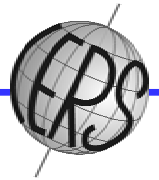

IERS Working Group on Combination
&
IERS Combination Pilot Project

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EGU 1st General Assembly 2004
April 26-30, 2004
Nice

Agenda

1. **Introduction and Status of the IERS CPP**
2. **Overview of Proposals**
3. **Status and Future of the IERS CPP**
   - IERS database for the CPP
   - Short contributions by the IERS CPP participants
   - Problems encountered etc., first results
4. **Tasks of the IERS WG on Combination**
5. **IERS CPP Workshop in Autumn 2004**
6. **Initiative „IERS2005“**
7. **Varia**

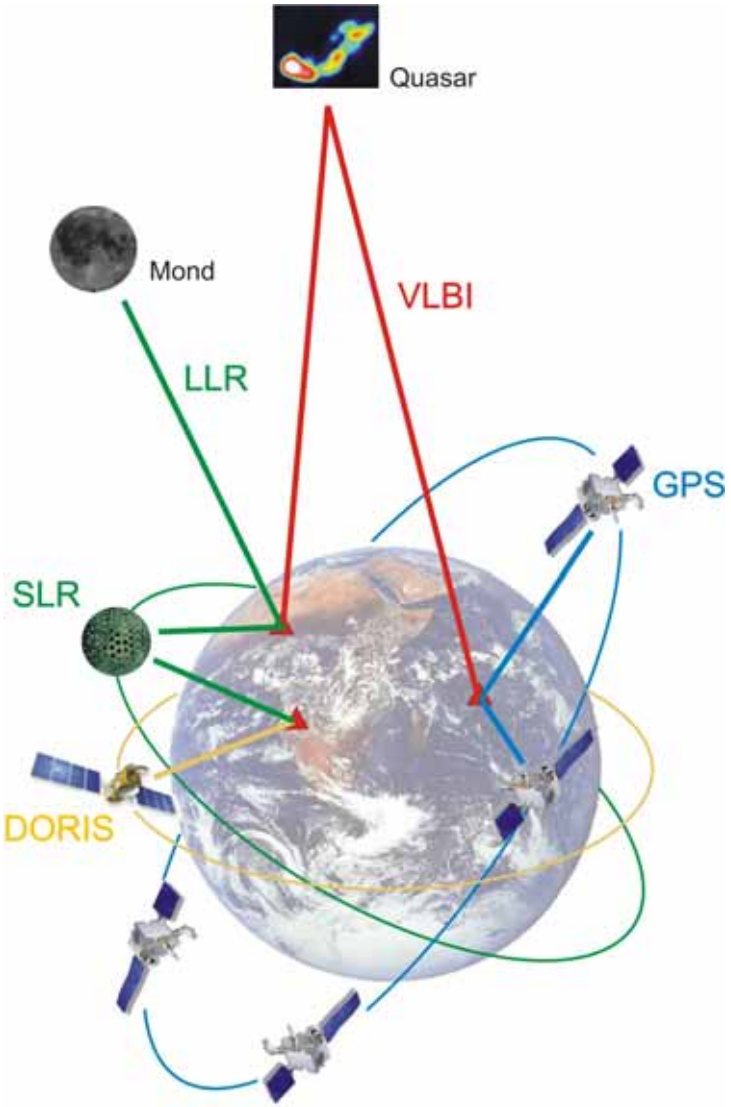
IERS Combination Pilot Project

Parameter space for a rigorous combination:

Parameter Type	VLBI	GPS/ GLON.	DORIS/ PRARE	SLR	LLR	Alti- metry
Quasar Coord. (ICRF)	X					
Nutation	X	(X)		(X)	X	
Polar Motion	X	X	X	X	X	
UT1	X					
Length of Day (LOD)		X	X	X	X	
Coord.+Veloc.(ITRF)	X	X	X	X	X	(X)
Geocenter		X	X	X		X
Gravity Field		X	X	X	(X)	X
Orbits		X	X	X	X	X
LEO Orbits		X	X	X		X
Ionosphere	X	X	X			X
Troposphere	X	X	X			X
Time/Freq.; Clocks	(X)	X		(X)		

