GGOS Working Group on Ground Networks and Communications
Austria Center Vienna
Room SM3
April 6, 2006   17:30 – 20:00

Review of Working Group Charter – (M. Pearlman)

Status of Network Satellite Laser Ranging – (W. Gurtner/J. Ries)

- What should the technology and infrastructure look like in 10 years?
- What TRF requirements does the technique satisfy?
- What network is required to satisfy the TRF requirements?

Very Long Baseline Interferometry – (C. Ma/D. Behrend)

- What should the technology and infrastructure look like in 10 years?
- What TRF requirements does the technique satisfy?
- What network is required to satisfy the TRF requirements?

GNSS – (A. Moore/N. Beck)

- What should the technology and infrastructure look like in 10 years?
- What TRF requirements does the technique satisfy?
- What changes in the network are anticipated over the next 10 years?

DORIS – (P. Willis)

- What should the technology and infrastructure look like in 10 years?
- What TRF requirements does the technique satisfy?
- What changes in the network are anticipated the next 10 years?

GGOS Working Group on Ground Networks and Communications

(Agenda Continued)

Gravity Field – ??

- Who controls the data archival and dissemination?
- Which data level is freely available, L0, L1, L2,... define what these levels of processing.
- Which gravity-measuring efforts are in-place and how and who runs them
- What do the current permanent gravity networks look like now (describe all types)?
- How many absolute gravimeters are there, who owns them and controls them, what are the end-product, and what is the deployment plan?
- How many super-conducting gravimeters are there, who owns them and controls them, what are the end-product, and what is (if any) the enhancement/expansion plan?
- How best could we incorporate these gravity networks into our overall activity on a "Global Geodetic Observing System" network design?
- What are expected to be the future requirements and how did you arrive at these?
- Describe on-going or planned, global and regional programs for each type of gravity measurements: surface, airborne, shipborne, space missions.
- Should all fiducial reference geodetic observatories have a gravimeter or a program of gravimeter occupations at regular intervals?
- What is the mechanism (if any) that coordinates gravity measuring campaigns of any type, and how and who initiates them?

Tide Gauge Network – (S. Jevrejeva)

- What the network looks like?
- What does the data look like? Where are the data stored?
- How do people get access?
- What kinds of products are generated from the data?
- Is the technology changing?

Site metadata effort - (C. Noll)

Ground Ties

Communications - ??

GGOS Working Group on Ground Networks and Communications

Objectives

- **Work toward the implementation of properly designed and structured ground-based geodetic networks to materialize the reference systems to support sub-mm global change measurements over space, time and evolving technologies.**

- **Work with the IAG measurement services (the IGS, ILRS, IVS, IDS and IGFS) to develop a strategy for building, integrating, and maintaining the fundamental network of instruments and supporting infrastructure in a sustainable way to satisfy the long-term (10-20 year) requirements identified by the GGOS Science Council.**

At the moment, the Working Group is examining options for 1 mm and 0.1 mm/yr reference frame stabilities.

Activities Planned and Underway

- Develop a plan for full network integration to support improvements in terrestrial reference frame establishment and maintenance, Earth orientation and gravity field monitoring, precision orbit determination, local deformation monitoring, and other geodetic and gravimetric applications required for the long-term observation of global change.

  – This integration process includes the development of a network of fundamental stations with as many colocated techniques as possible, with precisely determined intersystem vectors. This network would exploit the strengths of each technique and minimize the weaknesses where possible.

  – The final design of the GGOS network must take into consideration all of the applications including the geometric and gravimetric reference frames, EOP, POD, geophysics, oceanography, etc. We will first consider the TRF, since its accuracy influences all other GGOS products.

Early Steps in the Process

- Define the critical contributions that each technique provides to the TRF, POD, EOP, etc;

- Characterize the improvements that could be anticipated over the next ten years with each technique;

- Understand the present error sources for each technique (instrument and modeling) and how these errors sources propagate into the analysis products;

- Using simulation techniques, quantify the improvement in the TRF, Earth orientation and other key products as stations are added and station capabilities (co-location, data quantity and quality) are improved;

The Working Group is assuming that the GNSS and the DORIS Networks will be at least as robust as they are presently and that planned upgrades in the ground systems and the satellites will come to fruition. Some augmentation is also assumed where the present networks would be significantly enhanced with additional stations.

Status

- SLR and VLBI are presently investigating the size and density of the networks that will be required to satisfy their individual requirements.
- We are still in the process of integrating the role of gravity field and tide gauge measurements within the context of the integrated network.
- In a next step, we will examine the current infrastructure in-place, for the analysis of the network-collected data, investigate their adequacy to meet the envisioned future network realizations and the product quality and latency vis-à-vis the GGOS goals, and suggest appropriate actions.
- Data and product communication needs to be examined once we have a firm idea of the networks for the next decade and the product availability requirements:
  - data must reach the analysis centers with minimal delays;
  - products must be expeditiously disseminated to the public and the users;
  - communication links between geodetic and other GEOSS-related networks, (e.g. oceanographic, atmospheric, seismic, etc.) must be facilitated to maximize clarity and minimize delays.

Working Group Publications

A preliminary discussion on these items is included in our Poster paper from the IAG Cairns meeting:

M. Pearlman, et al, "GGOS Working Group on Networks, Communication, and Infrastructure" (http://cddis.gsfc.nasa.gov/docs/GGOS_IAG_0508.pdf)

Members of the Working Group

- IGS: Angelyn Moore, Norman Beck
- ILRS: Mike Pearlman, Werner Gurtner
- IVS: Chopo Ma, Zinovy Malkin
- IDS: Pascal Willis
- IGFS: Rene Forsberg, Steve Kenyon
- ITRF and Local Survey: Zuheir Altamimi, Jinling Li
- IERS Technique Combination Research Centers: Marcus Rothacher
- IAS (future International Altimetry Service): Wolfgang Bosch
- Data Centers: Carey Noll
- Data Analysis: Erricos Pavlis, Frank Lemoine, Frank Webb, John Ries, Dirk Behrend

International Laser Ranging Service

SLR 10 years from now?

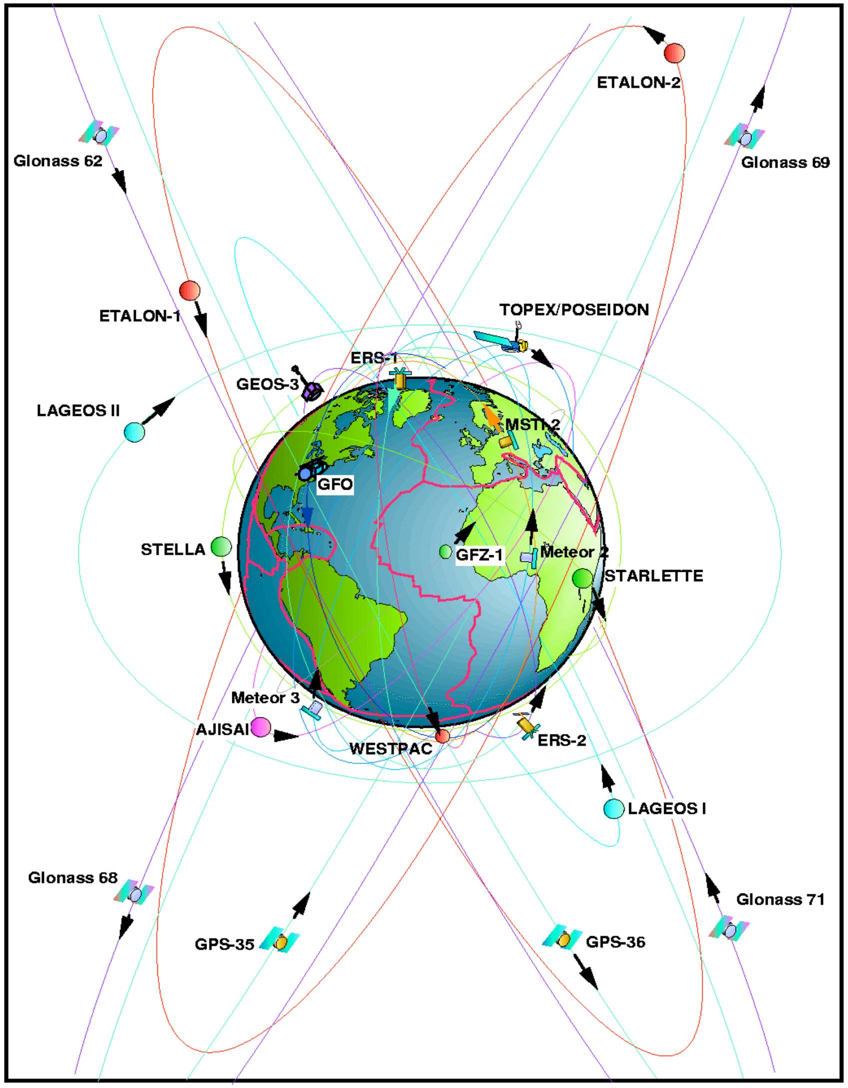
- Operations
  - semi-autonomous and autonomous
  - Real-time communication: Data flow, scheduling
  - Specialization (e.g., low - high targets)
  - Commercialization of non-scientific tracking support
- Accuracy
  - Improved system accuracy (mm tracking)
  - Modeling improvements (e.g. atmosphere)
  - Target definition (retrorefector design)
  - Network design: Better distribution
- Capabilities
  - Rapid pass interleaving
  - Kilohertz lasers
  - Transponders → interplanetary ranging

Improving the Determination of the Terrestrial Reference Frame with an Enhanced Satellite Laser Ranging Network

J. Ries[1], R. Eanes[1], F. Lemoine[2], E. Pavlis[3]

[1] UT/CSR
[2] NASA/ GSFC
[3] JCET/UMBC

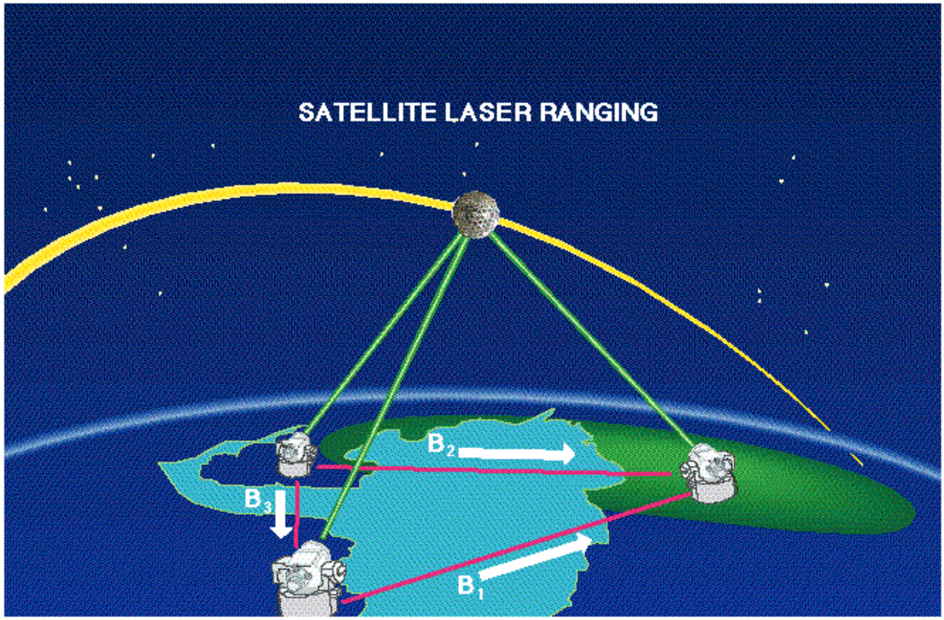
EGU General Assembly
Vienna, Austria
April 3-7, 2006



Motivation

- Continue developing a mechanism for reliably evaluating the impact of changes in the SLR network

- We need to be able to:
  - Evaluate current level of TRF error (not confidently known)
  - Optimize use of available or future SLR resources
  - Determine level of tracking needs to meet future science requirements



Procedure (1)

- Generate a set of simulated SLR data incorporating some ‘guesstimate’ of dynamical and observation modeling errors
  - Dynamical modeling errors:
    - Static gravity: EIGEN-GRACE01S vs GGM02C
    - Tides: 1% error in solid earth tides; FES2004 vs CSR4.0
    - Seasonal terms in first 20 zonals + C21/S21
    - Error in J2, J3 & J4 rates, GM error
    - Surface forces: Perturb reflectivity, albedo, emissivity, shadow model, 100% error in ‘Yarkovsky’ forces
    - Stochastic along-track forces (~20 pm/s^2)
  - Measurement modeling errors:
    - Station coords: 5 mm & 0.5 mm/y random errors in pos & vel
    - Station displacement: 1-2% error in geometric tides, 5% error in pole tide and ocean loading
    - White noise: 3-16 mm depending on station
    - Stochastic biases: 7-29 mm Gauss-Markov with few-day time constant

Procedure (2)

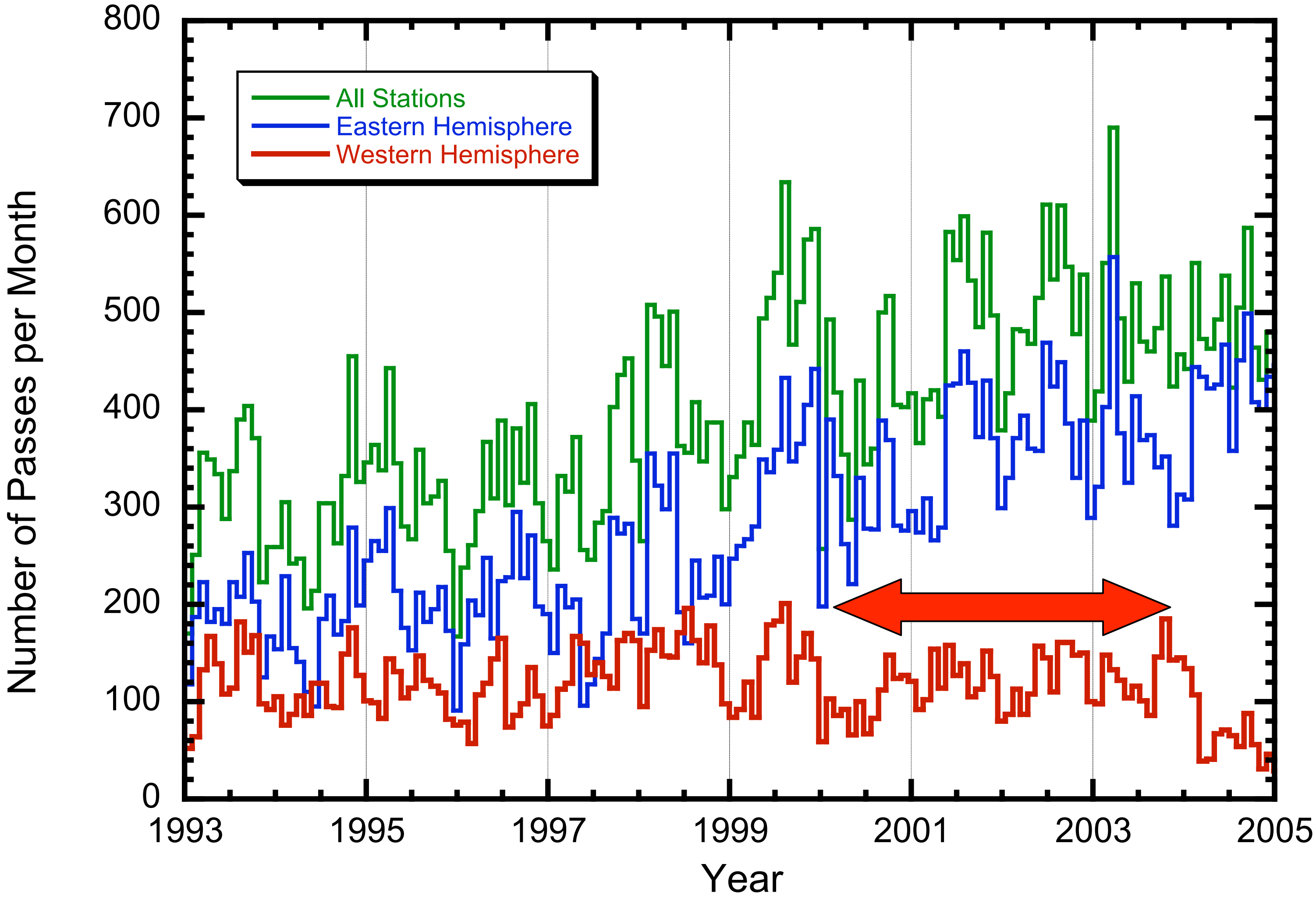
- Calibration of modeling errors to be consistent with observed performance with LAGEOS-1/2
  - Important to perturb as much of model as possible to provide rich and realistic spectrum of errors
  - Should include systematic biases as well as stochastic errors
- Insert seasonal geocenter signal (3-6 mm in this case) and compare recovery to actual performance from LAGEOS-1/2
  - Use recovery of geocenter variability as a quick proxy for TRF origin improvement
- Test selected SLR network scenarios

Tracking Data Sampling

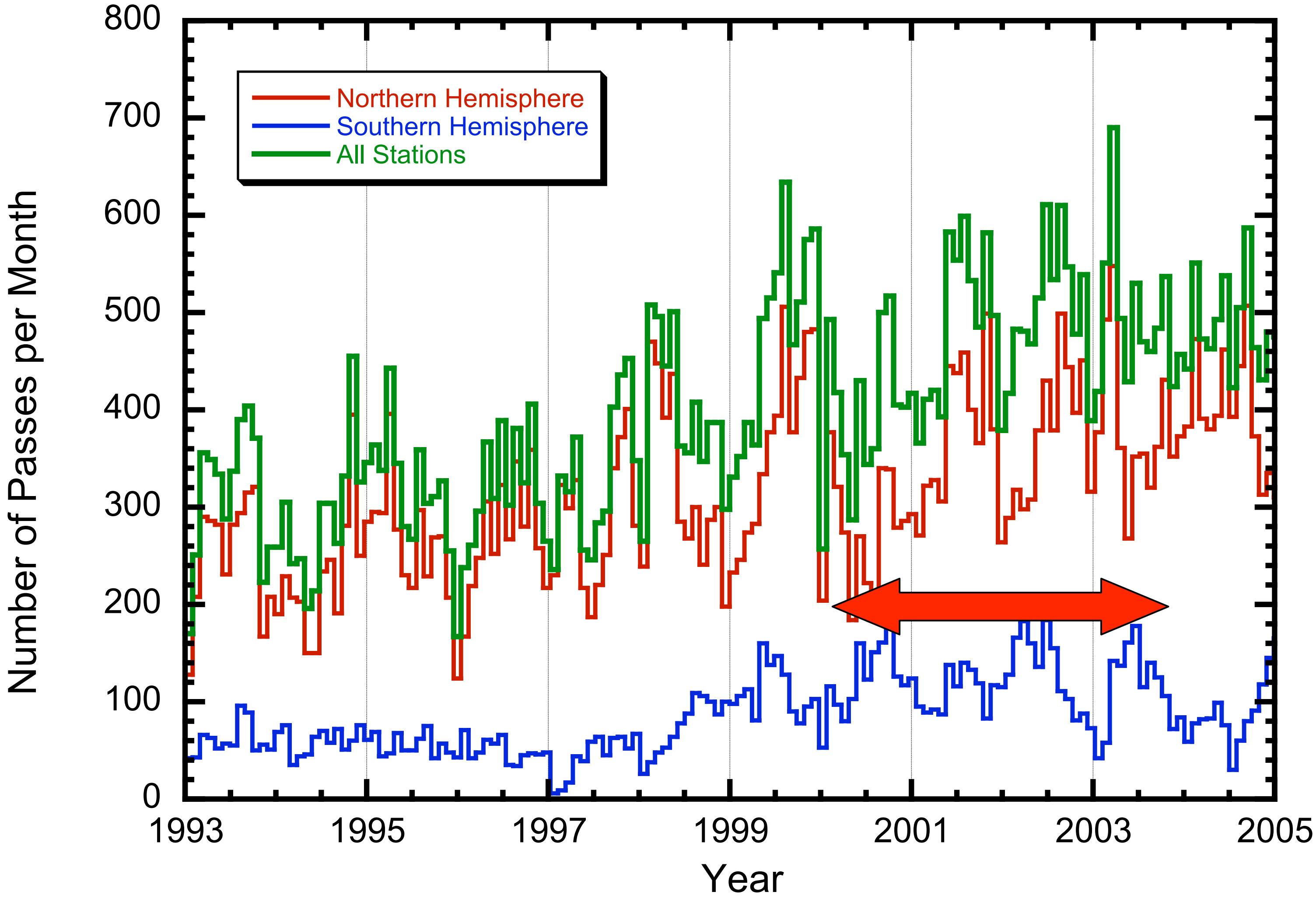
- Realism of SLR data distribution and acquisition patterns is probably most critical aspect
  - Chose ‘core’ network of 25 stations which contribute the dominant share of the useful ranging data over the reference period (2000-2004)
  - Reduced pass acquisition to a percent of possible passes based on actual station performance
  - Reduced data within passes to emulate gaps in tracking (LAGEOS passes often broken up to track other lower satellites)
  - *Adjusted percent of successful passes to reflect seasonal performance in different geographic regions*

