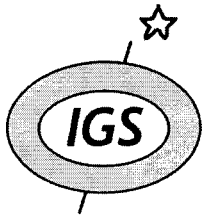


International GPS Service
Of
The International Association of Geodesy

GPS Measurements of Earth Rotation:

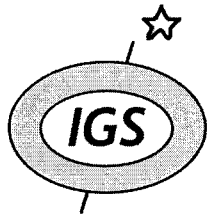
The Contributions of the IGS

R. Neilan, IGS Central Bureau, JPL-Caltech, USA
J. Kouba, Natural Resources of Canada, Ottawa
G. Beutler, and T. Springer, Astronomical Institute, University of Bern
M. Feissel, Institut Geographique National, France
Ch. Reigber, GeoForschungsZentrum, Potsdam, Germany

http://igscb.jpl.nasa.gov

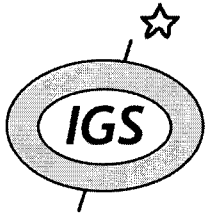
European Geophysical Society
Nice, France
April 28, 2000

Overview



- Mission & History of IGS
- Evolution of GPS Measurements
- IGS Products - Current level of Precision
- IGS ITRF Realizations and Transformations

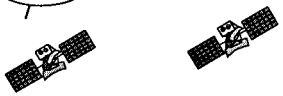
The IGS Mission



To provide a service to support geodetic and geophysical research activities, through GPS data and data products.

- **A network of about 200 permanent precision geodetic receivers produce GPS data on a daily basis**
- **The GPS data sets are used by the IGS to generate:**
  - ▲ **High accuracy GPS satellite ephemerides**
  - ▲ **Coordinates and velocities of the IGS tracking stations**
  - ▲ **GPS satellite and tracking station clock information**
  - ▲ **erp's, ionospheric, tropospheric information**
- **Approved activity of the International Association of Geodesy (IAG) since January 1, 1994. A FAGS service as of 1996.**
  - ▲ **Federation of Astronomical and Geophysical Data Analysis Services**

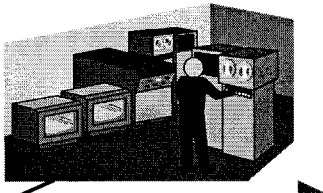
ORGANIZATION OF THE INTERNATIONAL GPS SERVICE

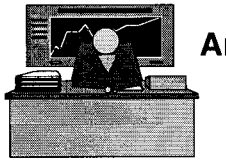


NAVSTAR GPS Satellites

INTERNATIONAL GOVERNING BOARD

Global Data Centers





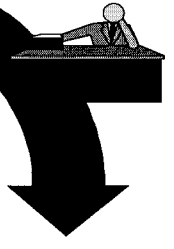
Analysis Center Coordinator

Operational & Regional Data Centers

INTERNET

Telephone - Modem, Radio Links

Analysis Centers

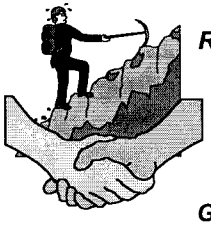


Global Network Associate Analysis Centers

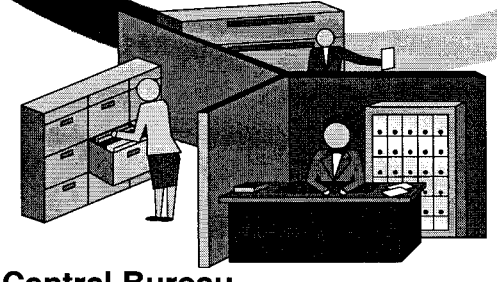
Regional Network Associate Analysis Centers

USERS
Practical, Custom, Commercial, Governments,...

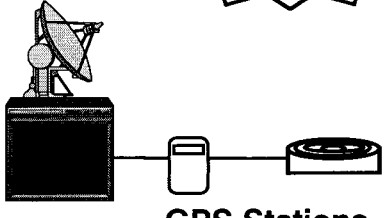
IGS Projects and Working Groups



Reference Frame Densification
Precise Time Transfer
Low Earth Orbiters
Ionosphere
Atmosphere
Sea Level
GLONASS Pilot Service Project



Central Bureau
Management, Network Coordinator, Central Bureau Information System



GPS Stations

In Support of Science

- The accuracies of the IGS data and products are to be sufficient to support scientific requirements
  - ▲ Access to and continued improvement of the ITRF (International Terrestrial Reference Frame)
    - ❑ Station position and velocities
    - ❑ Monitoring Earth rotation parameters
  - ▲ Monitoring deformation of the solid Earth and hydrosphere variations
  - ▲ Precise time transfer
  - ▲ Scientific satellite orbit determination, LEO's
  - ▲ Ionospheric monitoring and research
  - ▲ Atmospheric applications - ground and space based for climate research, eventually weather forecasting