IERS Combination Pilot Project: sub-space (red rectangle)

Vision of a Rigorous Combination

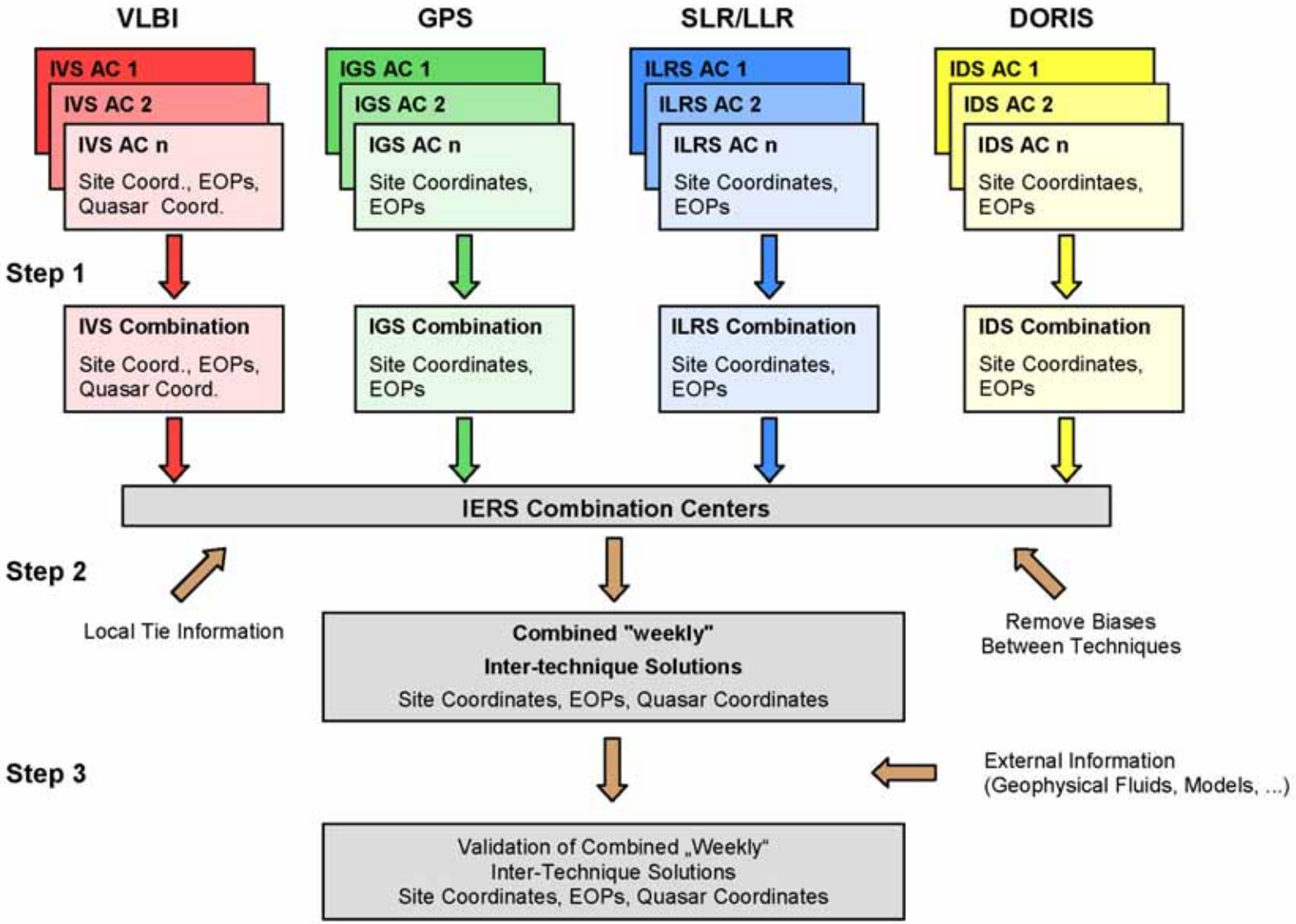


- Make use of the **strengths** of the individual observation techniques
- Profit from **co-location** of instruments (sites and satellites)
- Ensure **consistency** of all IERS products