SLR Site Map (current network)

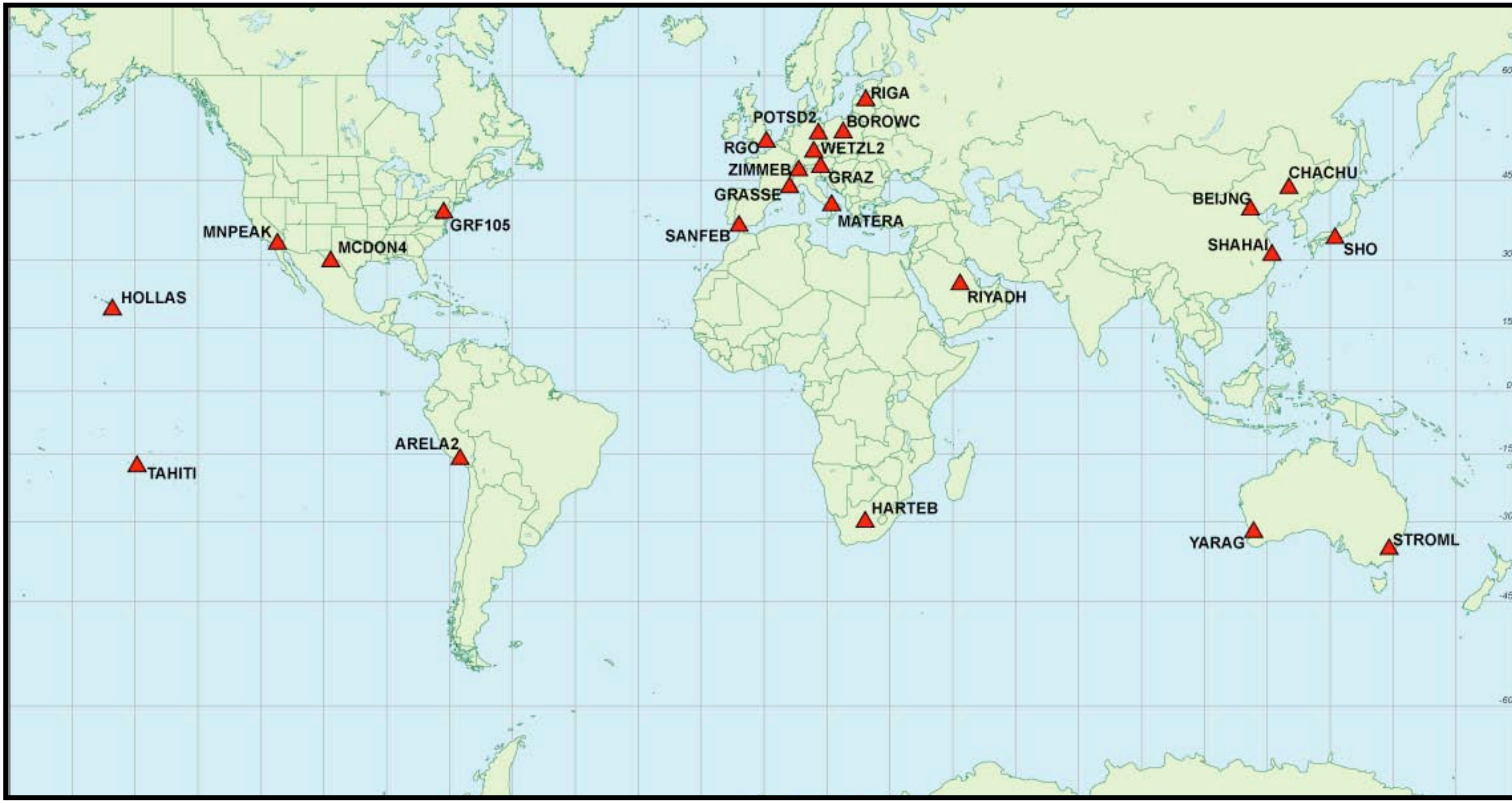
Actual SLR Tracking Patterns (1)



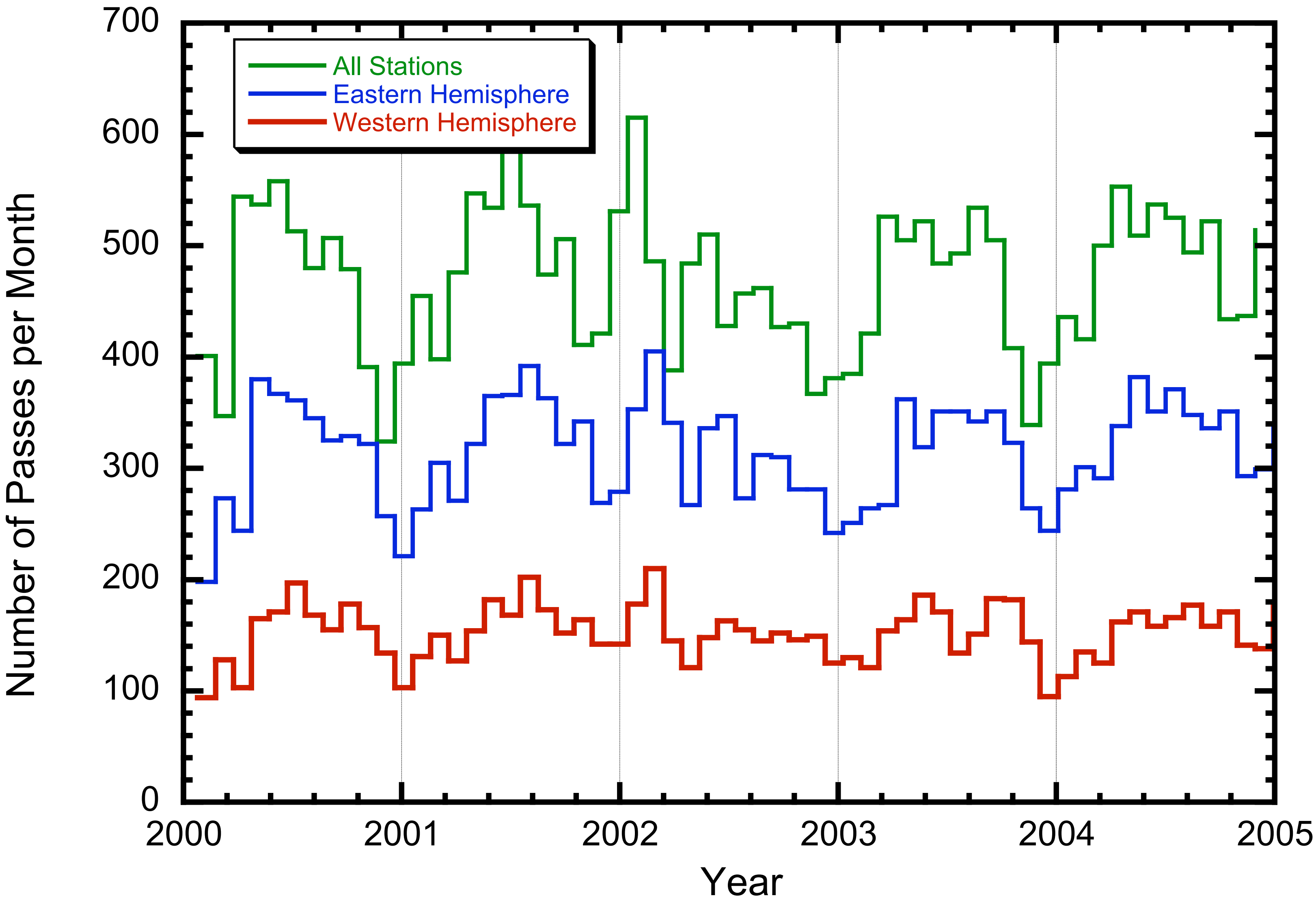
Actual SLR Tracking Patterns (2)



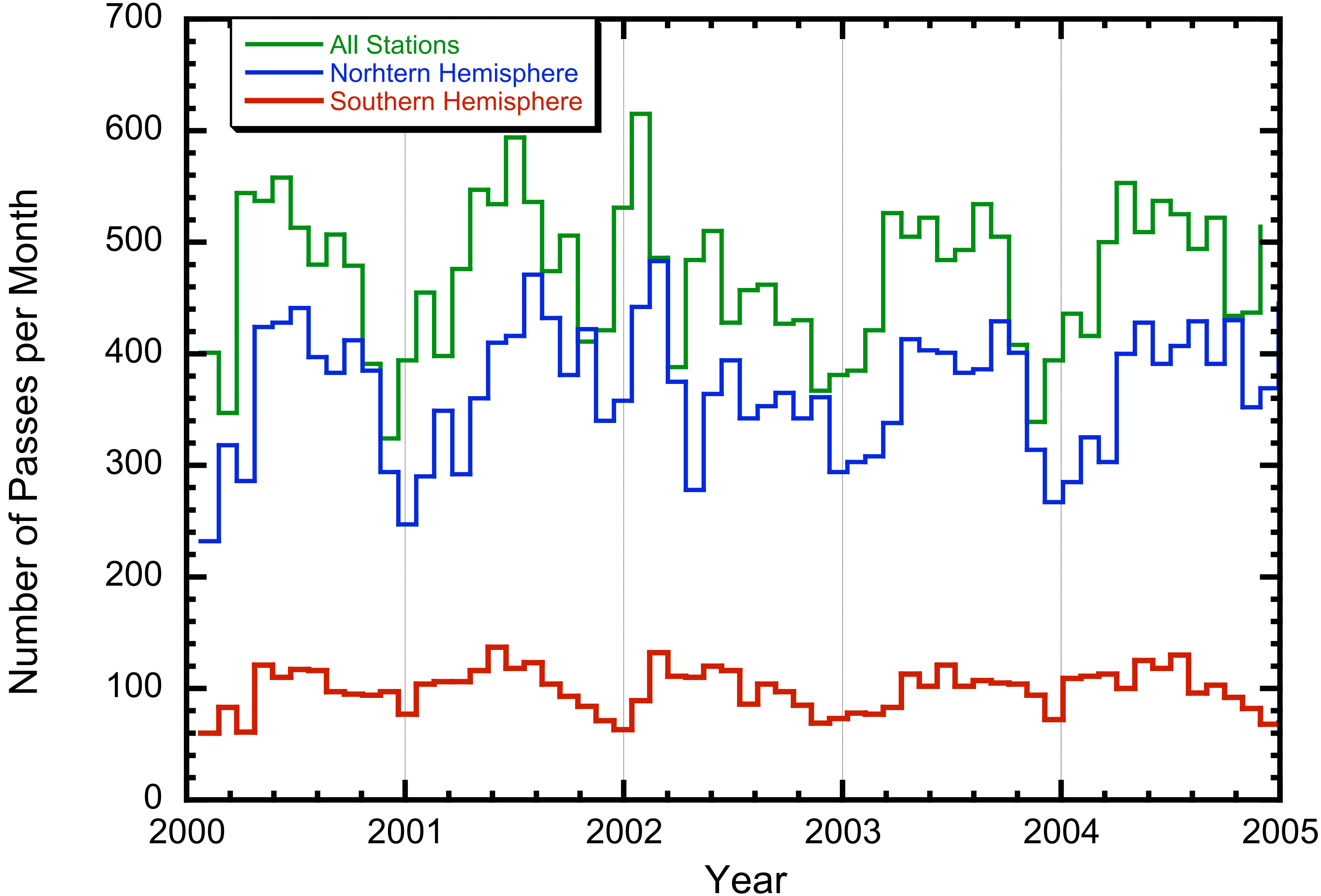
SLR Site Map (simulation core network)



Simulated Tracking Patterns (1)



Simulated Tracking Patterns (2)

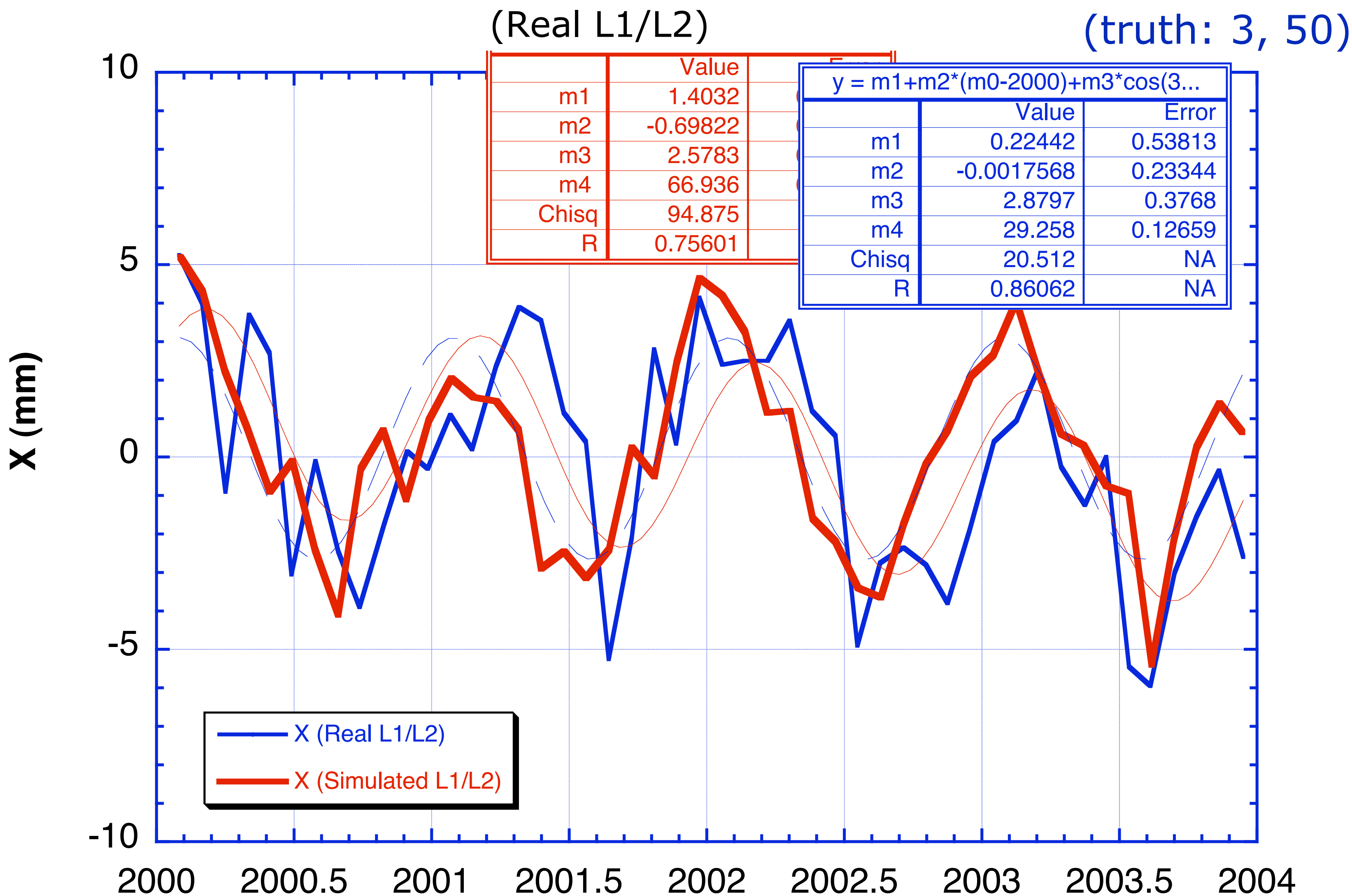


Coarse Verification of Simulation Fidelity

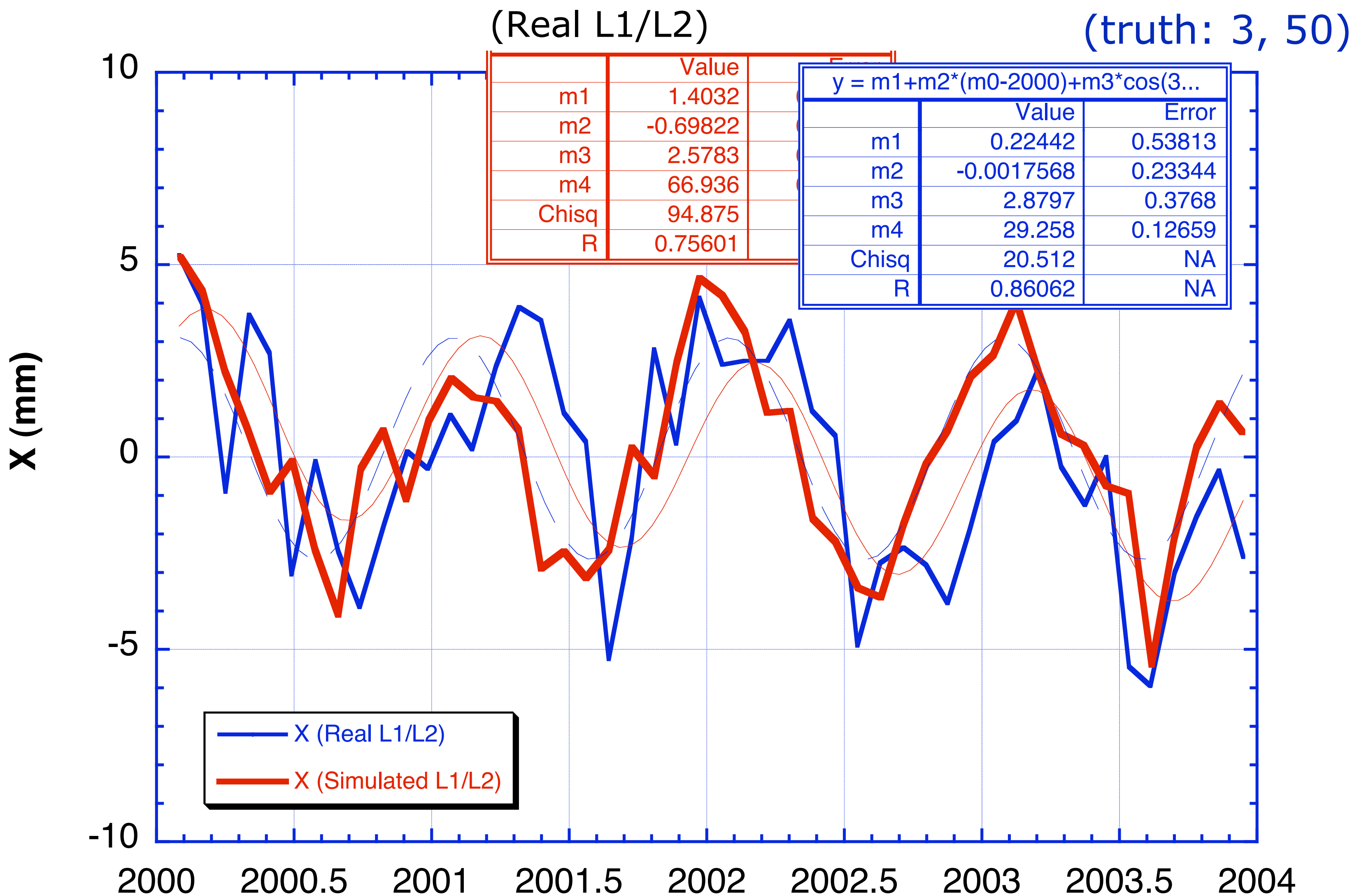
Case	SLR Fit (mm)	Avg # passes/mo	Avg # obs/pass	Time-bias (μsec)
Real L1/L2*	13 / 12	510 / 450	11 / 12	47 / 47
Simulated L1/L2	13 / 14	460 / 380	11 / 12	39 / 51