Historical Perspective

Key factors in formation of IGS

- All geodynamics and geodetic organizations realized the potential of GPS by early 90's
- Motivating goal: Millimeter positioning in support of science anywhere in the world
- Not one agency can nor should assume the capital investment & recurring operations costs for the entire infrastructure
- Join with key international partners to form federation, define cooperation, set standards, science quality driven
- IGS History documented in Annual Report Series (1994)

IGS Evolution

	Pilot Project		IGS Approved Service --->					
	'92	'93	'94	'95	'96	'97	'98	'99
Stations	28	42	95	112	139	194	201	221
Data Access	3+ day	3 day	.....	1 day	.....	6hr	<6hr	Hourly & 1-4 hr
Orbit rms, cm	50	40-25	25-16	~10	....	5 - 10	....	3-10
Orbit access	2-3 wk	....	....	2 wk	....	2 wk, 1d	....	-> Sub-daily, 'ultra'
CBIS Access			3000 files	5000 files	25,000 files	30,000 files	2109 hosts	2244 hosts

Estimated Quality of IGS Products

Products	Predicted	Rapid	Final	Units	Biases
Orbit	100.0	10.0	5.0	cm	10.0
Clock	150.0	0.5	0.3	ns	?
Pole		0.2	0.1	mas	0.3
LOD		30.0	20.0	μs/d	20.0
Stations Horizontal			3.5	mm	10.0
Stations Vertical			8.0	mm	20.0
Troposphere ZPD			4.0	mm	6.0
Geocenter X,Y			7.0	mm	20.0
Geocenter Z			13.0	mm	50.0
Terrestrial Scale			0.4	ppb	15.0

June 1999

Network Densification

- In 1993 the IGS realized that simultaneous processing of many stations was impractical
- IGS groups began investigating the rigorous combination of solutions rather than raw data analysis
  - ▲ 1994 Workshop on Densification of the International Terrestrial Reference Frame initiated
  - ▲ SINEX - Solution Independent Exchange Format accepted in 1996
  - ▲ Combination of global station solutions since late '96
  - ▲ Polyhedron Solutions improving (see Annual Report Series)
  - ▲ IGS contribution to ITRF significant
- Establish IGS Reference Frame Coordinator June '99 at Natural Resources of Canada, Remi Ferland

IGS Reference System

- Provides convenient and precise "IGS reference system" through
  - ▲ the core IGS combined products: orbits, Earth rotation parameters (ERP), station positions/velocities and satellite/station clocks
  - ▲ additional combined products, consistent with the core products: tropospheric zenith path delays (ZPD), ionospheric TEC (total electron content) maps and associated rec./satellite diff. calibration biases (DCB)
  - ▲ IGS combined orbits (since 1994) ; clocks and ERP (since 1995); station positions (since 1996) and tropospheric ZPD (since 1997)

IGS Combined Offficial Products

- Core Combined Products: orbits/clocks/ ERP/station positions
  - ▲ IGS Final orbit, clock and ERP combined solutions (10 day delay)
  - ▲ IGS Rapid orbit, clock and ERP combined solutions (17 hour delay)
  - ▲ IGS Predicted orbit and clock combined solutions (1 hour before the observation day)
  - ▲ Nine Associate ACs (AACs) produce regional station position solutions in SINEX format
  - ▲ Up to eight ACs, AACs contribute global orbit, ERP, global station position (SINEX) solutions and up to five ACs clock solutions