$$X_{inertial}(t) = R(t) \cdot X_{earth\text{-}fixed}(t)$$

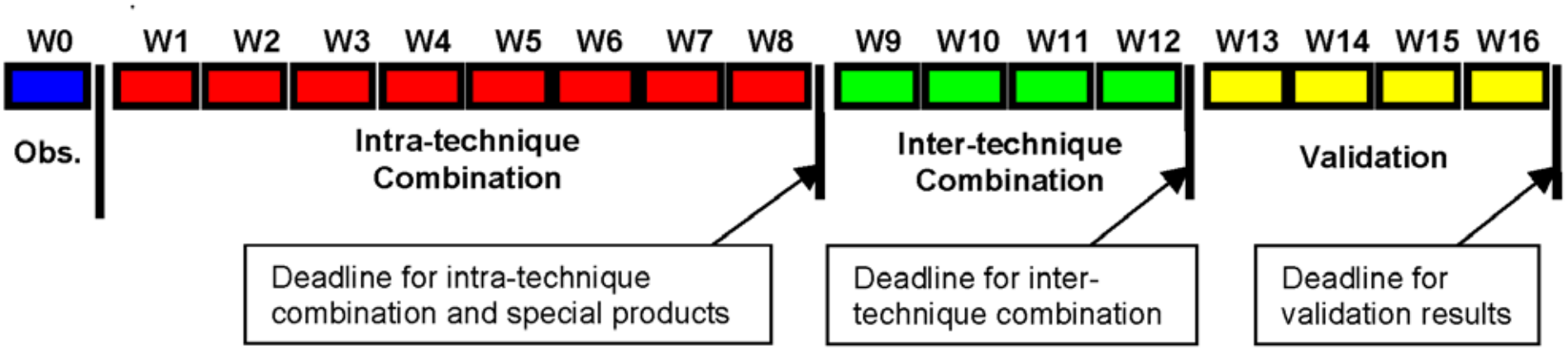
- Differ between technique-specific systematic **biases** and genuine geodetic/geophysical **signals**
- **Final goal**: All common parameters of all observing techniques are rigorously combined to consistent IERS products

IERS Combination Pilot Project



IERS CPP: Submission Schedule

- **Intra-technique combinations** (weekly SINEX files) due 8 weeks after the observations
- **Inter-technique combinations** (weekly SINEX files) due 12 weeks after the observations
- **Validation of inter-technique combinations** (report) due 16 weeks after the observations
- **Special combined products** due 8 weeks after the observations



IERS CPP Proposals (1)

PARTICIPANTS: STEP 1

Institute/ Organization	Technique	Resulting parameters	Additional information
IDS	DORIS	Coordinates: weekly ERP (pole): daily	a) IDS Analysis Centers b) minimum constraints
IGS	GPS	Coordinates: weekly ERP (pole + rate, LOD): daily	a) IGS Analysis Centers b) inner constraints
ILRS	SLR	Coordinates: weekly ERP (pole, LOD): daily	a) ILRS Analysis Centers b) no constraints
IVS	VLBI	Coordinates: daily ERP (pole, UT1-UTC, nutation): daily	unconstrained normal equations
AUSLIG	VLBI	Coordinates: daily ERP + rates, nutation: daily	a) Kalman filter technique b) NNR/NNT for TRF c) ICRF fixed
CNES	DORIS	Coordinates: weekly ERP (pole): daily	unconstrained solutions
IGN/JPL	DORIS	Coordinates: weekly EOP: daily	free-network solutions
JCET	SLR	Coordinates: weekly ERP (pole, LOD): daily	loose constraints
NCL	GPS	Coordinates: weekly ERP (pole, LOD): daily	a) minimum constraints b) as IGS GNAAC
NCL	SLR	Coordinates: weekly ERP (pole, LOD): daily	a) minimum constraints b) as for ILRS pilot project

IERS CPP Proposals (2)