* For core network and after stringent editing (30-day arcs)

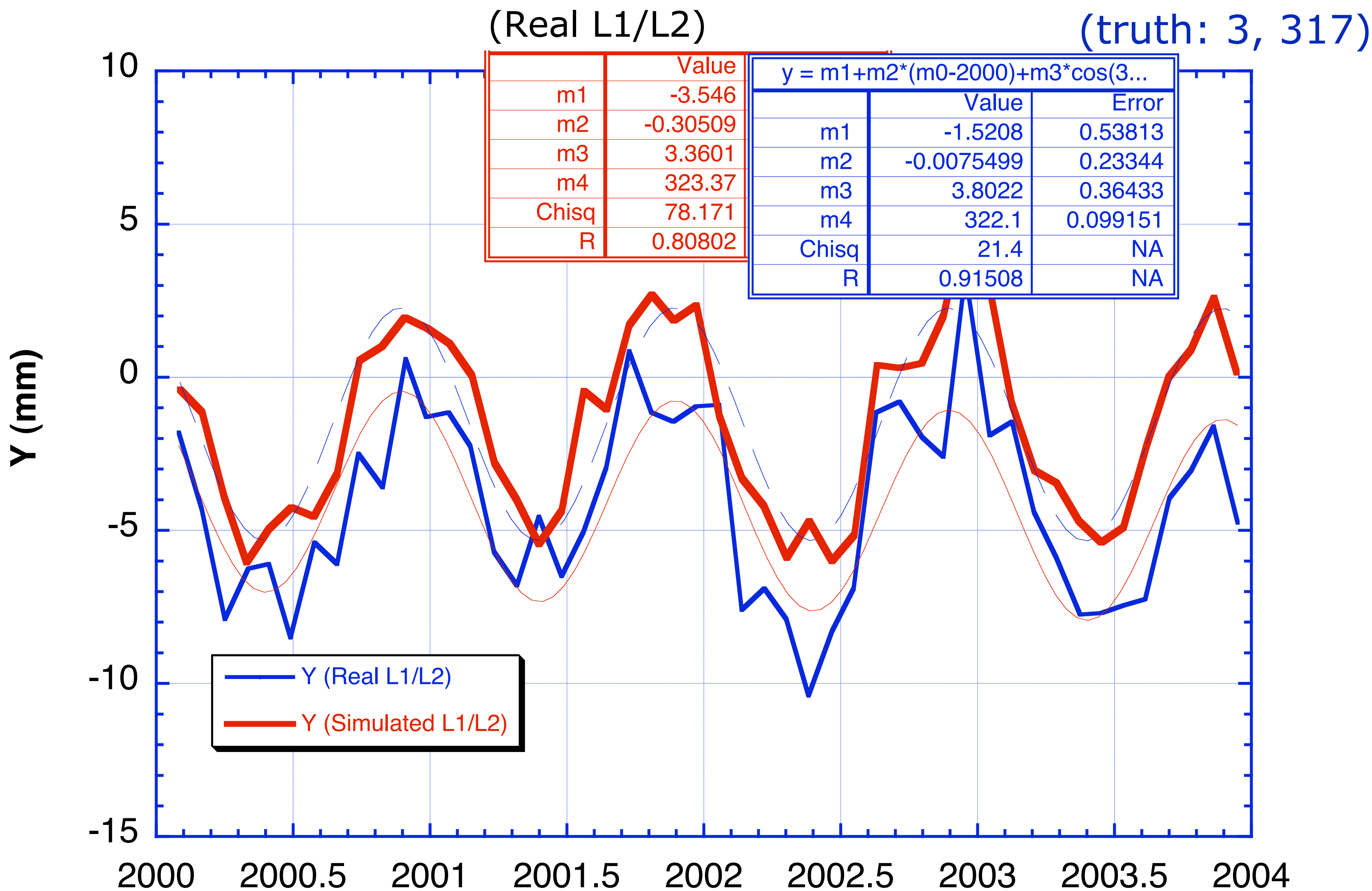
Results for Simulated LAGEOS-1/2 (X)



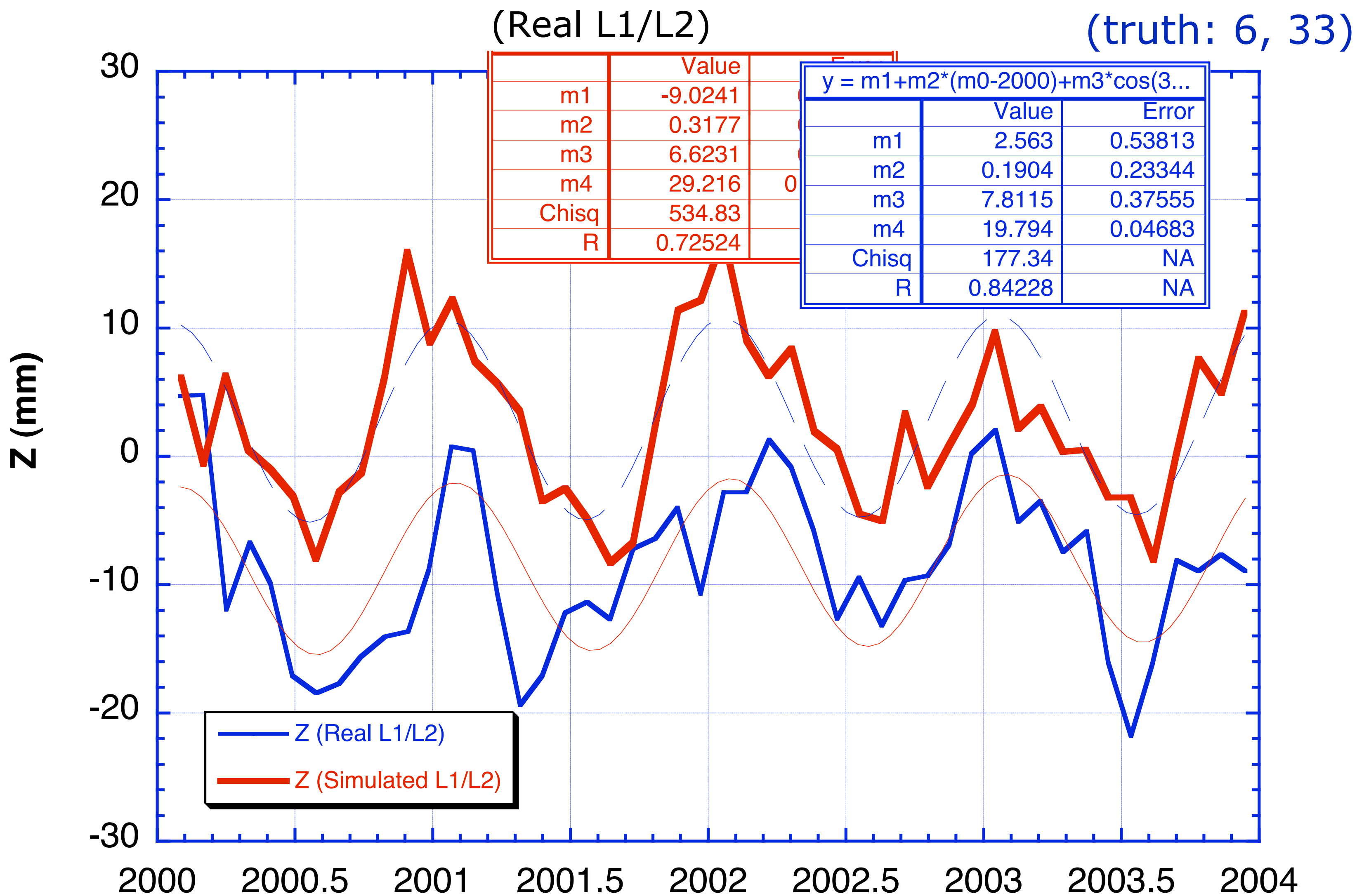
Results for Simulated LAGEOS-1/2 (X)



Results for simulated LAGEOS-1/2 (Y)



Results for simulated LAGEOS-1/2 (Z)

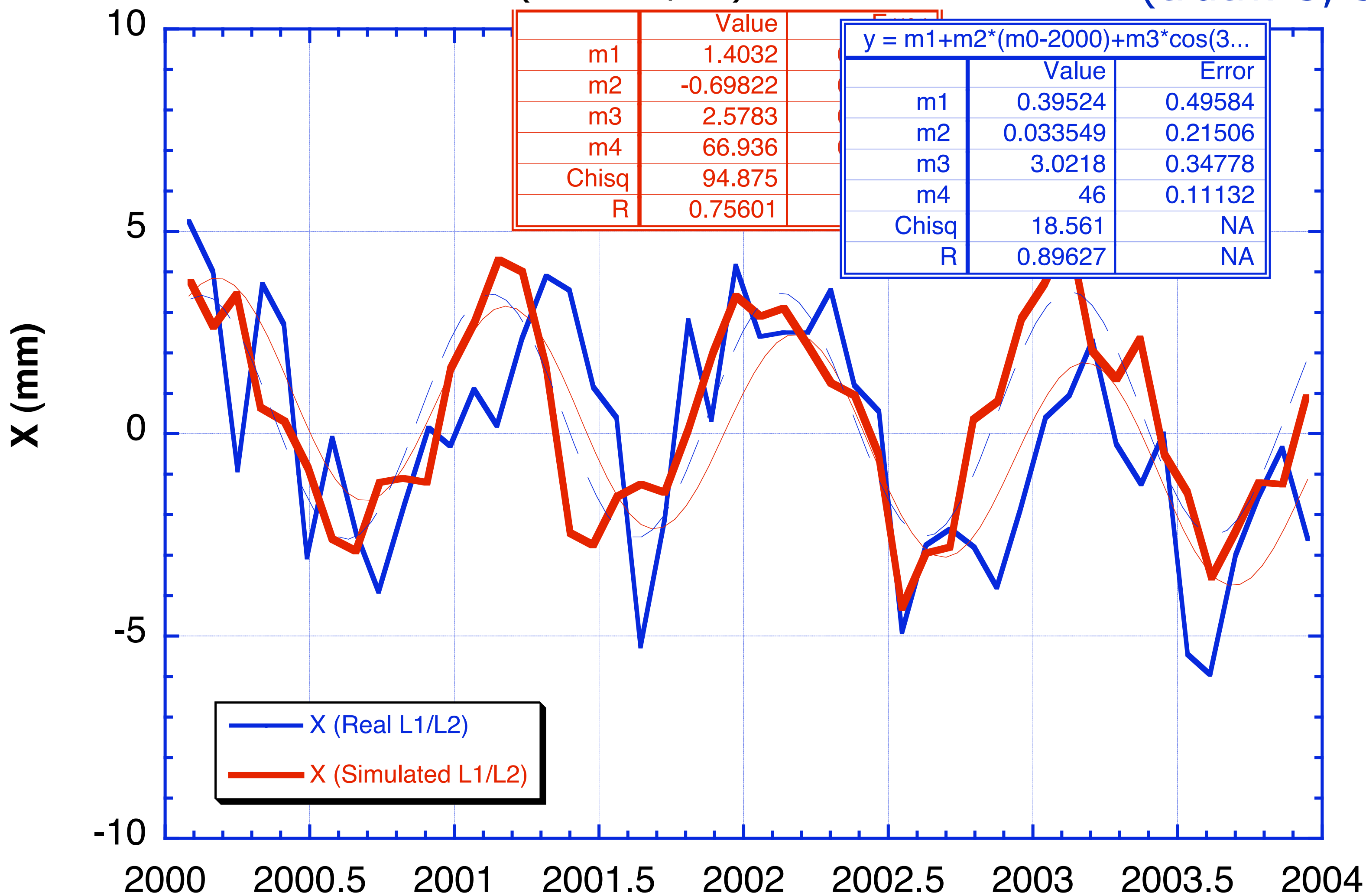


Simulation Appears Reasonable

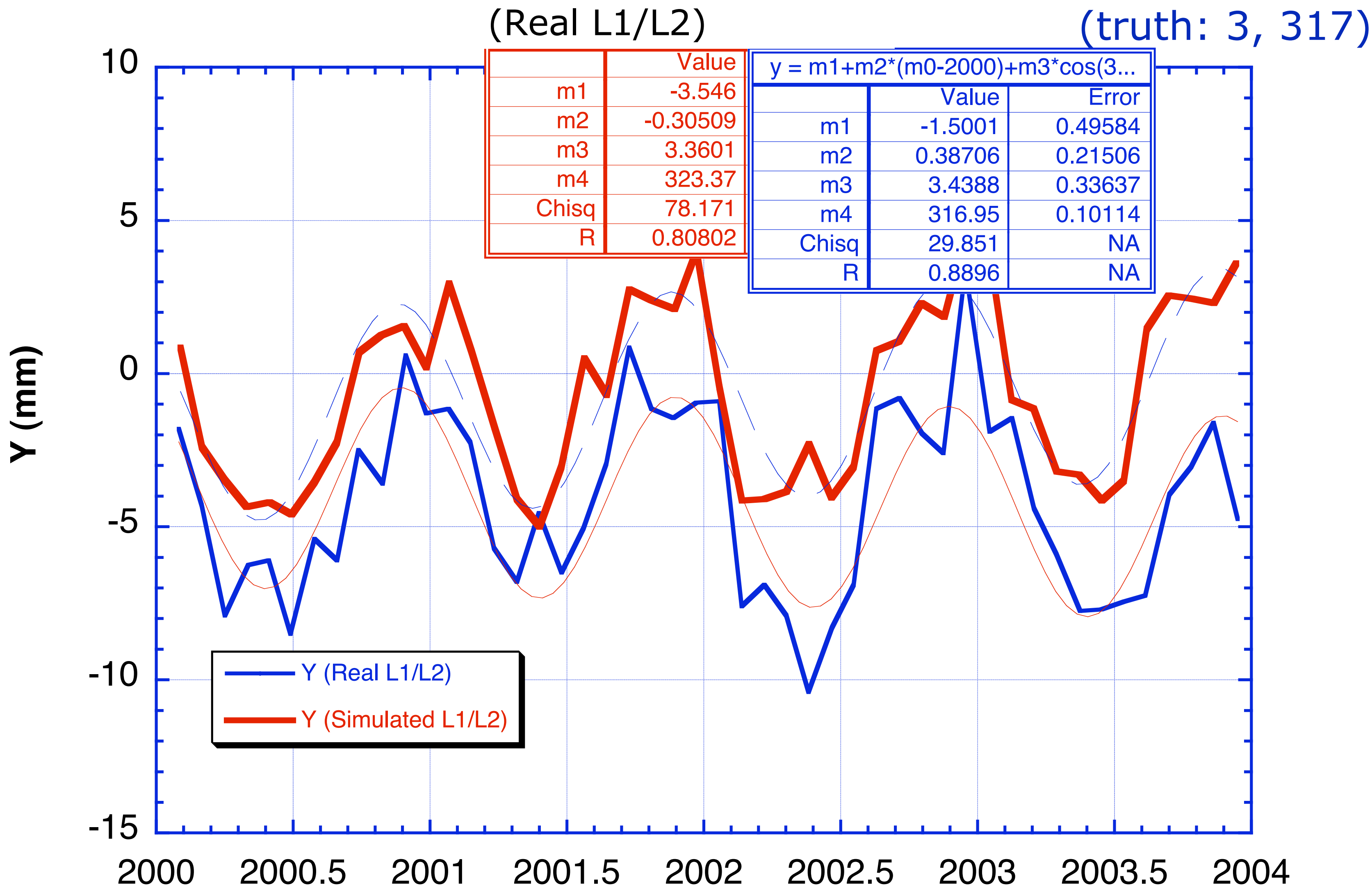
- Variations from month-to-month seem consistent with actual geocenter estimates from LAGEOS-1/2
- Use simulation to test variations in network performance or distribution
  - Improved core: improve yield at Hawaii, Tahiti, Arequipa; all stations improved accuracy
  - Extended network: improve yield at Hawaii, Tahiti, Arequipa; add 6 stations
- Look for cleaner recovery of seasonal variation of geocenter to indicate more robust origin sensitivity

Results for Improved Network (X)