Product Precision and Timeliness

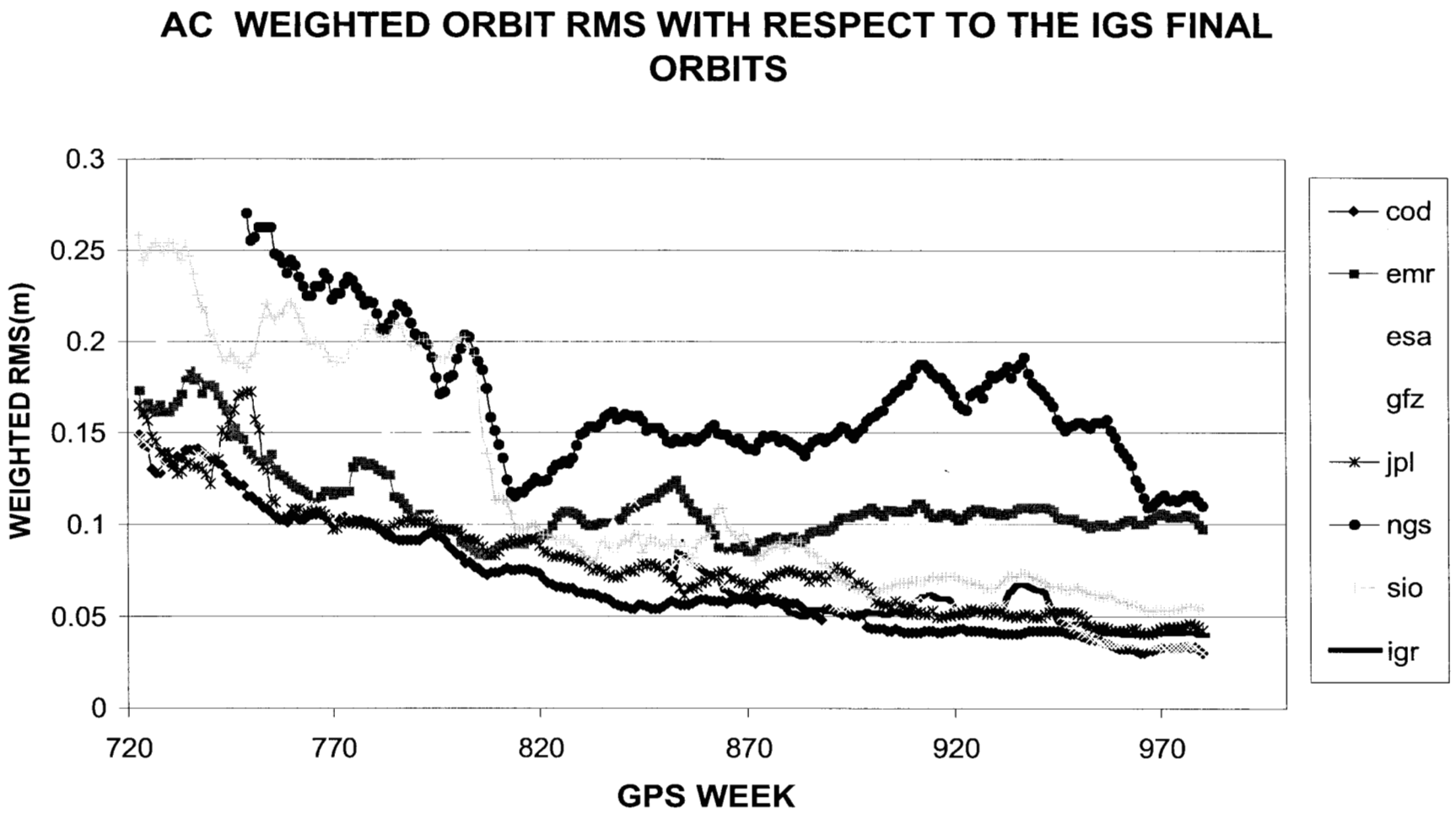
IGS Combined Products

	Availability	Interval	Precision	
Satellite Orbits&clocks			*orbits*	*clocks*
Predicted	**Real-time**	**15 min**	**50 cm**	**150 ns**
Rapid	**17 hours**	**15 min**	**10 cm**	**.5 ns**
Final	**10 days**	**15 min**	**5 cm**	**.3 ns**