PARTICIPANTS: STEP 2

Institute	Techniques	Short description of combination process
ASI	all	a) weighting based on chi square b) additional site eccentricities c) geocenter as additional parameter d) loosely constrained solution
DGFI	all	a) variance component estimation b) additional helmert parameters
IGN	all	a) variance component estimation b) additional helmert parameters
JCET	SLR + LEO GPS	a) variance component estimation b) loose constrained solution
NCL	GPS + SLR	a) variance component estimation
Wuhan University	all	a) variance component estimation b) set up of systematic parameters between techniques

IERS CPP Proposals (3)

PARTICIPANTS: STEP 3

Institute	Parameters	Short description of validation process
IGN	Coordinates EOPs Quasar coordinates	a) reliability + quality of local ties b) comparison with external solutions c) weaknesses, model deficiencies, inconsistencies
JCET	Coordinates ERPs	a) usage in precise orbit determination b) coordinate comparisons and external solutions c) spectral analysis of ERPs
JPL	ERPs	a) comparison with OAM, AAM
NCL	Coordinates ERPs	a) coordinate + ERP residuals after Helmert transformation b) repeatabilities (Helmert parameters, coordinates)
USNO	EOPs	a) comparisons (Bulletin a/B, C04, geophysical fluids, single techniques) b) correlation, coherence, power spectrum
Wuhan University	Coordinates EOPs Quasar coordinates	a) weighted transformation parameter estimation b) parameters after transformation and transformation parameters

IERS CPP Proposals (4)

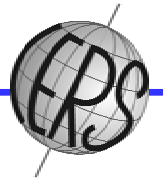
PARTICIPANTS: SPECIAL PRODUCTS

Institutes	Techniques	Short description of special product
AICAS	all	transformed to the celestial system
GRGS	all	combination on observation level including TRF, EOPs (UT1, polar motion, nutation corrections)
JCET	GPS + SLR + DORIS	include orbits in the combination (together with coordinates, EOPs)
USNO	all	sub-daily ERPs
USNO	VLBI + GPS	daily nutation
USNO	all	combined EOPs (polar motion, UT1, nutation), aligned to C04

IERS CPP: Timetable

January 26, 2004:	Dissemination of the Call for Participation
February 22, 2004:	Due date for proposals
February 27, 2004:	Information of participants about proposal acceptance
February 29, 2004:	Start of IERS Combination Pilot Project with GPS Week 1260 (first intra-technique combinations due 8 weeks later, i.e. end of April 2004; first inter-technique solutions due 12 weeks later, i.e., end of May).
April 29, 2004:	Meeting of IERS WG on Combination (during the EGU Meeting in Nice)
October 2004:	Progress Meeting of the IERS CPP at the IERS Workshop 2004
October 2005:	Evaluation of the CPP and discussions concerning the transitions to new IERS products

IERS WG on Combination: Tasks (1)



1) ***Coordination of the Combination Pilot Project (CPP)***

   Realization of a new set of highly consistent IERS products around 2005.

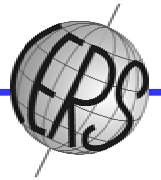
2) ***Standards for a Rigorous Combination***

   Define standards concerning the models, the parameterization for various parameter types, the *a priori* representation of the parameters, and the processing strategies in order to ensure consistency of the individual contributions.

3) ***Document on "Rigorous Combination of the IERS Products"***

   Document describing in detail the procedures, problems, and steps for a rigorous combination of the IERS core products. This document will contain the general guidelines for the different groups and centers that are involved in the combination tasks.

IERS WG on Combination: Tasks (2)



4) Systematic Biases, Local Ties and Co-Location

Investigation of systematic biases between the space geodetic techniques and develop procedures to handle these biases.

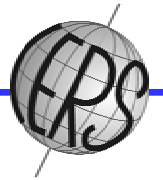
Develop combination strategies concerning all the relevant parameters (e.g., quasar coordinates; UT1 (VLBI) and LOD (satellite techniques); nutation offsets and rates; ...)

Strategies for weighting, datum definition, use of local ties, etc.

Check the quality of the local ties available using the results of the individual or combined space geodetic technique solutions and discuss the possible deficiencies with the IERS WG on Site Surveys and Co-Locations.

Document the histories of station coordinate time series and develop approaches and guidelines to handle non-linear station behavior.