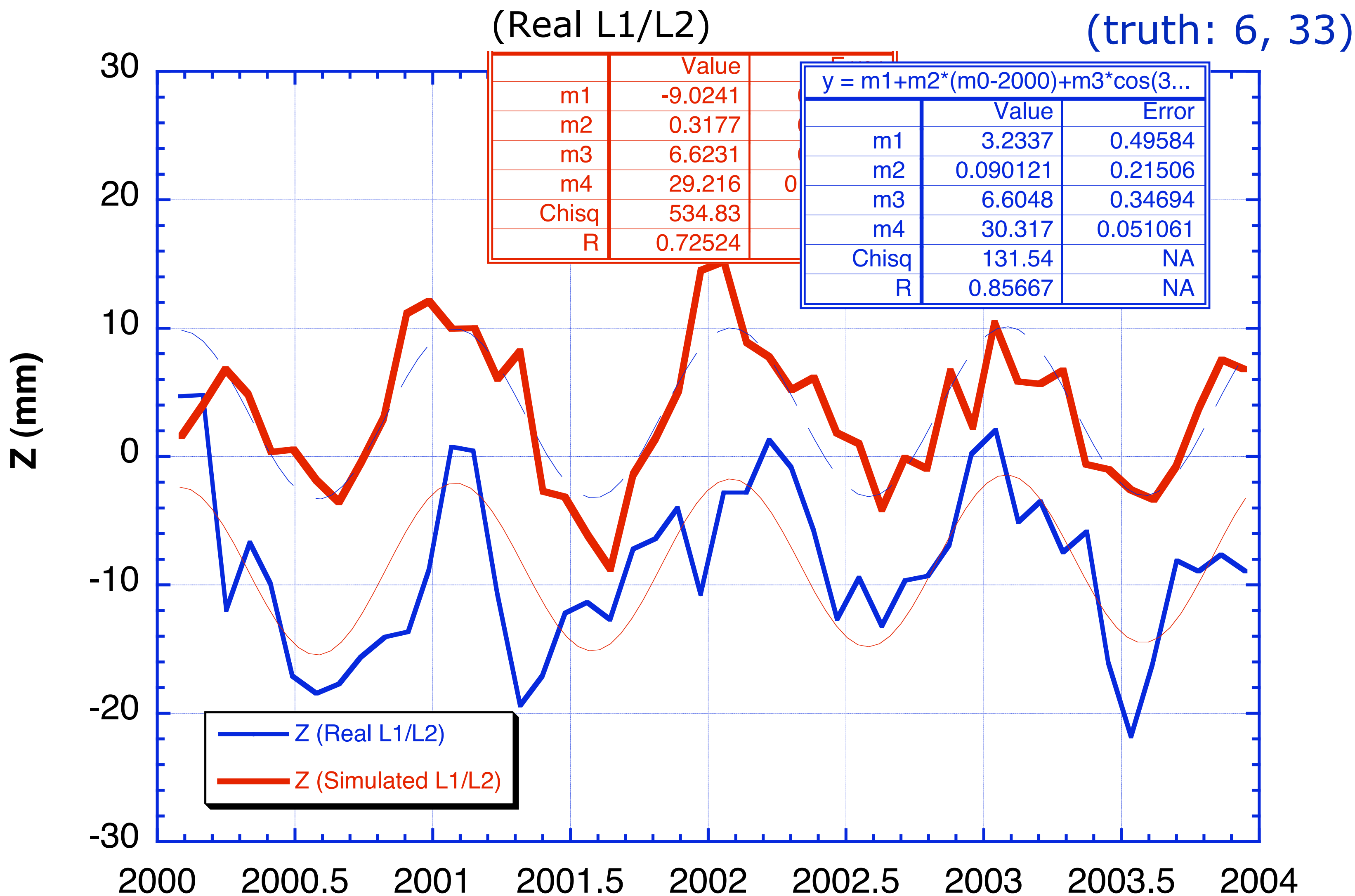
(Real L1/L2) (truth: 3, 50)



Results for Improved Network (Y)

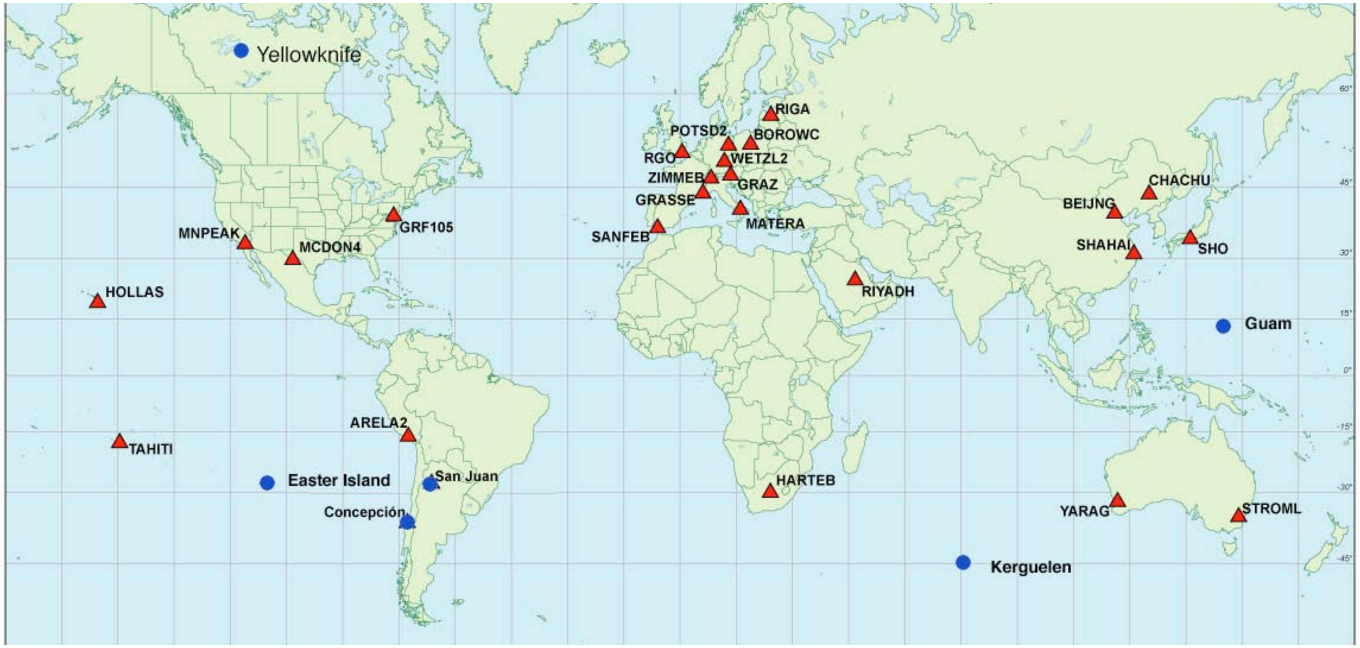


Results for Improved Network (Z)

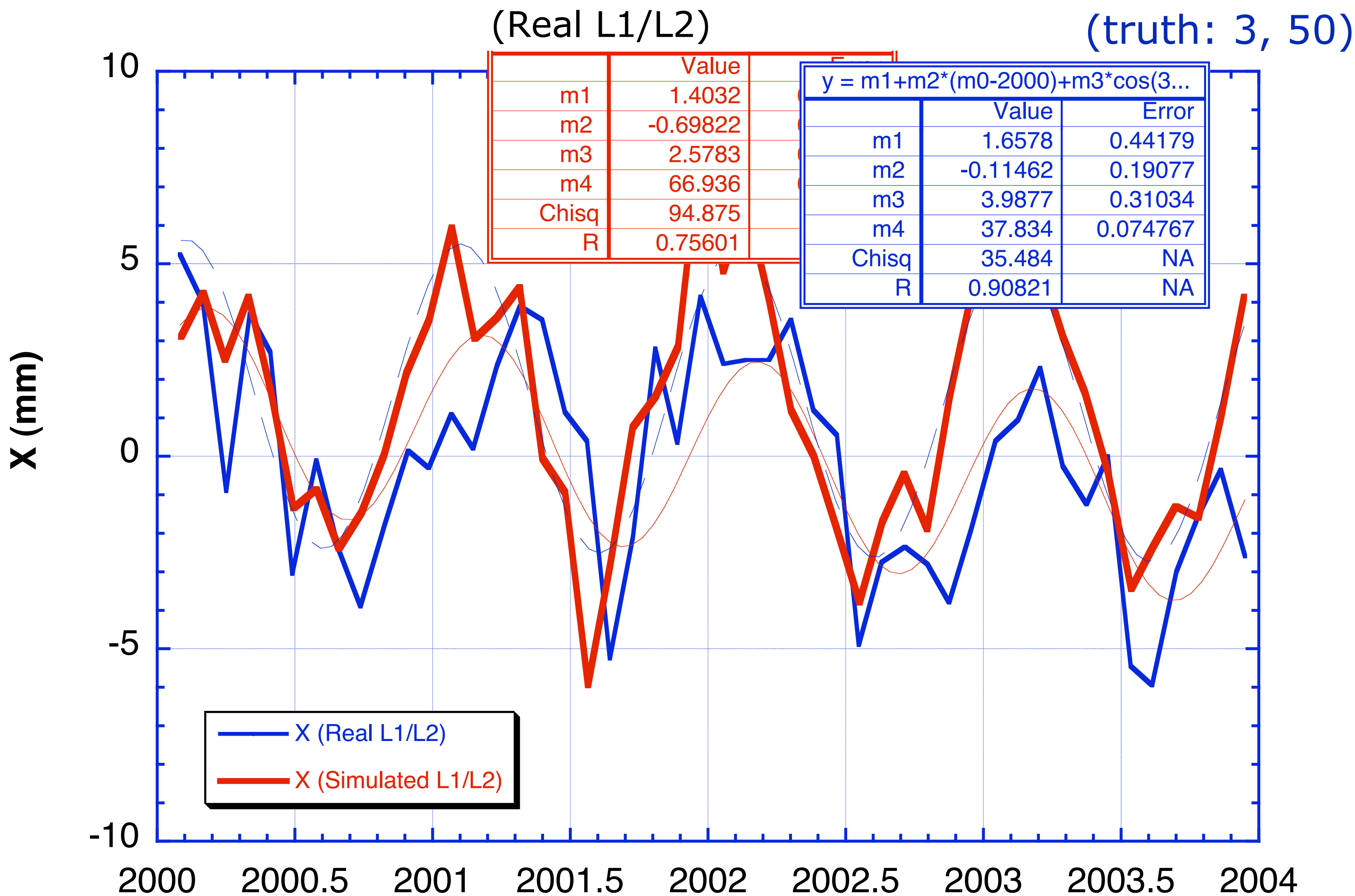


Impact of Improved Network

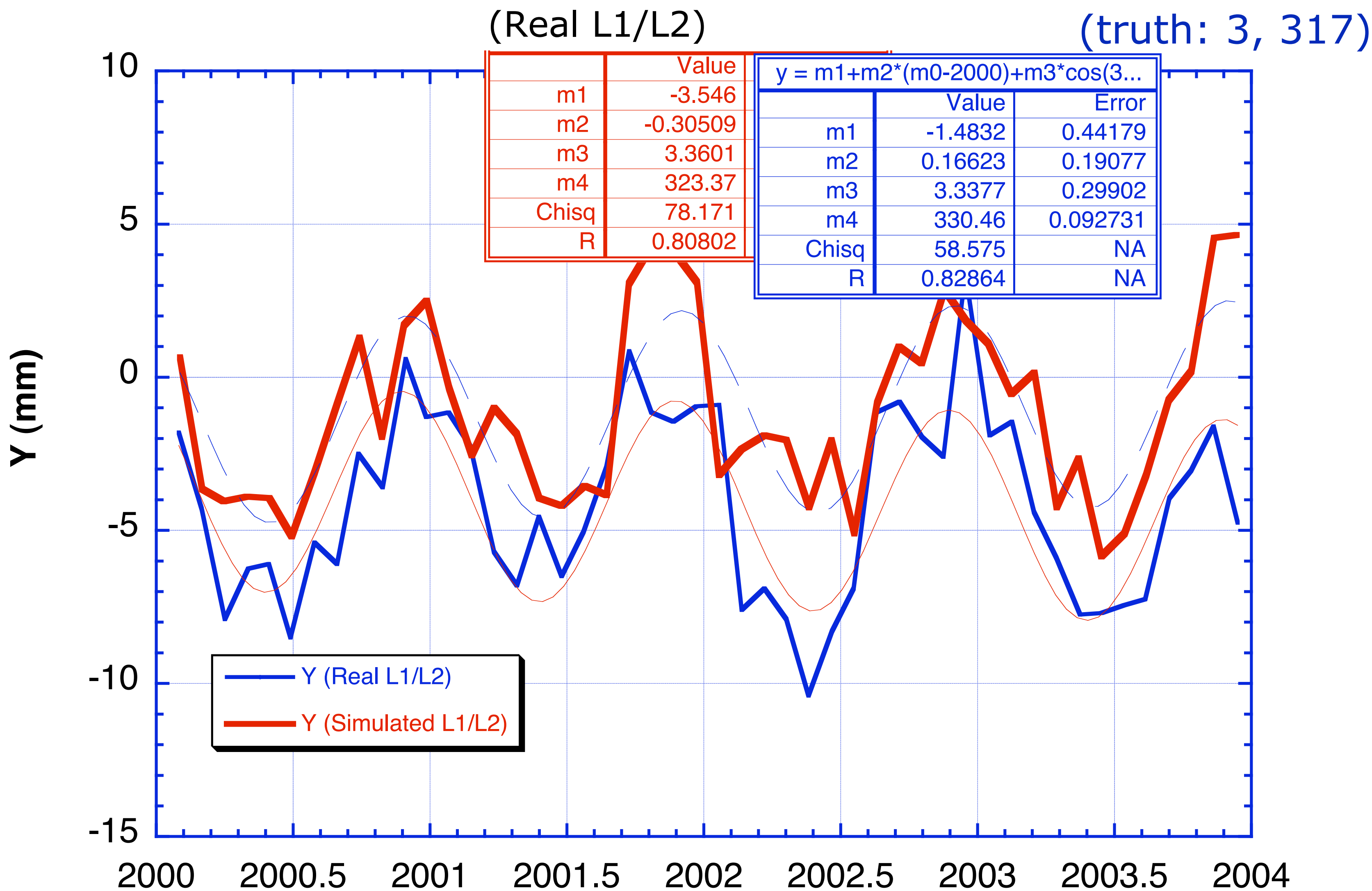
- Effect of improving accuracy and yield of current network appears to be disappointingly modest
  - May be reasonable; network geographic coverage not changed
  - May also indicate an error component that is unreasonably large
- Test ‘extended network’ scenario



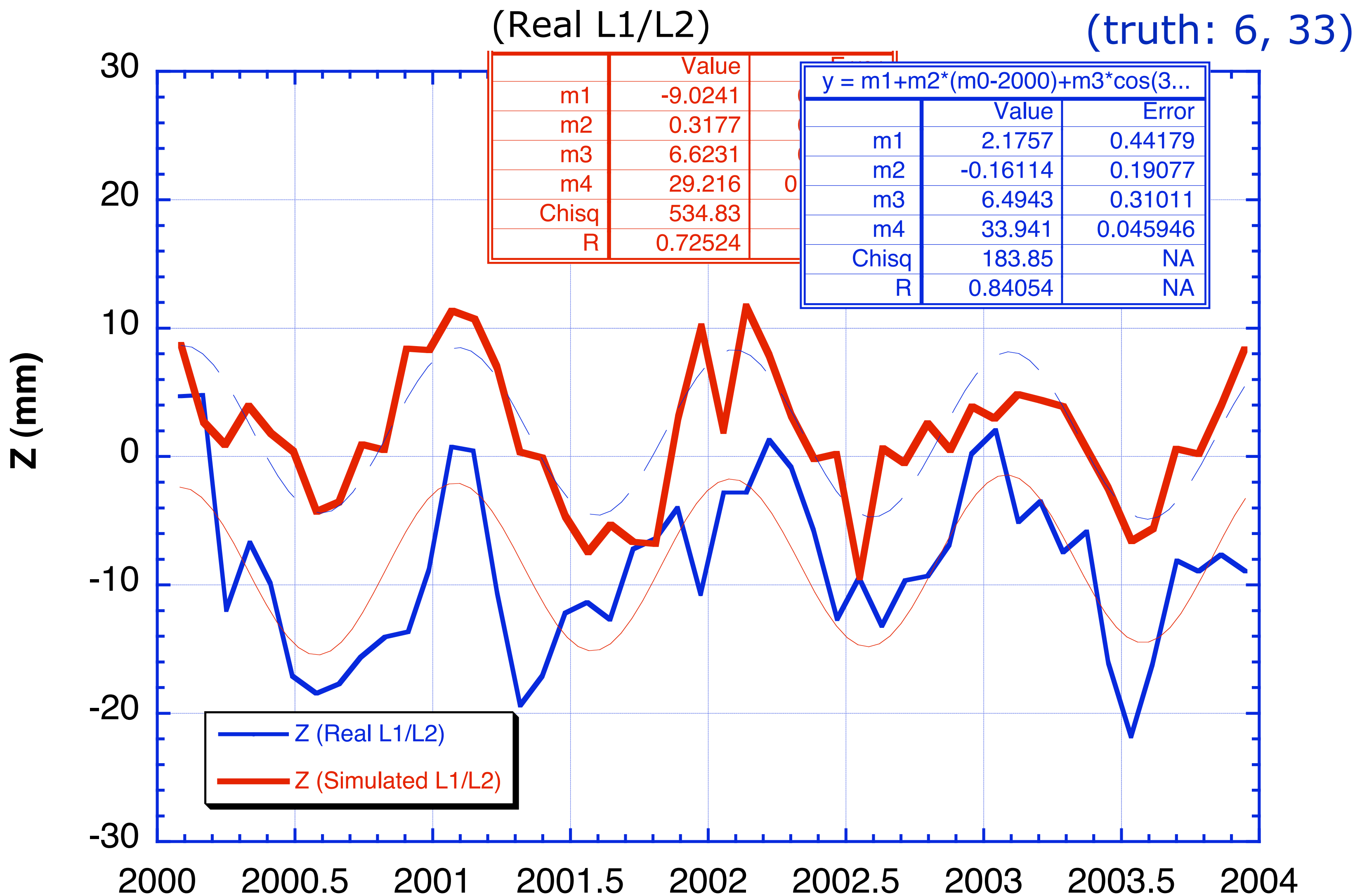
Results for Extended Network (X)



Results for Extended Network (Y)



Results for Extended Network (Z)



Conclusions

- Modest improvement from ‘improved network’ but little additional benefit from ‘extended network’
  - Not expected; very likely indicates an exaggerated component of error model (e.g., ocean loading)
- Conundrum…SLR simulation will provide a tool to help us understand what limits our geocenter determination, BUT we need to understand the errors that limit our results in order to design the simulation
- Taking an optimistic view…in constructing the simulation, we may learn as much about our system as from running the simulation itself

Future Work

- Continue to refine error models to provide as rich a perturbation spectrum as possible, yet remaining consistent with observed results
  - Additional modeling errors should be included (e.g., EOP, more complicated time variable gravity, atmospheric loading)
- Exchange simulated data between analysis centers and verify realism of error models
- Use simulated data in full network adjustments to investigate effects on origin and scale of SLR reference frame
- Extend simulation to include combinations with VLBI to investigate impact on ITRF

Backup Material

Residual analysis (Actual LAGEOS-1)

