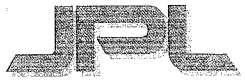
Revolutionary New Capabilities in Orbit

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







Current R&D Focus

GPS system modeling and parameter estimation

Millimeter-level baseline determination for orbiting arrays

Multi-sensor atmospheric sensing

Atmospheric occultations

Ionosphere dynamics

Improve reliability and accuracy of real time systems

Transition to TASS operations and flight demonstrations

Development and demonstration of ocean reflection technology

Next generation GNSS receiver and exploration of new science capabilities