IERS WG on Combination: Tasks (3)



5) Validation of Combined Products

Validation of the rigorously combined IERS products. Possible approaches are repeatability studies, use of independent information from the Global Geophysical Fluids Center (GGFC), accurate geophysical or geodynamical models, etc.

6) Long-Term Series of SINEX Files

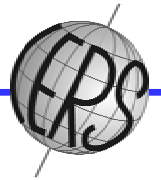
Organize activities to obtain complete series of ”weekly” SINEX files from all space geodetic techniques for multi-year solutions and consistent long-term ITRF, EOP, and ICRF realizations based on these ”weekly” SINEX series.

7) Definition of future IERS products

Recommend the set of consistent IERS products to be routinely generated by the IERS Combination Centers in the future.

Procedures to allow a transition from the present IERS Product Centers to a future organization.

IERS WG on Combination: Tasks (4)



8) Additional Combination Aspects

Stimulate research and studies in the field of the combination of space geodetic techniques. This includes combination aspects such as the combination of atmospheric information, subdaily EOP series, nutation series from GPS and VLBI, station clocks used for both, VLBI and GPS instruments, etc.

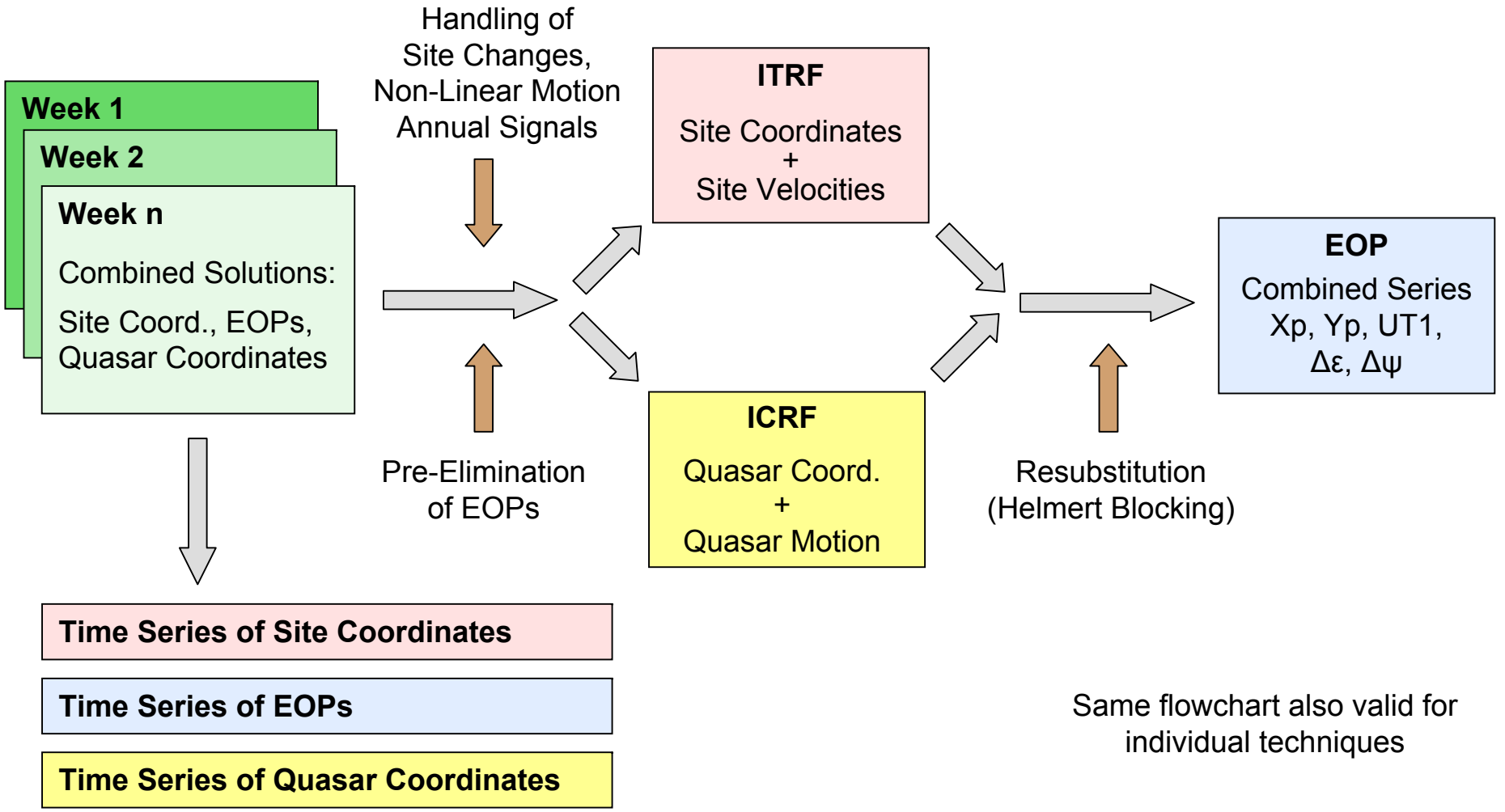
Study interactions between gravity field coefficients and the ITRF and EOPs in close cooperation with the IERS WG on Datum Definition of Global Terrestrial Reference Frames (IERS WG 1).