STATION	PASSES	TOTAL OBS	EDITED OBS	PCT EDITED	GOOD OBS	RAW RMS	B/TB RMS	POLY RMS
1884 RIGA__	226	2611	21	0.8	2590	2.38	0.80	0.68
7080 MCDON4	1090	9166	9	0.1	9157	1.21	0.40	0.31
7090 YARAG_	2599	28499	6	0.0	28493	1.10	0.34	0.25
7105 GRF105	1497	15938	7	0.0	15931	1.07	0.35	0.29
7110 MNPEAK	1911	19443	6	0.0	19437	1.18	0.33	0.26
7124 TAHITI	275	2898	0	0.0	2898	1.27	0.44	0.35
7210 HOLLAS	623	5924	9	0.2	5915	1.52	0.48	0.41
7237 CHACHU	928	9258	55	0.6	9203	2.60	0.85	0.74
7249 BEIJNG	144	1070	22	2.1	1048	3.02	1.43	1.18
7403 ARELA2	142	1493	0	0.0	1493	1.17	0.36	0.30
7501 HARTEB	1076	12146	9	0.1	12137	1.41	0.31	0.21
7810 ZIMMEB	1555	19937	8	0.0	19929	1.21	0.50	0.38
7811 BOROWC	346	3885	8	0.2	3877	1.76	0.80	0.68
7824 SANFEB	362	2776	107	3.9	2669	3.22	1.14	0.87
7832 RIYADH	984	10570	0	0.0	10570	1.26	0.46	0.35
7835 GRASSE	858	9980	1	0.0	9979	1.09	0.33	0.26
7836 POTSD2	422	3975	3	0.1	3972	1.23	0.68	0.56
7837 SHAHAI	345	3021	16	0.5	3005	1.81	0.83	0.73
7838 SHO___	490	5263	10	0.2	5253	2.34	0.99	0.84
7839 GRAZ__	1659	21865	0	0.0	21865	1.03	0.31	0.24
7840 RGO___	2114	25153	0	0.0	25153	1.05	0.33	0.26
7849 STROML	1477	13769	11	0.1	13758	1.19	0.41	0.34
7941 _MLRO_	268	2779	0	0.0	2779	1.09	0.38	0.25
8834 WETZL2	1147	10389	36	0.3	10353	2.02	0.66	0.52
TOTALS	22538	241808	344	0.1	241464	1.24	0.42	0.33

(RMS of range-biases: 0.9 cm   RMS of time-biases: 4.7 microsec)

Residual analysis (Sim. LAGEOS-1)

STATION	PASSES	TOTAL OBS	EDITED OBS	PCT EDITED	GOOD OBS	RAW RMS	B/TB RMS	POLY RMS
1884 RIGA__	292	3473	7	0.2	3466	2.93	0.93	0.86
7080 MCDON4	936	9135	6	0.1	9129	0.98	0.31	0.28
7090 YARAG_	2056	20944	22	0.1	20922	1.18	0.26	0.21
7105 GRF105	1638	18788	18	0.1	18770	1.07	0.27	0.23
7110 MNPEAK	2585	24929	23	0.1	24906	1.18	0.26	0.22
7124 TAHITI	267	2823	2	0.1	2821	1.46	0.36	0.31
7210 HOLLAS	767	8072	6	0.1	8066	1.51	0.31	0.25
7237 CHACHU	865	9370	5	0.1	9365	2.70	0.83	0.78
7249 BEIJNG	367	3964	7	0.2	3957	2.69	0.98	0.91
7403 ARELA2	680	6883	7	0.1	6876	1.20	0.38	0.34
7501 HARTEB	402	4221	5	0.1	4216	1.35	0.41	0.35
7810 ZIMMEB	889	10461	16	0.2	10445	1.13	0.46	0.43
7811 BOROWC	389	4636	10	0.2	4626	2.51	0.98	0.93
7824 SANFEB	361	4043	7	0.2	4036	3.42	1.00	0.93
7832 RIYADH	896	9291	8	0.1	9283	0.96	0.28	0.26
7835 GRASSE	482	5592	10	0.2	5582	1.41	0.37	0.34
7836 POTSD2	562	6686	7	0.1	6679	1.40	0.47	0.43
7837 SHAHAI	251	2464	2	0.1	2462	1.79	1.09	1.02
7838 SHO___	474	4553	4	0.1	4549	2.39	0.91	0.84
7839 GRAZ__	1567	18310	22	0.1	18288	2.08	0.20	0.17
7840 RGO___	1820	22000	39	0.2	21961	0.99	0.29	0.26
7849 STROML	2200	21941	23	0.1	21918	1.17	0.29	0.25
7941 _MLRO_	307	3355	4	0.1	3351	1.00	0.30	0.26
8834 WETZL2	1176	13992	11	0.1	13981	1.72	0.47	0.43
TOTALS	22423	241941	276	0.1	241665	1.34	0.33	0.30

(RMS of range-biases: 1.2 cm   RMS of time-biases: 3.8 microsec)

Geocenter Motion Estimates From SLR

Data used	X (amp)	X (phase)	Y (amp)	Y (phase)	Z (amp)	Z (phase)	Reference (comments)
SLR (L1/L2)	2.2	60	3.2	303	2.8	46	Eanes et al., 1997
SLR	2.1	48	2.0	327	3.5	43	Bouille et al., 2000
Topex (SLR/DORIS)	1.8	41	2.9	320	2.4	37	Eanes, 2000
SLR (L1/L2)	2.6	32	2.5	309	3.3	36	Creteaux et al., 2002
SLR (L1/L2)	1.3	47	2.1	321	2.0	26	Eanes, 2005 (12-years weekly solutions)
SLR (L1/L2)	2.7	55	3.4	317	6.2	36	Ries, 2005 (12-years monthly solutions)
Mean (mm)	2.1	47	2.7	316	3.4	37	
Stdev (mm)	0.5	10	0.6	9	1.5	7	

Directions of VLBI Technology Development

- Broadband Concept
- Design of Broadband Feed
- Digital Backend
- High Bandwidth Recording
- Antennas
- e-vlbi

Network Design

- VLBI Simulation/Covariance Analysis Procedure
- Validation of Simulation Procedure
- Combined Analysis of Geodetic Data Types

Broadband delay concept

- Use 3 or 4 frequency bands with continuous frequency coverage across each band (e.g., S,C,X, and Ka)
- Observations from 3 or more bands can be analyzed to achieve a much higher per-observation precision than from current S/X system
- Use an optimized RF frequency sequence to do phase delay resolution at low SNR and compensate for using smaller diameter antennas

  SNR ~ D1*D2   (Baseline antenna diameters)

Broadband Delay Concept (continued)

• Receiver/backend could be equipped with total power radiometers at frequencies from 20-32 GHz -> measurement of line of sight water vapor delay variations

• Allows optimal choice of frequencies within each band to avoid RFI from commercial satellite downlink and broadcast allocations

• Investigations are ongoing to determine expected errors in the broadband concept due to a number of effects (e.g. radio source structure, frequency-dependent effects, characteristics of feed in both polarizations)

Design of broadband feed

- Chalmers University of Technology (Sweden) has developed dual polarized feed to receive 1-13 GHz for SKA (Square Kilometer Array)

- More design work required for > 15 GHz

- Additional feed would allow extending frequency range up to 32 GHz

Digital Back End

- Received signal digitized as early as possible in signal chain to avoid analogue losses
- In present design concept ~13 GHz bandwidth of receiver output will be processed by 4 identical digital processors – each selecting any 1-2 GHz bandwidth slice to be recorded
- 4-8 GHz observed bandwidth (in each polarization) can be acquired → require 32-64 Gbps data rate

(4 x 1 GHz bandwidth, 2 polarizations, 2bit/sample at Nyquist freq → 32 Gbps)

High Bandwidth Recording

• Current operational VLBI sessions run at 256 Mbps

• R&D sessions are being run at 1 Gbps in high SNR mode – observation sigmas ~ 25% operational sigmas

- First results indicate less unmodeled error and better analysis solution fits (wrms residuals)

- Solution with phase delay observable (factor of ~30-40 better than group delays) can be done

• Broadband recording would allow much higher observation rate using smaller antennas (Petrachenko, 2006)

- 1100 obs/day per station compared with the current 200-450 obs/day per station (slew rate ~ 5 deg/s)

- 4 RF bands each producing 8 Gbps → 32 Gbps

- Disk record rates expected to grow from 330 Mbps (2003) to 2 Gbps (2010) (Mujunen & Ritikari, 2004) →16 disk system~32 Gbps


DELL
Locked Power Ready Selected
0/1
2/3
4/5
6/7
USN-0205/2000/1024
mark5-11
Mark 5 VLBI Data System

VLBI System Characteristics

	Current	VLBI2010
antenna size	6–100 m dish	10–12 m dish
slew speed	~20–200 deg/min	≥300 deg/min
sensitivity	200–15,000 SEFD	≤ 1,800 SEFD
frequency range	S/X band	~1–14 GHz X/Ka (Ka~32GHz)
recording rate	128, 256 Mbps	1–2 Gbps
data transfer	disk-based	e-VLBI

12m Cassegrain Antenna key specifications

Surface Accuracy 0.3mm (0.012 inches) RMS all causes. Easily suitable for use at up to 32 GHz. Dual shaped,F/D 0.375

Pointing Accuracy 0.005 degree

No on site panel alignments required

Factory assembled mount reduces installation time

Designed for lower cost volume manufacture in a wide range of sizes and configurations

Operating temp range-15 to +55 Deg C

Specs apply in winds of 35mph

100 mph survival in stow

Allen Telescope Array from the SETI Web site. ATA 6 m antennas at Hat Creek.

Highlights of recent e-VLBI developments

- August 2004
  - Network link to Haystack upgraded to 2.5 Gbps
  - Real-time fringes at 128 Mbps, Westford and GGAO antennas, Haystack Correlator
- February 2005
  - Real-time fringes Westford-Onsala at 256 Mbps
  - Used optically-switched light paths over part of route
- Starting April 2005
  - Start routine e-VLBI transfers from Tsukuba and Kashima
- Starting ~June 2005
  - Automated regular e-VLBI UT1 Intensive data transfers from Wettzell
- September 2005
  - CONT05 data from Tsukuba transferred to Haystack via e-VLBI
- Fall 2005
  - Effort initiated to connect Ny Alesund to Haystack
- November 2005
  - Global real-time e-VLBI demos at 512 Mbps

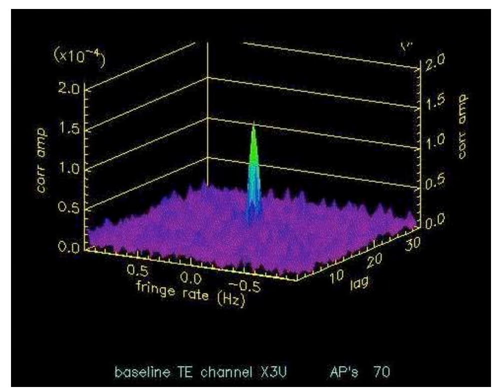
Real-time e-VLBI SC05 Demo

Nov 2005

Real-time transmission and processing of data from antennas in Westford, MA, Greenbelt, MD, and Onsala, Sweden at <u>512 Mbps/antenna</u>

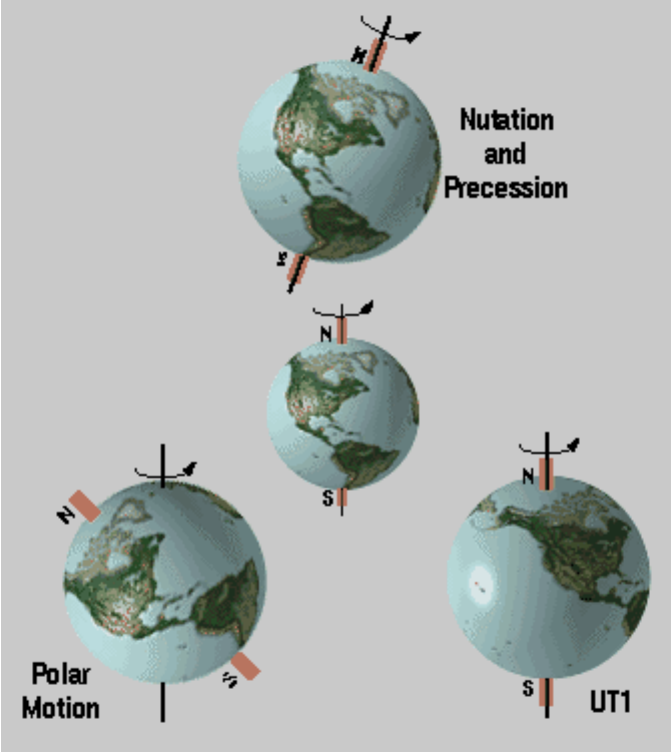
All except Kashima equipped with Mark 5 data systems; Kashima uses Japanese K5, included via VSI-E

Correlation results displayed in real-time at SC05 meeting →



From Alan Whitney

Contributions of VLBI Technique



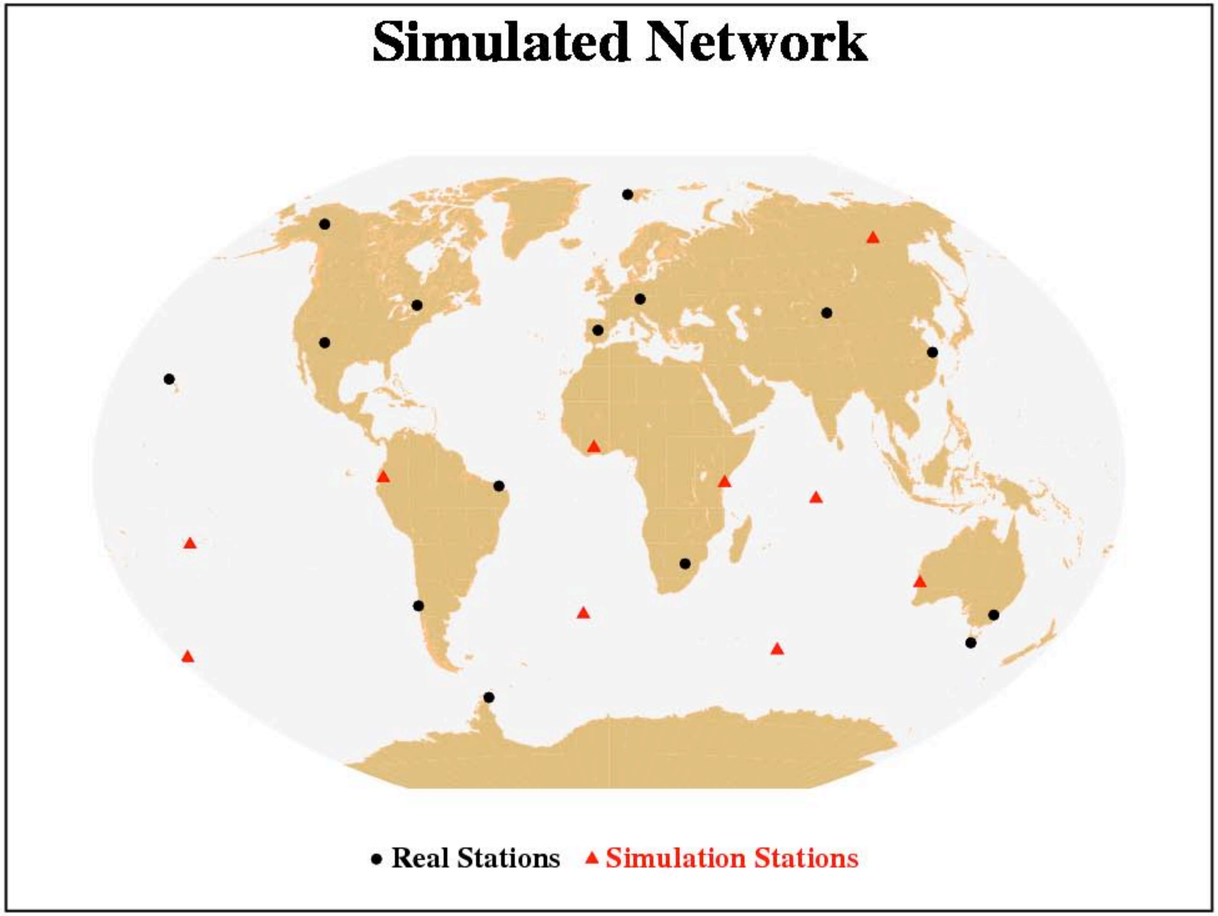
- UT1
- Scale
- Nutation
- Precession

Network Design

• Use simulation and covariance analysis to analyze network performance
  - Some testing of simulations for 16, 20, and 25 station networks has been done

• Optimize in a geometrical sense the design of a new network of VLBI antennas
  - increase the number of VLBI sites
  - improve the geographical distribution of sites specifically in the Southern Hemisphere (Africa, South America and Australia)

• Determine required performance characteristics of new antennas (and upgrades of current antennas) to meet overall network goals



Simulation stations are in GPS locations chosen to improve global coverage of the network

VLBI Simulation/Covariance Analysis Procedure

- Specify network antenna locations, antenna sensitivities, slew rates, SNR requirements
- Generate an observation schedule for a 24-hour VLBI experiment session with the SKED program
- Make a simulation observation file
- Run the simulation data file with the SOLVE analysis program to estimate Earth orientation parameters or station positions
- Perform Monte Carlo simulations by generating simulated observations and making repeated SOLVE runs with different input simulated observations

➔ Precision (repeatability) of estimated parameters (e.g. station positions, baseline length, Earth orientation)

- Compare simulation precision with formal parameter errors

Validation of Simulation Procedure

• Run simulated observations through SOLVE with actually observed experiment observation schedules

• Compare simulation precision with observed precision

• Dominant VLBI errors are atmosphere and clocklike (maser + instrumental) delay errors

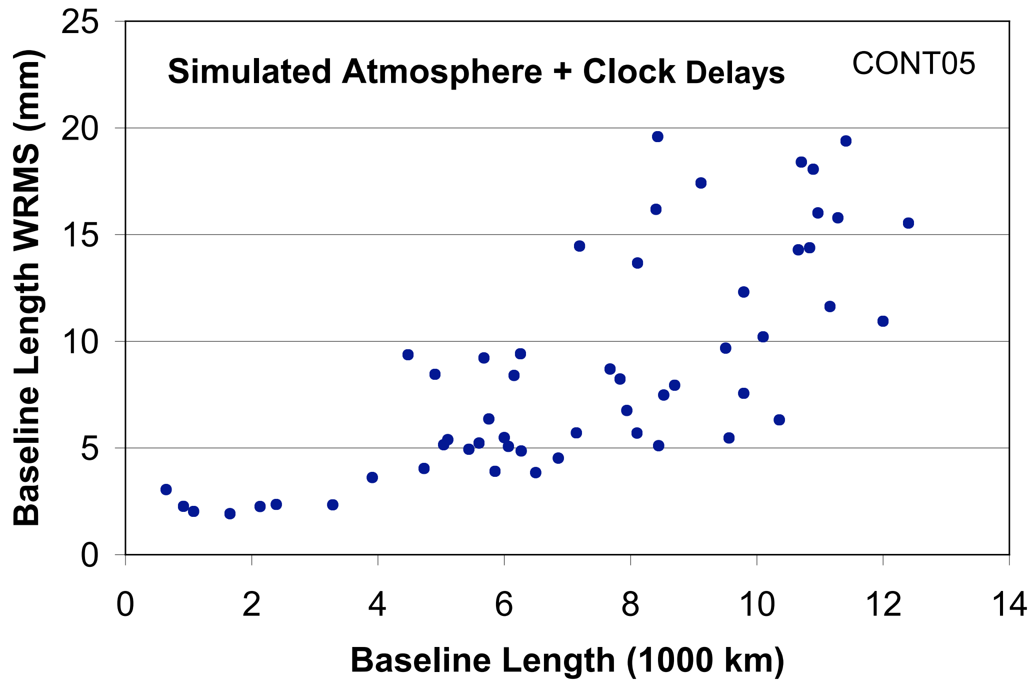
• CONT05 test

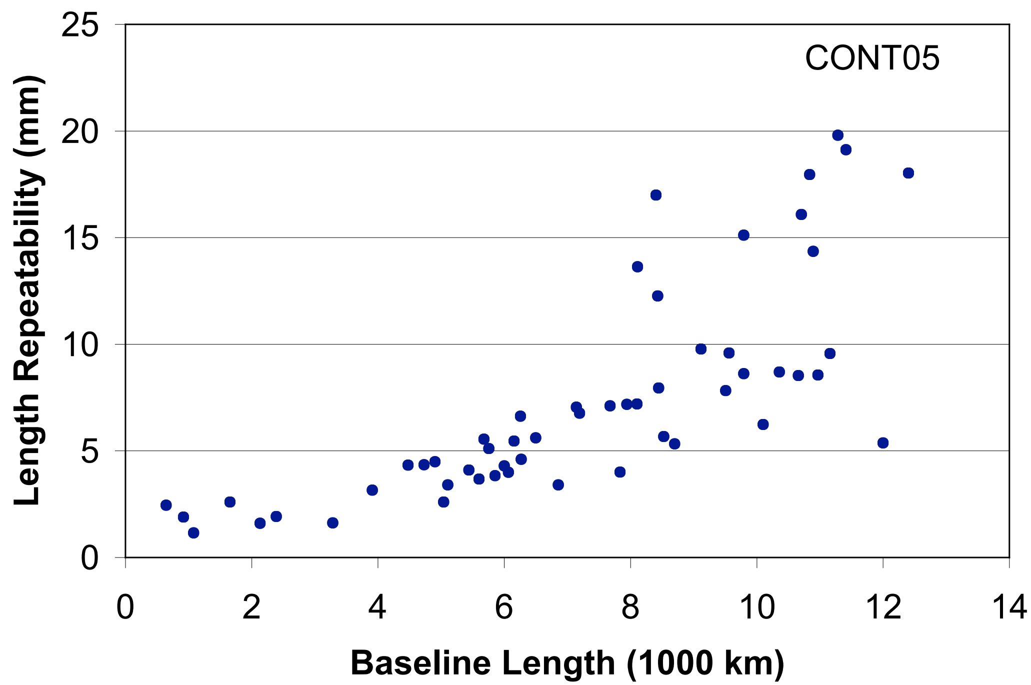
- 15 experiment sessions (September 2005) using nearly the same observing schedule