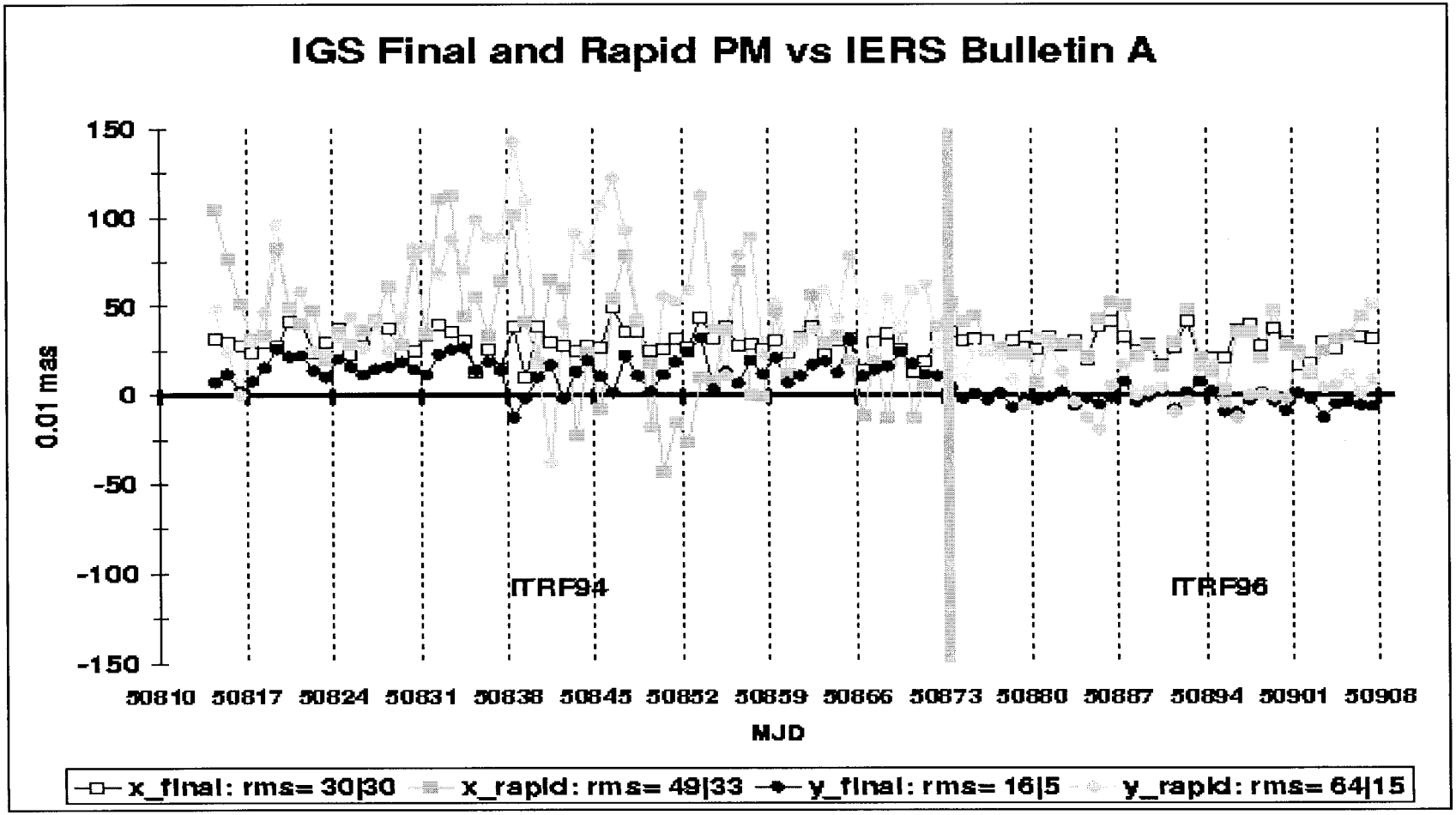
IGS Combined (Prelim.) Station		*Positions*	*Velocities*
Weekly solutions	**2-4 weeks**	**7 days, 1-5 mm**	**1-3mm/y**

Earth Rotation Parameters			***parameters***	***rates/LOD***
Rapid Polar Motion	**17 hours**	**1 day**	**.2 mas**	**.4 mas/d**
Final PM	**10 days**	**1 day**	**.1 mas**	**.2 mas/d**
Rapid UT /LOD	**17 hours**	**1 day**	**.10 ms**	**.06 ms/d**
Final UT /LOD	**10 days**	**1 day**	**.05 ms**	**.03 ms/d**
Tropospheric ZPD	**<4 weeks**	**2 hours**	**4 mm**	
Ionosph. grid TEC	**<4 weeks**	**2 hours**	**2 TECU (~ .2 m)**	

IGS ORBIT IMPROVEMENT



Earth Rotation Parameters



Consistency

- Consistent with the current international conventions
  - ▲ International Earth Rotation Service (IERS) Conventions 1996
  - ▲ International Terrestrial Frame (ITRF) (currently ITRF97)
  - ▲ ITRF realizations used for IGS Products (for more details see the presentation on: IGS ITRF Realization and Transformations)
- IGS classic products (orbits/clock/ERP/stations) are mutually consistent
  - ▲ Since December 1998, combination of minimally constrained AC solutions
  - ▲ Nearly exact ITRF transformations (e.g. for the ITRF97-ITRF96 and for all the future ITRF changes)
  - ▲ IGS satellite clock solutions are aligned to the GPS time via broadcast clock corrections:
    - ❑ in the future IGS combined clock solutions should be aligned to UTC.