- Simulated data generated as random walk processes with typical expected atmosphere and clock variances

- Simulation baseline length WRMS precision ~ Observed precision

• Tests using entire history of VLBI geodetic observing sessions


Simulated Atmosphere + Clock Delays
CONT05
Baseline Length WRMS (mm)
Baseline Length (1000 km)
0
5
10
15
20
25
0
2
4
6
8
10
12
14


CONT05
Length Repeatability (mm)
Baseline Length (1000 km)
0
5
10
15
20
25
0
2
4
6
8
10
12
14

Expected Additional Capability of Simulation Tool

- Simulate more complex tropospheric delay variations, e.g., azimuthal asymmetry, turbulence
- Account for correlation between observations on different baselines involving the same station

 - Current work shows that formal parameter uncertainties are more realistic, length repeatabilities better, accuracy of EOP improved

 - Effect of correlations becomes more significant for networks with the large number of stations expected in future networks

- Simulate other sources of delay error

 - Radio source structure error (frequency dependence when considering the observing frequency of the proposed broad band (e.g. 2-32 GHz) observing strategy

 - Antenna structure deformation effects

Combined Analysis of Geodetic Data Types

- Building capability for combined analysis of VLBI, SLR, GPS, and DORIS data with GEODYN/SOLVE2 system

- We have successfully implemented procedure to transfer VLBI data to GEODYN and to analyze there

- Currently working on simulations based on a combined analysis of VLBI and SLR observing schedules, solution parametrizations, and error models (e.g., ocean loading, Earth tides, atmosphere delay, clocks)

Anticipated changes in the technology in the next 10 years (external influences)

- GPS:
  - L2C (2nd civil signal) – Full operational capability (FOC) 2013
  - Block IIF/L5 (3rd civil signal) - launch 2007, operational control 2009, FOC 2014
  - GPS III: Satellite RFP due out soon. BOC1,1 @ L1; nominal 1st launch 2013
- GLONASS:
  - currently 13 operational; plan to return to 24 sats by 2011
  - recent M satellites have 2nd civil signal @L2, but few receivers yet
  - K satellites (3rd civil signal @L2) launch 2008
- Galileo:
  - 4 operational sats 2008
  - FOC 2010
- LEOs with GPS: More of them

To utilize these will require new equipment, and upgrades to analysis (including new spacecraft models).

Anticipated changes in DORIS technology
In the next 10 years

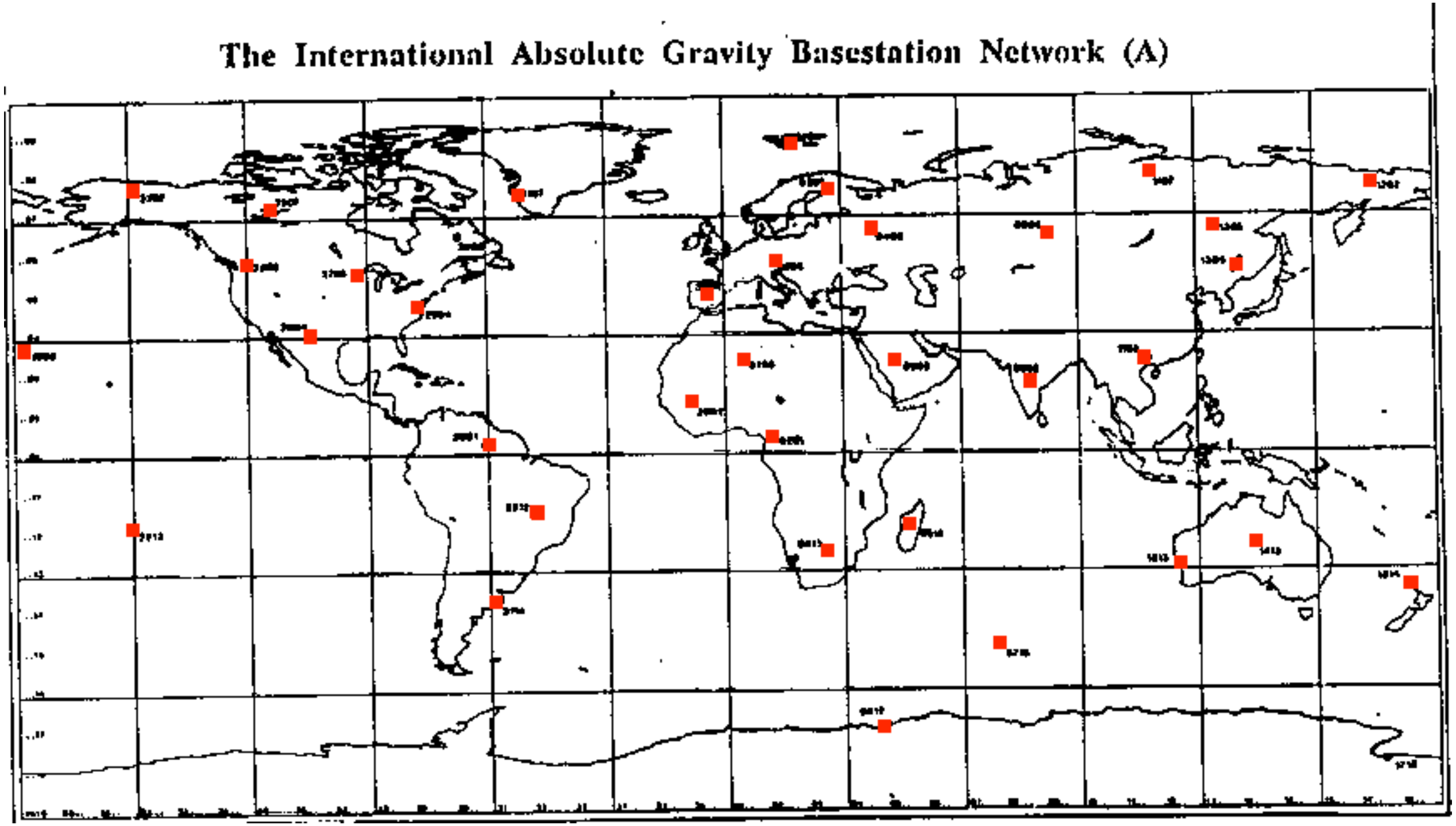
Several new satellite launches expected 2008-2009
(but long-term DORIS constellation difficult to predict)

New multi-channel receivers on-board
(more data on ground + potentially larger ground network)

Improved geodetic results
(better phase measurements + emulation between DORIS Analysis Centers: from 2 to 4+)

P. Willis, F. Lemoine

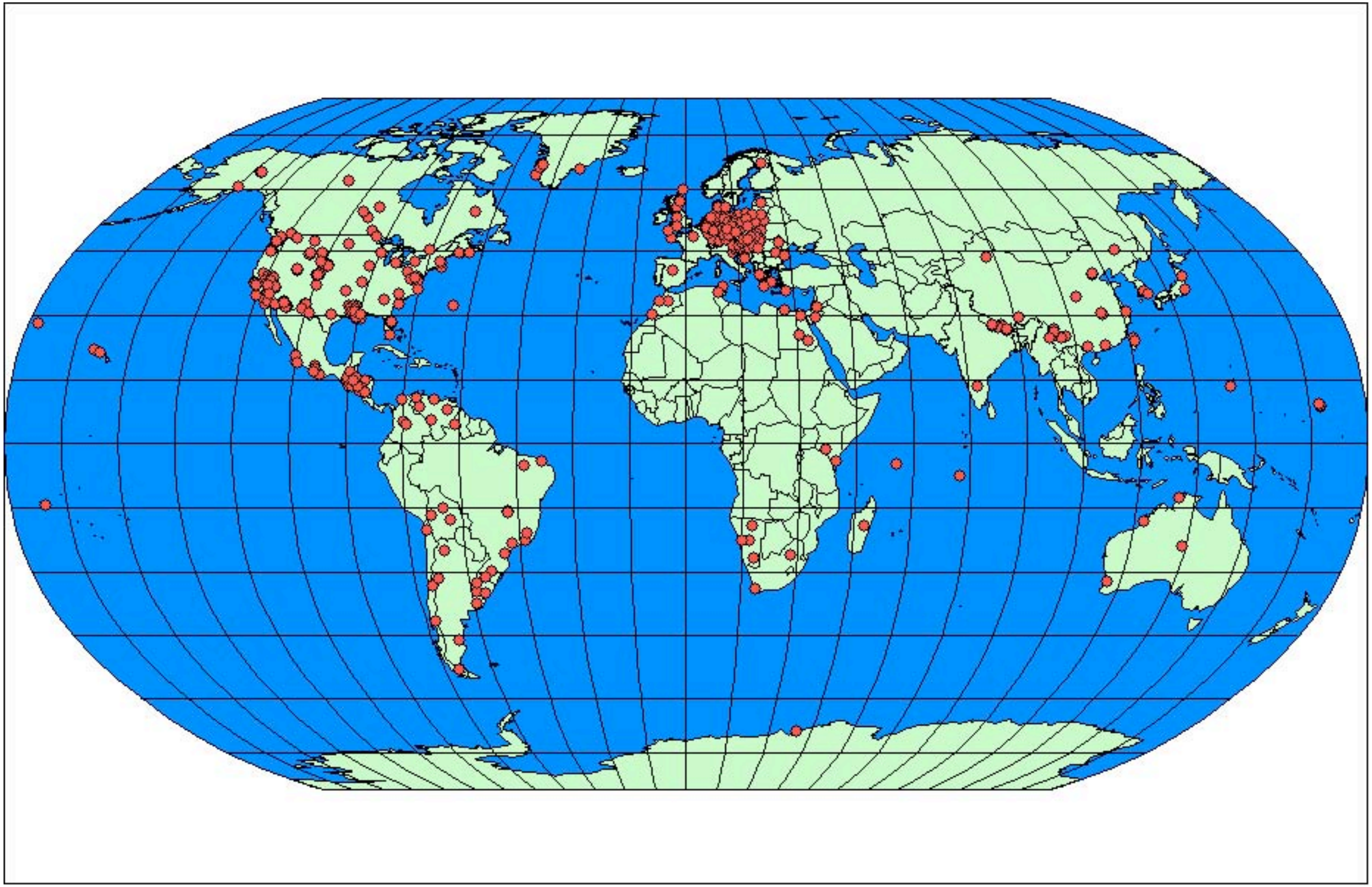
Absolute gravity network (IABGN – International Absolute Base Gravity Network) proposed by Gert Boedecker



Absolute gravimetry- a global network to be coordinated by IGFS; NGA has currently best global coverage

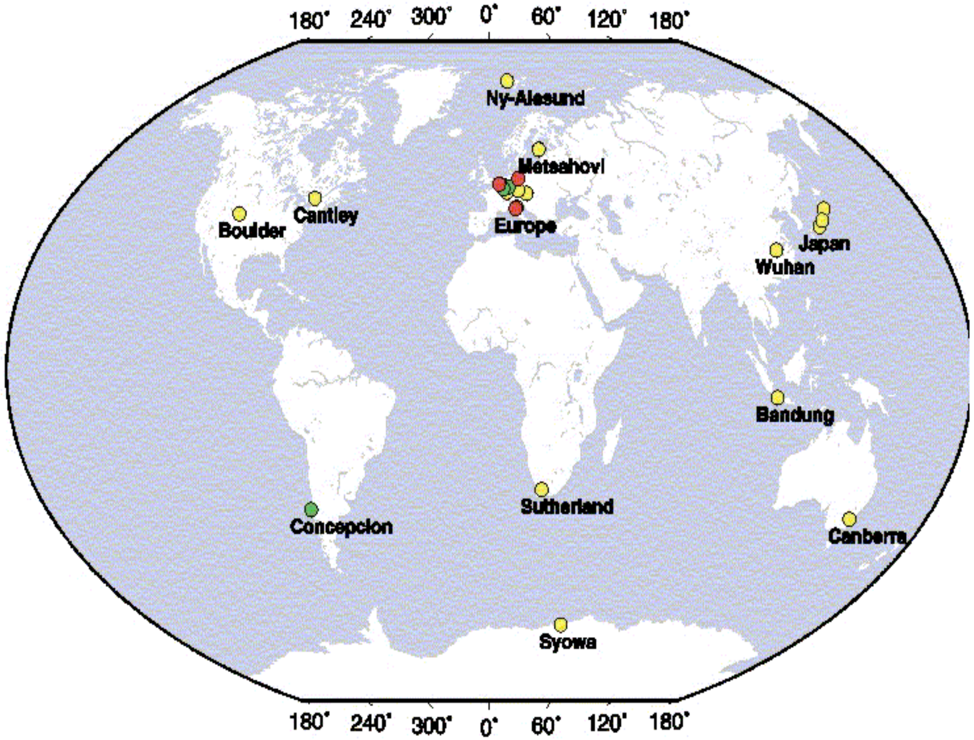
Absolute gravimeter (FG-5), capable of 10^{-9} accuracy within a few hours usually 1 day measurement.
Local environmental effects are the main limitation in accuracy of such measurements

NGA coverage of absolute gravity



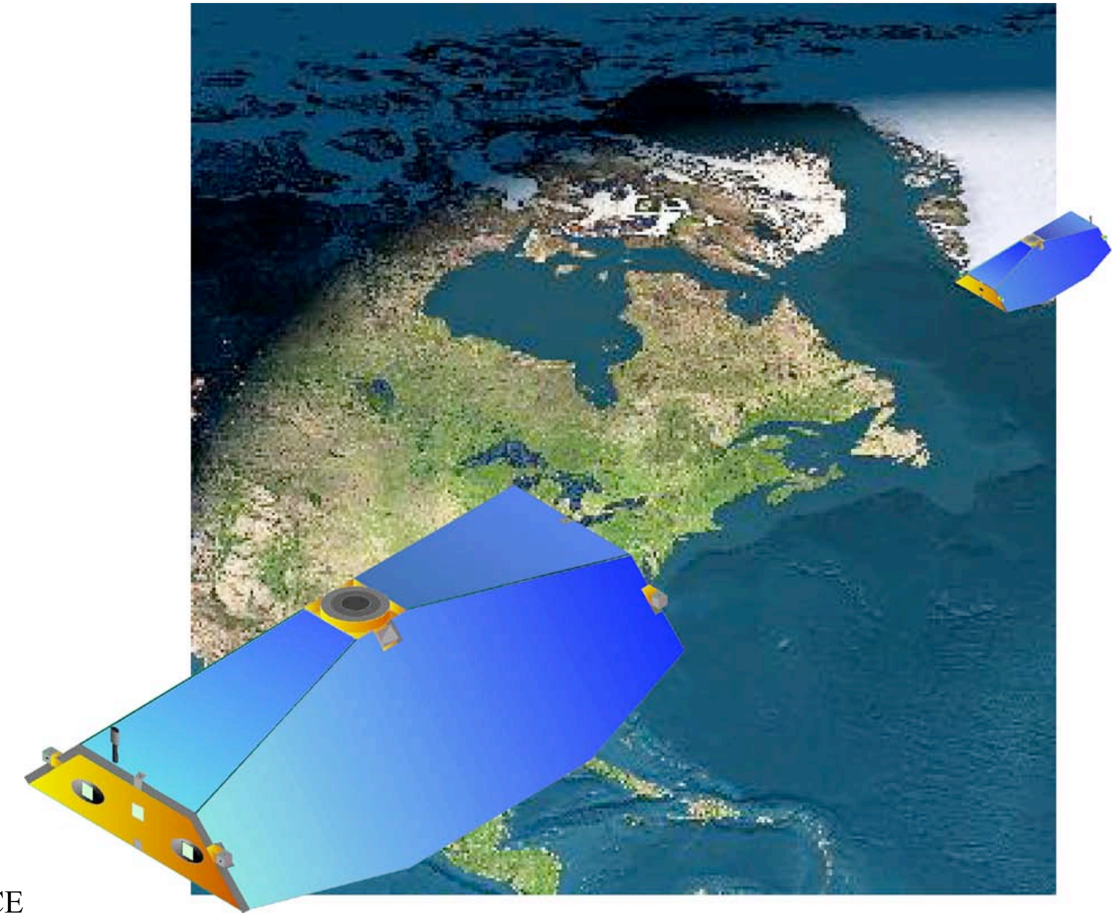
o

Superconducting gravimetry – observatories globally coordinated in "Global Geodynamics Project"



Current network of coordinated superconducting gravimeter observatories (GGP project 1997-2003)