Compatibility of IGS Products

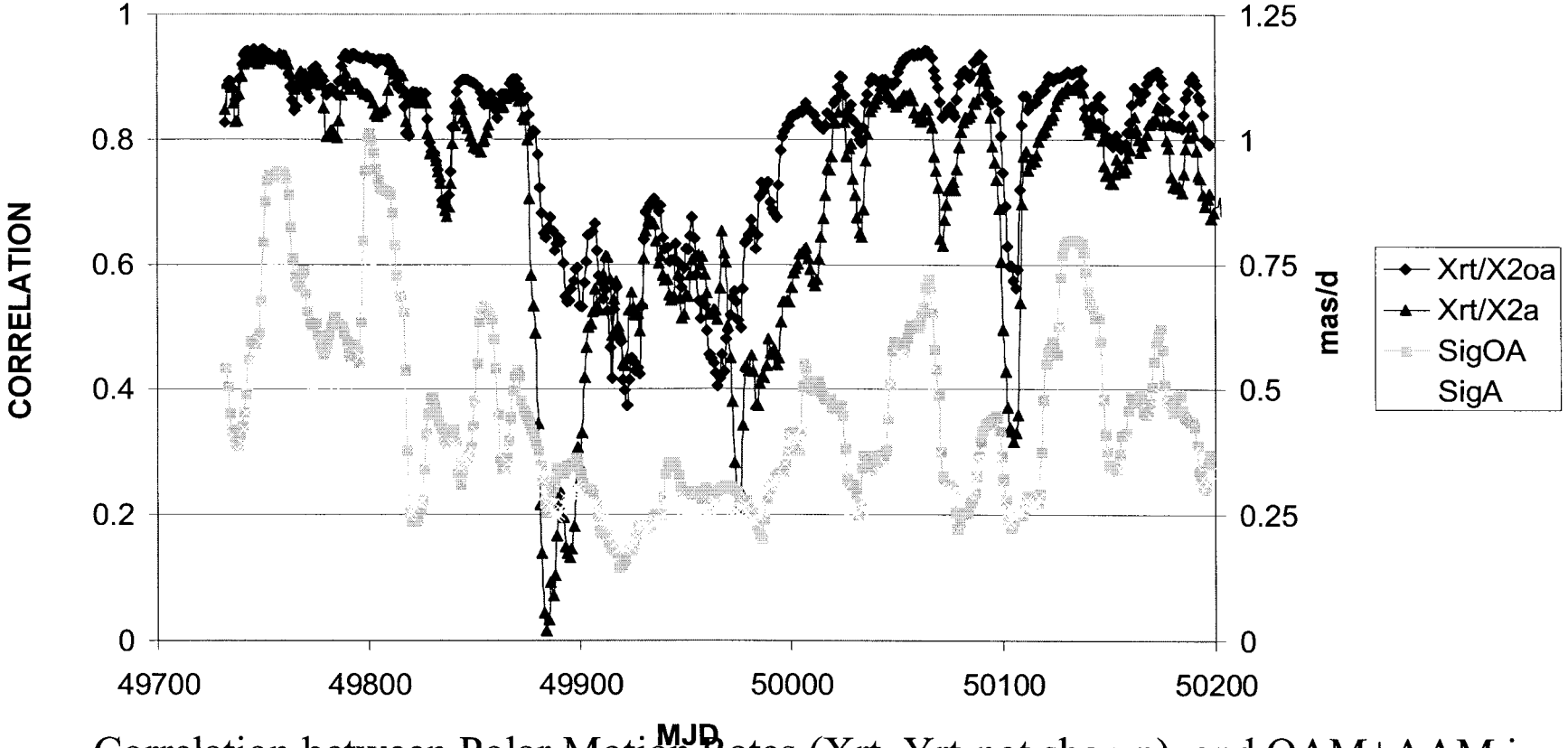
- **IGS CORE products (orbits/clock/ERP/stations)**
  - ▲ **are mutually compatible and consistent since Dec 1998**
  - ▲ **the orbit/clock consistency of utmost importance for precise point positioning**
  - ▲ IGS station (SINEX) solutions **are compatible/consistent with IGS antenna offsets (**station log files**) and the antenna calibration (phase center) tables (**IGS_01.pcv**), both available at IGS CB Archives**

Scientific Applications

- **Earth Orientation Parameter (EOP) monitoring**
  - ▲ IGS Polar Motion rates of unprecedented precision (0.1 mas/day) and resolution (1 day, or even 2 hours for CODE AC solutions!)
  - ▲ Continuously available with delays of less than 24h (IGS Rapid)
  - ▲ Independent short period (<30 days) nutation determination (by CODE AC)
- **Global Change Studies**
  - ▲ Correlation studies of ERP rates Atmospheric (AAM) and Oceanic Angular Momentum (OAM)
  - ▲ Gravity LEO satellite missions (CHAMP, GRACE, GOCE, etc.)
  - ▲ Ionospheric studies and correlation with EOP, atmosphere, etc.
  - ▲ ...

Polar Motion and AAM

30 day correlation of IGS Polar Motion X rates with O+AAM (Xrt/X2oa) and AAM (Xrt/X2a) during Jan. 95- Apr 96.



Correlation between Polar Motion Rates (Xrt, Yrt-not shown) and OAM+AAM is nearly always better than 0.8 (except for the low signal period at or below 0.25 mas/d)