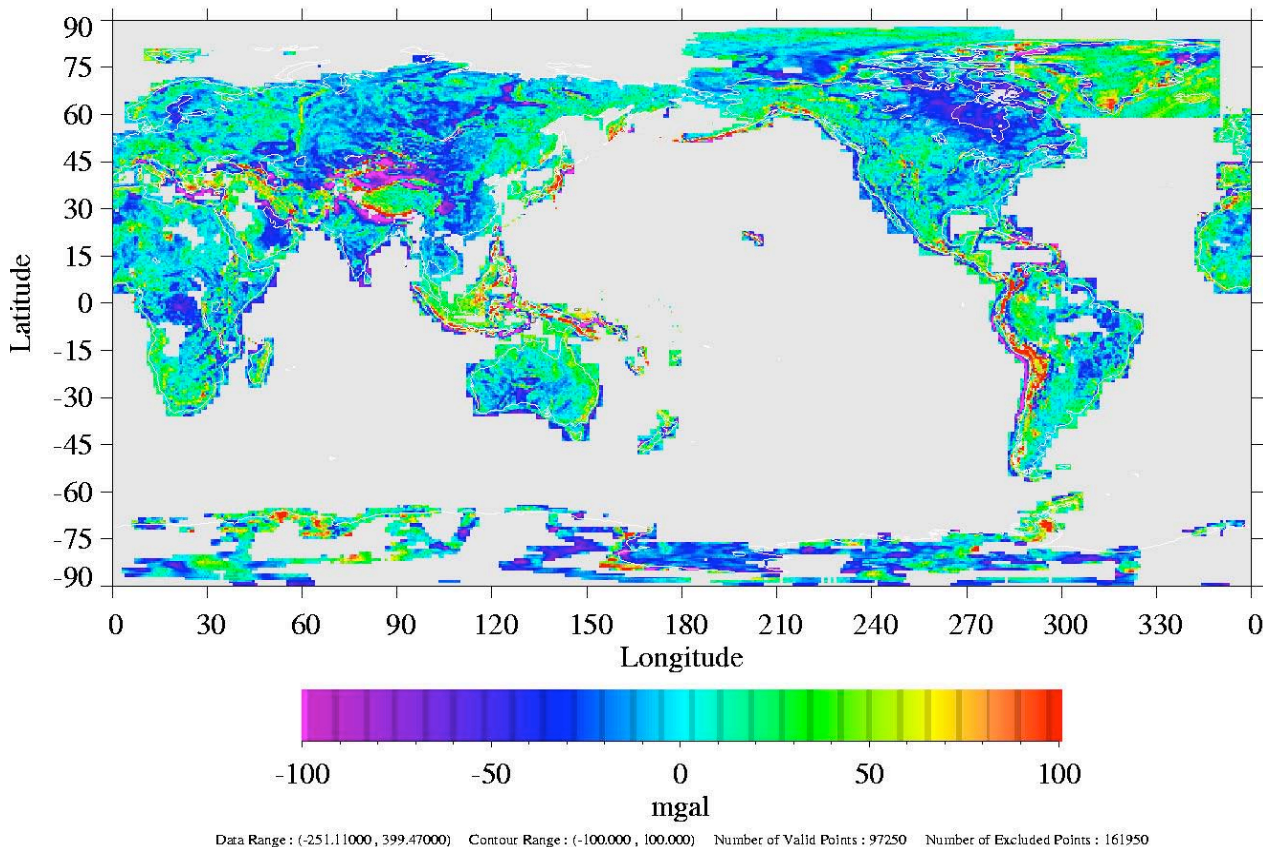
Satellite gravity – no networks per se .. but the core of global gravity field determination



GRACE

Global terrestrial data coverage – for improving intermediate wavelengths of high-resolution geopotential models

DMA (091296) 30’ Terr. Gravity Anomalies



PSMSL, GLOSS and GPS at Tide Gauges

Philip L. Woodworth
Svetlana Jevrejeva

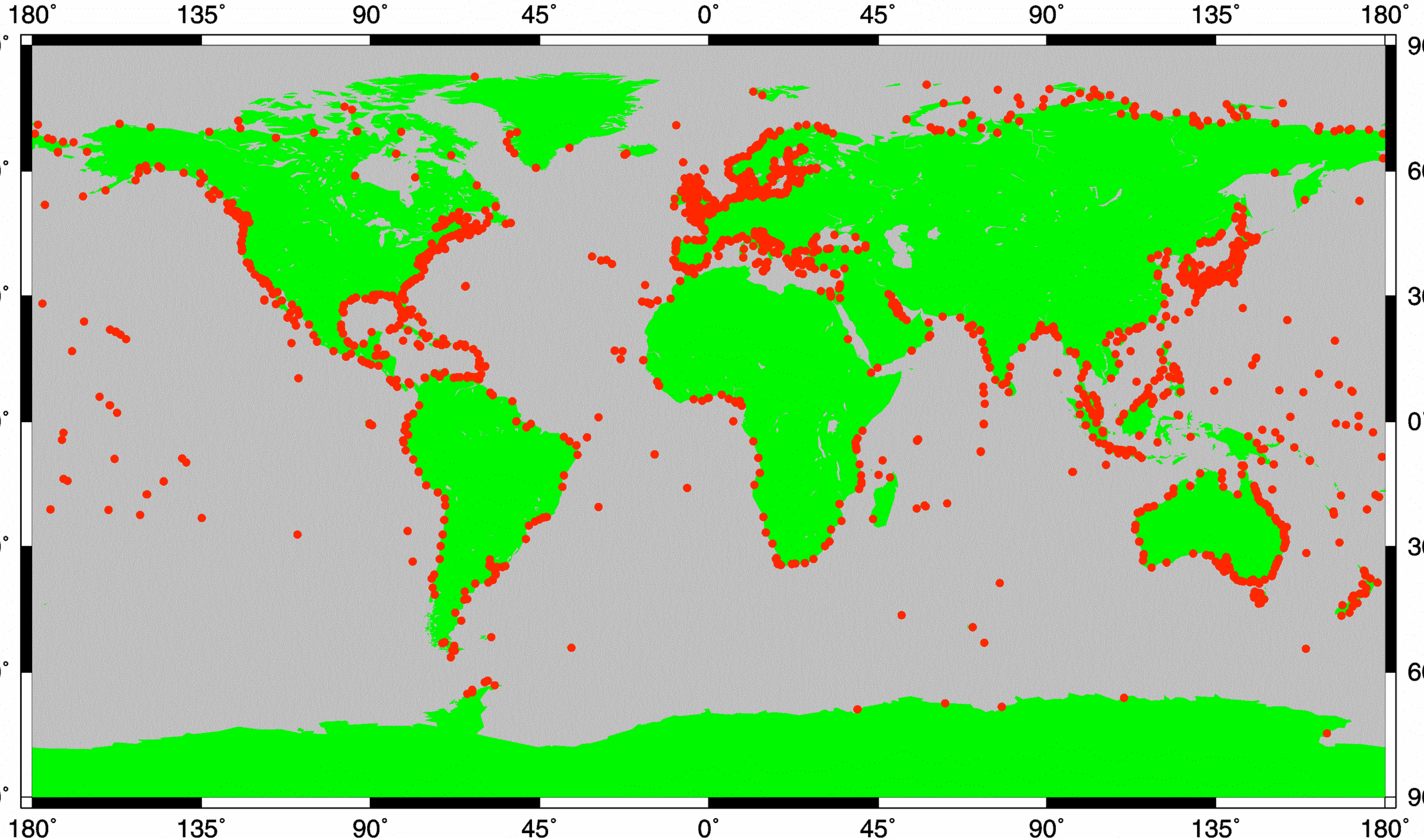
GGOS Meeting at EGU April 2006

www.pol.ac.uk/psmsl

PSMSL

- The PSMSL is the global data bank for long term sea level change information from tide gauges
- Contains 50000 station-years of monthly means from 2000 stations
- Established by IUGG in 1933 as one of the ‘permanent service’ members of FAGS (ICSU). The IAG considers the PSMSL to be an ‘IAG service’
- Responsible for
  - collection,
  - analysis (including research as high level quality control),
  - distribution of monthly and annual MSL data,
  - provision of a wider ‘Service’
- Funded by FAGS, IOC and UK NERC

Distribution of PSMSL Stations

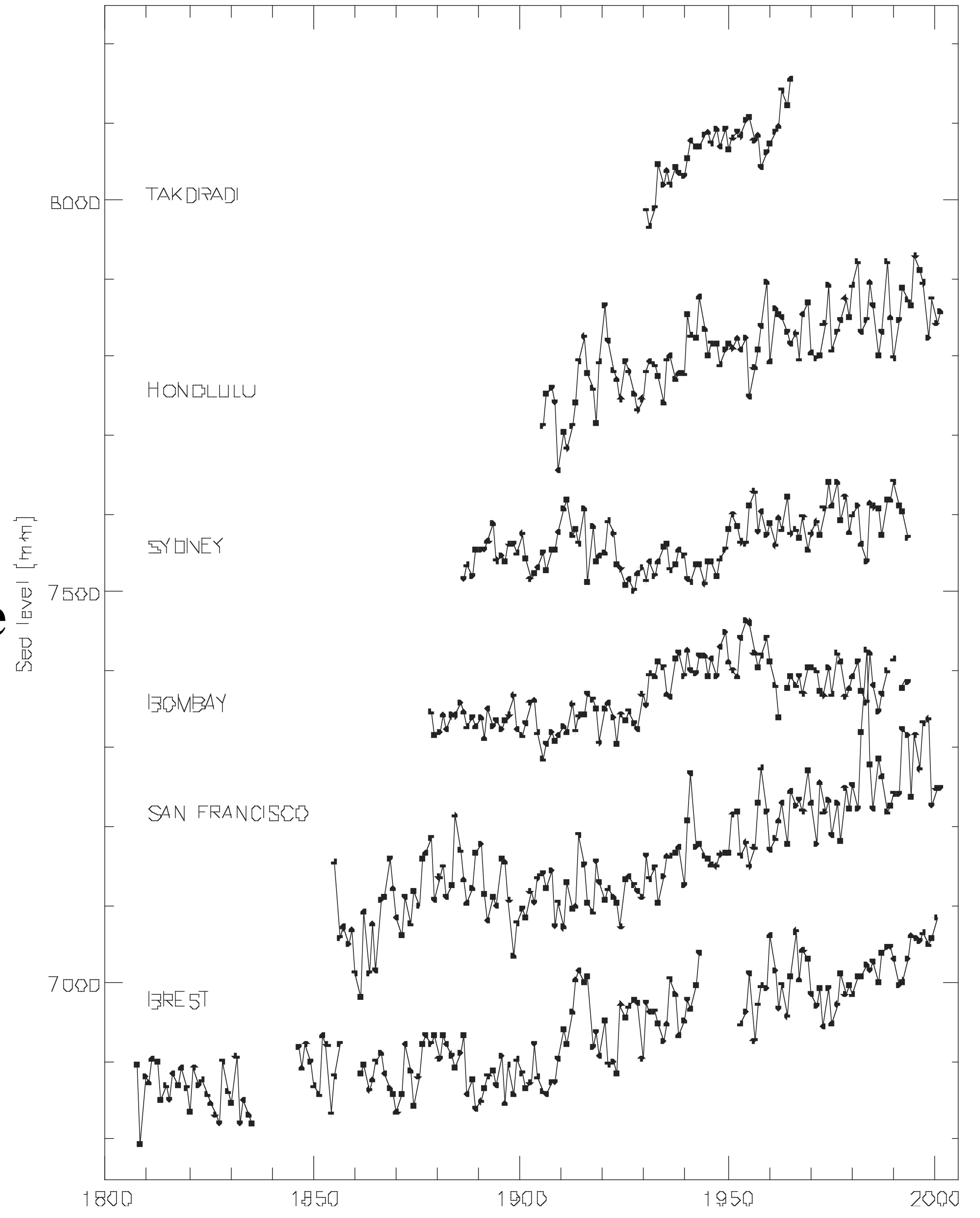


Global Sea Level Change:

Long records from each continent from PSMSL data bank.

Most records show evidence for rising sea levels during the past century

IPCC concluded that there has been a global rise of approximately 10-20 cm during the past 100 years



Publications

• The PSMSL has a responsibility to publish scientific results on sea level changes, as well as collect data.

• Main papers are listed each year in PSMSL Annual Reports

• Notable papers :

➢ Sea level chapter of *IPCC Third Assessment Report* (2001)
➢ Review of use of tide gauges during WOCE for *Oceanography & Marine Biology* (2001)
➢ Review of work of PSMSL for *Journal of Coastal Research* (2003)
➢ Review of science of sea level change for *The Sea* (2004)

Data Receipts

On average, 1500 station-years entered into data bank each year.

• All regions are represented, although most data continues to be from Europe, N America and Japan

• Gaps in S America, Africa and parts of Asia receiving attention as part of GLOSS

➔ All data now distributed via web (occasional CD)

GLOBAL SEA LEVEL OBSERVING SYSTEM (GLOSS)

- GLOSS is a programme of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the IOC and WMO with primary aim to increase quality and quantity of data to PSMSL

- PSMSL has provided main management function to GLOSS

- Over a dozen training courses were held at POL between 1983-1997. Courses since in Brazil (1999), Saudi Arabia (2000), Guatemala (2001), India and Chile (2003), Malaysia (2004) with PSMSL organisation or involvement. Japan and Belgium (2006).

- Emphasis on training materials, manuals, sea level software etc.

- In 2003 proposals for major enhanced GLOSS funding prepared (GLOSS Adequacy Report, EU/Flanders proposals, EOS article).

GLOBAL SEA LEVEL OBSERVING SYSTEM (GLOSS)

- GLOSS is based around a 'core network' of approximately 300 stations. These are similar to (although not all the same as) the stations in the 'GCOS network'.

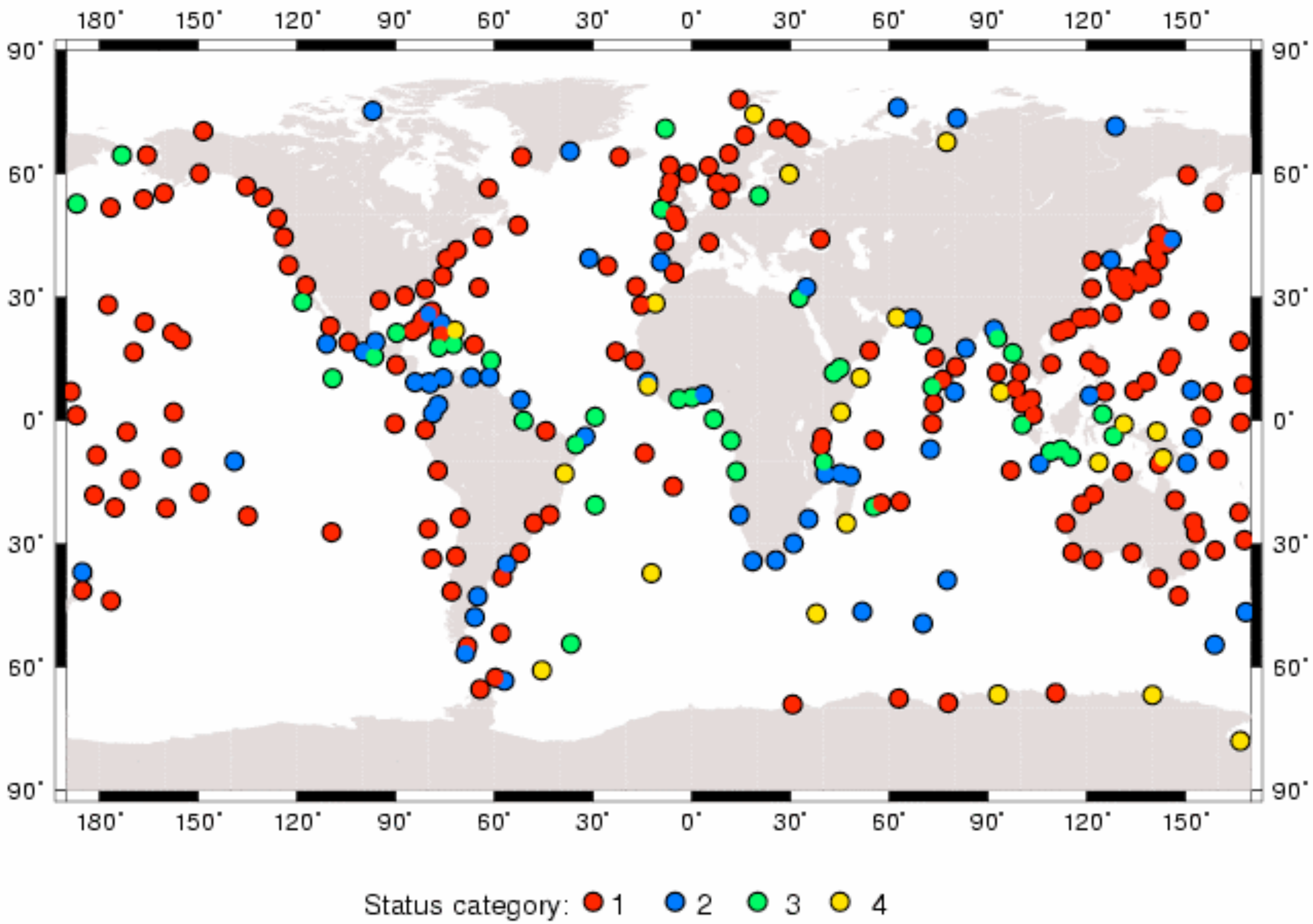
- The core network is about 2/3 operational.

- For more GLOSS details see

http://www.pol.ac.uk/psmsl/programmes/gloss.info.html

which gives positions of stations. A link to the 'GLOSS Handbook' provides metdata details on each station.

GLOSS status within the PSMSL dataset. October 2005



GLOSS STANDARDS

• Main GLOSS standard is that a tide gauge should be able to measure sea level to 1 cm in all weather (wave) conditions

• Main geodetic standard – there should be a local network of at least 5 BMs relevelled annually (one of which would be the GPS BM)

• Standards are defined in the 'IOC GLOSS Manuals'
http://www.pol.ac.uk/psmsl/manuals

Last edition available is no.3. Edition 4 is in press.

Also to some extent in the GLOSS Implementation Plan 1997 (see above GLOSS link).

Geodetic Fixing of Tide Gauge Benchmarks

- Vertical land movements are a major ‘contaminant’ of PSMSL sea level records

- In early 1990s IAPSO (and PSMSL) initiated the first series of meetings on use of GPS and Absolute Gravity (and DORIS) for measuring land movements ➔ the ‘Carter Reports’

- IGS/PSMSL state-of-the-art meeting at JPL in 1997 ➔ establishment of CGPS@TG Working Group (chair Mike Bevis) ➔ Dedicated web site and pooled experiences

- A number of follow-up meetings in 1999, 2001, 2002, 2003 ...

- TIGA (Tide Gauge) activity initiated, and subsequently extended, as an IGS pilot project.