Problems/Solutions

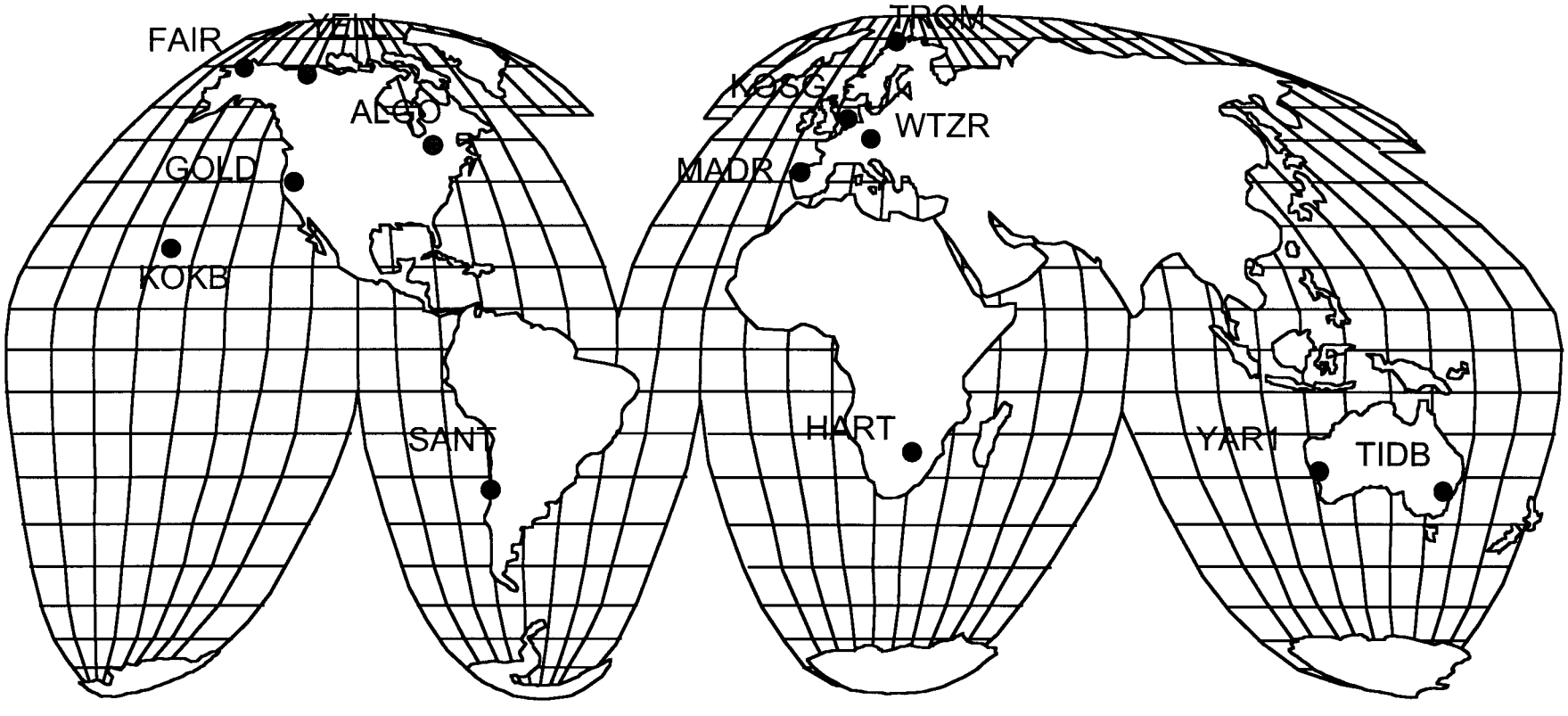
- IGS Combined Orbits :
  - In 24 h files with 15 min sampling (0-23:45 GPS time); can be easily concatenated to span daily boundaries; easily be fitted with low order polynomials for continuous representation
  - Small daily discontinuities (at the dm level)
  - Possible orbit origin offsets (biases at the cm level)
  - Improvements at the AC level, I.e. smaller daily AC orbit discontinuities (<dm) and smaller orbit origin offsets (< cm) required
- IGS Combined ERP:
  - May be biased at the .1 mas level due to AC ERP biases
  - New IGS SINEX ERP combination should help
- IGS Combined Clocks (see also compatibility):
  - Daily clock discontinuities (< 1 ns)

IGS ITRF Realization-'92,'93,'94

- Used for the IGS Realizations of ITRF92-93-94
- Limited number of stations
  - ▲ VLBI and/or SLR collocations
  - ▲ Good ITRF coordinate solutions
  - ▲ Good GPS data quality, latency and long observation history
- Missing stations were occasionally having significant impact on the IGS ITRF realization stability
  - ▲ at times only 8 stations were available
- Sub-optimal stations distribution.
- Small discontinuities between IGS realizations of ITRF

IGS ITRF Realization

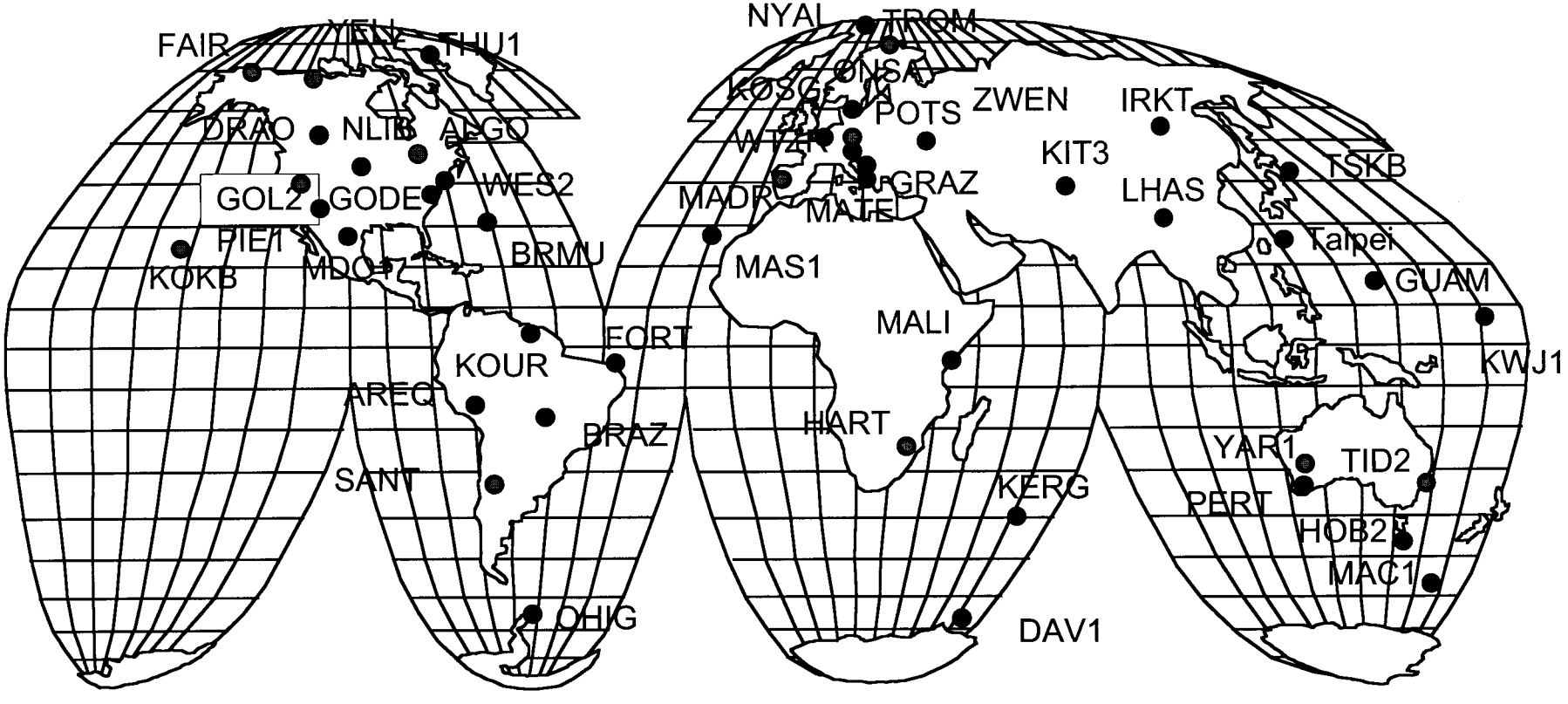
Station set (13) used for the IGS Realization of ITRF92-93-94



- **IGS Global Tracking Sites**

IGS ITRF Realization ITRF96

Station set (47)