Geodetic Fixing of Tide Gauge Benchmarks

- A data base of tide gauges which have GPS receivers nearby is maintained by Guy Woppelmann on behalf of GLOSS, PSMSL and TIGA:

http://www.sonel.org/stations/cgps/surv_update.html

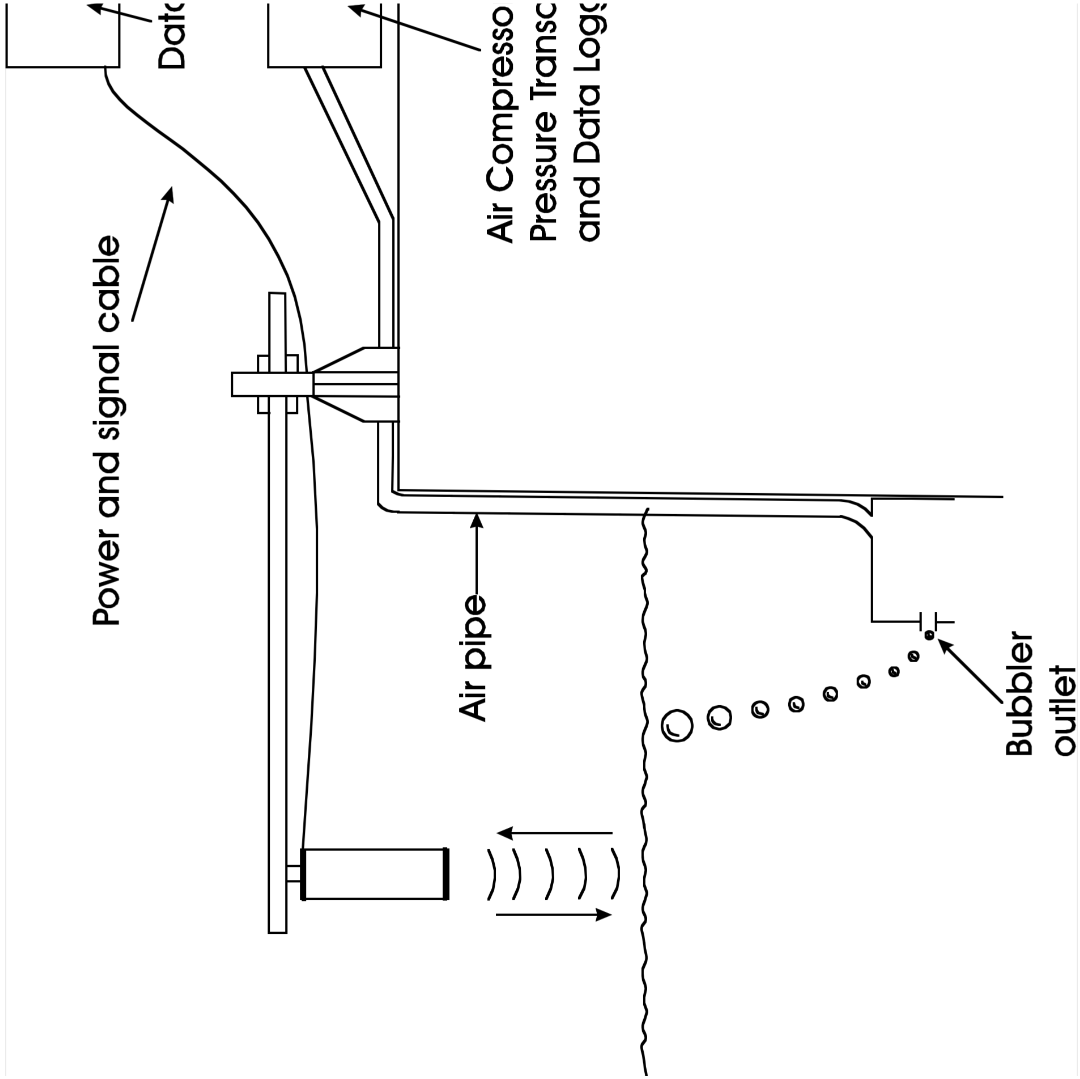
- GLOSS preference is to have a GPS receiver actually at the gauge (i.e. physically connected to it) rather than say on nearby rock plus levellings. An ideal is to have two receivers. (This has been a long standing discussion.)

Tide Gauge Technicalities

- Tide gauges come in many forms: float, pressure, acoustic, radar – see the IOC Manuals for advantages of each type in particular locations
- However there is now becoming a standard, especially in developing countries, for a new station to have a radar gauge plus a pressure sensor:

1. The radar gauge is the primary sea level sensor (5,10,15 minute averages of sea level)
2. Pressure sensor is backup and samples e.g. every minute (e.g. for tsunami warning) or even 1 Hz (for waves)
3. Data sent in real time to a centre (fixed or mobile telephone, Orbcomm, BGAN, VSAT, Meteosat, GTS ….)

Radar gauge test installation at Liverpool



Radar gauge test installation at Liverpool

Approximate Tide Gauge Costs

- Radar plus pressure system as described above (8K$)
- Telemetry (6K)
- Ongoing costs:

1. ISP, phone etc rental
2. Refurbishments (pressure gauge corrosion)
3. Staff costs for regular calibration, levelling etc.
4. Security (a big problem in many places)
5. Plus GPS costs if a receiver required nearby

How to Get the Data - Global Sea Level Data Centres

- PSMSL – long term MSL information (delayed mode)
- BODC (PSMSL) – delayed mode higher-frequency (hourly, 6, 10 or 15 minute) data from GLOSS sites
- UHSLC – GLOSS Fast and Real-Time Centre

There are also several regional (ESEAS, MedGLOSS) and of course many national centres.

Ground Networks and Communications Working Group

Site Metadata Summary

Carey Noll
Manager, CDDIS
NASA GSFC

Background

- CDDIS serves as a global data center for the IGS, ILRS, IVS, and IDS
- Support of all these measurement services provides a unique opportunity to identify network sites and instrument co-locations
- CDDIS archive contains data from all ILRS, IVS, and IDS sites and data from 85% of IGS sites (plus additional GNSS sites not part of IGS network)
- CDDIS also part of Inter-service Data Integration of Geodetic Operations (INDIGO) activity
- As part of its planned tasks, INDIGO will further extend current efforts in this area

Background
(continued)

- As part of its data archiving function, the CDDIS extracts metadata from all incoming data
- Examples of metadata extracted from incoming data
  - Spatial
  - Temporal
  - Instrument type (GNSS, SLR, VLBI, DORIS)
  - Target (SLR and DORIS satellite)
- Other metadata available about archived sites
  - Monument location (geographic, coordinates)
  - IDs (DOMES, station numbers, service-specific codes)
  - Fixed vs. mobile occupation
  - ITRF related (included in ITRF2005, availability of site ties)
- Developed automated queries to CDDIS metadata to bring this information together

Full Site List Example

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION | + NASA Homepage

INDIGO

Inter-service Data Integration for Geodetic Operations

+ ABOUT | + NEWS | + TASKS | + PRESENTATIONS | + LINKS

Full IGS, ILRS, IVS, and IDS Site Occupation History (ordered by site name)

Notes:

+ Table represents *ALL* space geodesy sites. Table was generated from metadata extracted from the data holdings in the CDDIS archive and thus not all IGS GNSS sites are included. However, site occupations from all ILRS/SLR, IVS/VLBI, and IDS/DORIS sites are reflected in the table.
+ Column definitions:
    + Ins.Type: Type of measurment instrument (GNSS, SLR, VLBI, DORIS)
    + Site Code: Site code specific to the service (IGS, ILRS, IVS, IDS)
    + DOMES: DOMES number
    + Type? F/M/E: Type of occupation, F=Fixed, M=Mobile, E=Engineering
    + Start Date: Start date of data in CDDIS archive
    + End Date: End date of data in CDDIS archive (blank indicates current site)
    + ITRF? Y/N: Site included in latest ITRF solution (ITRF2004/5), Y=Yes, N=No
    + Tie?: Site tie information, NT=No Tie information available

Site Information as of 01-Mar-2006 19:33

Site Name	Country	E. Lat.	N. Long.	Ins. Type	Site Code	DOMES	Type? F/M/E	Start Date	End Date	ITRF? Y/N	Tie?
Adelaide	Australia	-34.43	138.39	GNSS	S021	50109S001	F	20000502	20050112	N	Y
Aguascalientes	Mexico	21.86	257.72	GNSS	INEG	40507M001	F	19981221	20020322	Y	Y
Aira	Japan	31.37	130.32	GNSS	AIRA	21742S001	F	19980228	---	N	Y
				VLBI	AIRA	21742S002	F	19970717	---	Y	Y
Ajaccio	France	41.93	8.76	DORIS	AJAB	10077S002	F	20020216	20020309	N	Y
				GNSS	AJAC	10077M005	F	20020321	---	N	Y
				SLR	AJAF	10077M002	M	19961002	20051027	Y	Y
Al Asad	Iraq	38.81	42.43	GNSS	IZAD	20306M001	F	20050627	---	N	Y
Albert Head	Canada	48.39	236.51	GNSS	ALBH	40129M003	F	19920611	---	Y	Y
					ALBX	---	F	19990401	19990727	N	Y
					HLBH	---	F	19920507	19920529	N	Y
					PGC5	40129M007	F	20040201	20040201	N	Y
Alert	Canada	82.49	297.66	GNSS	ALRT	40162M001	F	20021119	---	Y	Y
Algonquin	Canada	45.96	281.93	GNSS	ALGA	---	F	19940223	19940224	N	Y
					ALGO	40104M002	F	19920223	---	Y	Y
				SLR	---	40104M003	M	19930611	19930916	Y	Y
				VLBI	ALGOPARK	40104S001	F	19840824	---	Y	Y
Alice Springs	Australia	-23.67	133.89	GNSS	ALIC	50137M001	F	19980430	---	Y	Y
Almaty	Kazakhstan	43.18	77.02	GNSS	SELE	12352M001	F	19970829	---	Y	Y
American Samoa	USA	-14.33	189.28	GNSS	ASPA	50503S006	F	20010812	---	Y	Y
				SLR	---	50503M001	F	19790816	19801105	N	Y
Amman	Jordan	32.03	35.88	GNSS	AMMN	22201M001	F	20000409	20020428	N	Y
Ankara	Turkey	39.89	32.76	GNSS	ANKA	---	F	19931017	19940601	N	Y
					ANKR	20805M002	F	19951101	---	Y	Y
				SLR	---	20805M001	M	19930307	19930613	Y	Y
Annapolis	USA	38.98	283.52	GNSS	USNA	49908S001	F	19950504	20051130	Y	Y
Antuco	Chile	-37.20	-71.44	GNSS	ANTC	41713S001	F	20020822	20040325	N	Y
AOA/Westlake	USA	34.16	241.17	GNSS	AOA1	40483S001	F	19940830	---	N	Y
Arequipa	Peru	-16.47	288.51	DORIS	AREA	42202S005	F	19900331	20011120	Y	Y

Co-Located Site List Example

Site Name	Country	E. Lat.	N. Long.	Ins. Type	Site Code	DOMES	Start Date	End Date	Type? F/M/E	ITRF? Y/N	Tie?
Aira	Japan	31.37	130.32	GNSS	AIRA	21742S001	19980228	20060227	F	N	Y
				VLBI	AIRA	21742S002	19970717	20061214	F	Y	Y
Ajaccio	France	41.93	8.76	DORIS	AJAB	10077S002	20020216	20020309	F	N	Y
				GNSS	AJAC	10077M005	20020321	20060228	F	N	Y
				SLR	AJAF	10077M002	19961002	20051027	M	Y	Y
Algonquin	Canada	45.96	281.93	GNSS	ALGA	---	19940223	19940224	F	N	Y
					ALGO	40104M002	19920223	20060228	F	Y	Y
				SLR	---	40104M003	19930611	19930916	M	Y	Y
				VLBI	ALGOPARK	40104S001	19840824	20061221	F	Y	Y
American Samoa	USA	-14.33	189.28	GNSS	ASPA	50503S006	20010812	20060228	F	Y	Y
				SLR	---	50503M001	19790816	19801105	F	N	Y
Ankara	Turkey	39.89	32.76	GNSS	ANKA	---	19931017	19940601	F	N	Y
					ANKR	20805M002	19951101	20060228	F	Y	Y
				SLR	---	20805M001	19930307	19930613	M	Y	Y
Arequipa	Peru	-16.47	288.51	DORIS	AREA	42202S005	19900331	20011120	F	Y	Y
					AREB	42202S006	20011212	20030823	F	Y	Y
				GNSS	ARE2	42202M005	20020219	20030922	F	Y	Y
					AREQ	42202M005	19940131	20060215	F	Y	Y
				SLR	AREL	42202M003	19900629	20040127	F	Y	Y
Arlit	Niger	18.73	07.38	DORIS	ARLA	33710S001	19900401	19921208	F	N	Y
					ARMA	33710S002	19921222	19990517	F	Y	Y
				GNSS	---	---	---	---	F	N	Y
Ascension Island	United Kingdom	-7.95	345.59	DORIS	ASDB	30602S004	19970310	20060131	F	Y	Y
				GNSS	ASC1	30602M001	19960421	20060224	F	Y	Y
Austin	USA	30.33	-97.70	SLR	---	40412M001	19810314	19810316	M	N	Y
				VLBI	AUSTINTX	40412M003	19870711	19870711	M	Y	Y
Badary	Russia	51.77	102.23	DORIS	BADA	12338S001	19920102	20020826	F	Y	Y
					BADB	12338S002	20040825	20050119	F	Y	Y
				GNSS	---	---	---	---	F	N	Y
				VLBI	BADARY	12338S003	---	---	F	N	Y
Bar Giyyora	Israel	31.72	35.08	GNSS	BARG	20702M002	19920725	19920808	F	N	Y
				SLR	---	20702M001	19860707	19940913	F	Y	Y
Beijing	China	39.61	115.89	GNSS	BJFS	21601M001	19991021	20060228	F	Y	Y
					GV2A	---	19920727	19920804	F	N	Y
				SLR	BEIA	21601S005	20030715	20031017	M	Y	NT
					BEIL	21601S004	19921210	20060223	F	Y	Y
					BEIT	21601M002	20000831	20001020	M	N	Y
Bermuda	Bermuda Island	32.37	295.30	GNSS	BRMU	42501S004	19930820	20060228	F	Y	NT
				SLR	---	40417M002	19781207	19800924	M	N	Y
				VLBI	BERMUDA	42501M002	19870802	19870808	M	Y	NT
Borowiec	Poland	52.10	17.07	GNSS	BOR1	12205M002	19950216	20060228	F	Y	Y
					BORG	12205M004	19980930	20050709	F	N	Y
				SLR	BORL	12205S001	19880513	20060227	F	Y	Y
Brest	France	48.38	355.50	GNSS	BRSG	10004M003	19981118	19990617	F	N	Y
					BRST	10004M004	19981015	20060201	F	Y	Y
				SLR	BREF	10004M002	20040913	20041026	M	Y	Y
				VLBI	BREST	10004M002	19890830	19890904	M	Y	Y
Brewster	USA	48.13	240.32	GNSS	BREW	40473M001	20011220	20060228	F	Y	NT
				VLBI	BR-VLBA	40473S001	19930421	20061206	F	Y	NT
Cachoeira Paulista	Brazil	-22.69	315.01	DORIS	CACB	41609S001	19920925	20030315	F	Y	Y
					CADB	41609S002	20040412	20060131	F	Y	Y
				GNSS	CHPI	41609M003	20030508	20060228	F	Y	Y

Future Plans

- Add site metadata information for other instruments/networks
  - Gravity
  - Tide gauge
- Create web query interface to information
  - Subseting of information by parameter
  - Change output order by parameter
  - Parameters
    - Site name
    - Country
    - Instrument type
    - Temporal parameters
    - Spacial parameters
- Link in site ties for co-located sites

INDIGO IAG Service Assessment

Data

Data				
Item	**IGS**	**ILRS**	**IVS**	**IDS**
Data Storage at …	Global, Regional, and Local Data Centers	Global, Regional, and Operational Data Centers	Data Centers	Data Centers
Primary (Global) Data Centers	CDDIS (USA), SIO (USA), IGN (France), KASI (S. Korea)	CDDIS (USA), EDC (Germany)	CDDIS (USA), BKG (Germany), OPAR (France)	CDDIS (USA), IGN (France)
Regional Data Centers	BKG (Germany), AUSLIG (Australia), NRCan (Canada), GODC (USA), JPL (USA)	Shanghai (China)	INAF (Italy), GeoDAF (Italy), NICT (Japan)	–
Data Availability	1990 to today	1976 to today	1979 to today	1991 to today
Data File Organization	daily, hourly, and sub-hourly files per station (grouped by year and day-of-year)	daily and monthly files per satellite and station (grouped by year and satellite)	sessionwise (grouped by year and session)	10-day "cycle" files per satellite (grouped by satellite)
Format of Data Files	RINEX (obs, nav, met)	NP format (quick-look), full-rate format	Goddard data base format (binary), NGS card format (ASCII) ftp://cddis.gsfc.nasa.gov/pub/vlbi/ivsdata/db (example data base file)	DORIS format
Auxiliary Data Files	official abbrev. for rcvr, ant, radomes (rcvr_ant.tab); ant. phase center (igs_01.pcv); reference pt info (antenna.gra)	satellite predictions in tuned inter-range vector (TIRV) and consolidated prediction format (CPF) (by email or ftp)	observing schedules, session logs, met data, notes	satellite information
Standard compression software	Z compressed format	Z compressed format	Z compressed format	Z compressed format
Special compression software	Hatanaka	–	–	–
Data Transfer Mechanism	FTP (HTTP at SIO)	FTP	FTP	FTP

Notes: – non-existent; n/a not applicable

INDIGO IAG Service Asessment

Products

Products					
Item	**IGS**	**ILRS**	**IVS**	**IDS**	**IERS**
Analysis Centers (AC)	about 10 ACs	DEOS (The Netherlands), CNSS (Russia), CSR (USA) plus about 20 Associate ACs	about 20 ACs	about 7 ACs	3 product centers (TRF, EOP, rapid service/prediction), convention center
Software	Gipsy/OASIS, Bernese, GAMIT, and others	Geodyn, SATAN, UTOPIA, DOGS, EPOS-OC, CoGeoS, Concerto, and others	Calc/Solve, Modest, Occam, Gloria, SteelBreeze, Geosat	Gipsy/OASIS, Geodyn, Zoom, GINS, Bernese (under test)	Various
Combined Solution	Analysis Center Coordinator and specialized coordinators	ASI (Italy) primary, DGFI (Germany) backup	Analysis Coordinator (Axel Nothnagel, Univ Bonn)	IDS Central Bureau	Combination Centers
Products Overview	components/prods.html	products_formats_procedures/index.html	products-data/products.html	http://lareg.ensg.ign.fr/ IDS/	http://www.iers.org/MainDisp.csl ?pid=8-10
Product Types:					
Satellite Orbit Prediction	sub-daily predictions included in IGS ultra-rapid solution (igu)	daily predictions in TIRV (Tuned Inter-Range Vector) and CPF (Consolidated Prediction Format), Rapid LEO Predictions Team	n/a	-	n/a
Satellite Orbit Determination	satellite ephemerides for GPS (3 types) and GLONASS	{satellite ephemerides}	n/a	{satellite ephemerides}	n/a
Satellite Clocks	GPS clock information	n/a	n/a	n/a	n/a
EOP	polar motion, polar motion rates, length-of-day	polar motion, length-of-day	session-wise EOP solution (EOP-S) 1-hour Intensive UT1 solution (EOP-I)	polar motion, length-of-day	long term, rapid service, and predictions for EOP
TRF	IGS tracking station coordinates and velocities	weekly time series of ILRS station positions	station positions, velocities, correlations roughly every 3 months	weekly and monthly time series of DORIS station positions, cumulative solutions (positions/velocities), time series of coordinates of the TRF origin, station coordinate difference plots	ITRF2000 (current product)
CRF	n/a	n/a	CRF solution at irregular time schedule	n/a	ICRF
TROP	zenith tropospheric path delay estimates	–	troposphere parameters per session and station	–	–
IONO	global ionospheric maps	–	–	derived vertical total electron content (VTEC)	–
Contribution to IERS	station positions, polar motion, polar motion rates, length-of-day (weekly combined solutions)	station positions, polar motion, length-of-day (weekly combined solutions)	EOP & position (DSNX) (combined solutions by session)	station positions, polar motion, length-of-day (weekly combined solutions)	n/a

Notes: – non-existent; n/a not applicable; { } planned