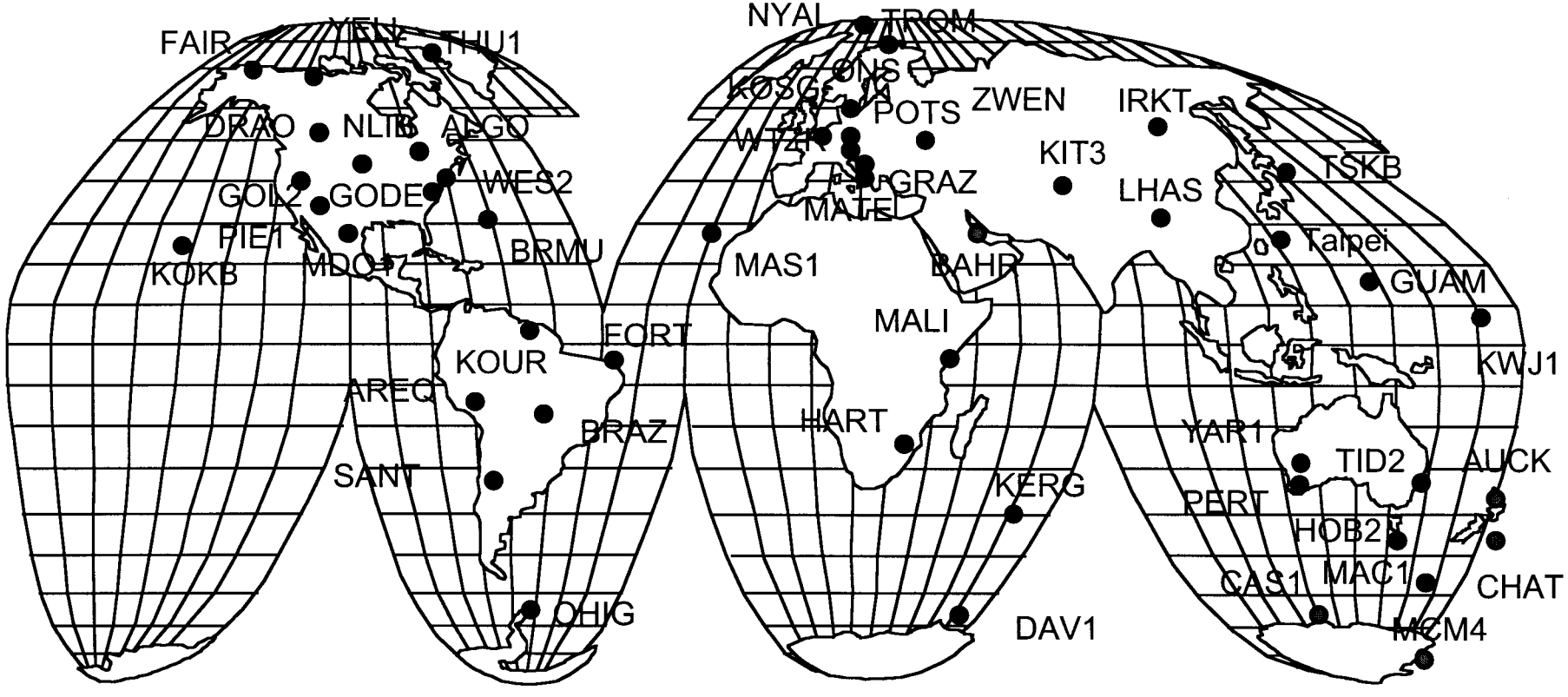
- **IGS Global Tracking Sites**
- **IGS "Original 13" Global Tracking Sites**

IGS ITRF Realization- ITRF97

- Reliable position/velocity ITRF/AC/IGS solutions
- Stable monumentation
- Quality and reliable station hardware (minimum hardware changes)
- Data quality (e.g. low multipath)
- Data latency (low and reliable communication)
- Long observation history (>2 years)
- Collocated with other techniques (VLBI, SLR, DORIS)
- Geographical location (world wide balanced geometry)
- Supportive and responsive station staff

IGS ITRF Realization ITRF97

Station set (51)



- **IGS Global Tracking Sites**
- **IGS "new" Global Tracking Sites**

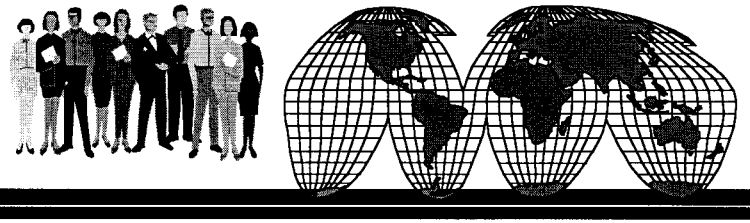
IGS ITRF Realizations - Dates

ITRF	FROM yy/mm/ dd	FROM GPS W.	TO yy/mm/ dd	TO GPS W.	# sta
92	94/01/02	0730	94/12/31	0781	13
93	95/01/01	0782	96/06/29	0859	13
94	96/06/30	0860	98/02/28	0946	13
96	98/03/01	0947	99/07/31	1020	47
97	99/08/01	1021	Now		51

IGS ITRF Transformation - ITRF

From ITRF	To ITRF	Epoch	T1 (mm) (mm/y)	T2 (mm) (mm/y)	T3 (mm) (mm/y)	D (ppb) (ppb/y)	R1 (mas) (mas/y)	R2 (mas) (mas/y)	R3 (mas) (mas/y)
93	92	1995.00	20. 2.3	8 0.4	3 -0.8	-0.1 0.11	1.66 0.12	0.68 0.15	0.55 -0.04
94	93	1996.50	-21 -2.7	-1 0	1 2.0	-0.2 -0.09	-1.27 -0.13	-0.87 -0.20	-0.54 0.04
96	94	1998.16	0 0.2	-1 -0.9	1 0.2	-0.4 -0.07	-0.21 -0.02	-0.01 0.01	-0.22 0.01
97	96	1999.58	-0.3 0.7	-0.5 -0.1	14.7 1.9	-1.430 -0.043	-0.159 -0.013	0.263 0.015	0.060 -0.003

Summary



- The economics of GPS make the measurement technology available to *all* IGS users
- The organization and outreach of the IGS enables users to take advantage of data, systems, and products developed cooperatively with the top international GPS experts
- Through the IGS standards are developed and adopted worldwide, contributing to robust, homogenous reference frame and implementing common processes
- IGS is a supporting foundation for nearly all GPS projects and numerous applications