Organize intensive observation campaigns (similar to CONT`02 for VLBI), where all major space geodetic techniques participate, in order to collect special data sets necessary to study details of the combination process.

IERS2005: Plan

- "**I**ntegrated **E**arth orientation parameters, **R**adio sources, and **S**ite coordinates **2005**"
- **IERS2005 = ITRF2005 + EOP2005 + ICRF2005 = first rigorously combined solution**
- IERS2005 will be based on **"weekly" SINEX files** from all techniques (site coordinates, EOP, and quasar coordinates) over the **entire history** of their data acquisition
- This step will **complement the IERS CPP** for years already past
- The Technique Services (TS) should deliver time series as **homogeneous** as possible over a time span as long as possible (following IERS conventions)
- **Individual AC solutions** might be accepted if the corresponding TS agrees

Future Combination: Multi-Year Solutions
(Fully Consistent Set of ITRF/EOPs/ICRF)



Same flowchart also valid for individual techniques

IERS2005: Timetable

Draft Schedule:

June, 2004: **Call** for submission of homogeneous **weekly SINEX files**

August, 2004: Due date for **submissions** of weekly SINEX files

March, 2005: Submission of **IERS2005 solutions** by the Combination Centers (e.g, the ITRF CCs)

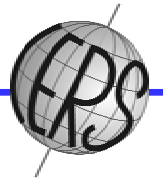
August, 2005: IERS2005 solutions **evaluated** and **compared;** Presentation at the **IAG Scientific Assembly 2005** (Cairns, Australia)

October 2005: After final refinements and documentation, official IERS2005 ready for **IERS DB decision** at IERS Workshop 2005 (Evaluation of IERS CPP)

Document "Rigorous Combination of the IERS Products" (1)

- There are **a lot of idea around**, how to rigorously combine IERS products
- But there exists **no document on the combination strategy and procedures**
- There are **many non-trivial issues** that have to be dealt with in a rigorous combination
- **Proposal:** the Analysis Coordinator together with a small group of interested experts compiles such a conceptual document
- The document should then be **discussed by all parties concerned** (TCs, PCs, CRCs, ...)
- This document should **serve as a reference** for the combination work
- Might become a part of the **IERS Conventions**

Document "Rigorous Combination of the IERS Products" (2)



1. **Introduction**
2. **Generation of SINEX Solutions**

(a) SINEX for Space Geodetic Techniques

- SINEX Format
- Time intervals for solutions
- Parameters to be included, parameterization and a priori values
- Modeling standards
- Constraining issues
- Treatment of non-linear station motion (jumps, Earthquakes, equipment change,…)
- Technique-specific issues

(b) SINEX for Local Ties

- Horizontal and vertical network solutions with correct variance-covariance information
- Combination of the two systems
- Conversion of variance-covariance matrix to geocentric coordinates
- Only information on the relative position in the SINEX file

Document "Rigorous Combination of the IERS Products" (3)

3. Combination of inter-technique SINEX Solutions

(a) Weekly ITRF/EOP/ICRF Combinations

- Combination strategy
- Time series of site coordinates and EOP
- Combination of UT1/LOD and nutation offsets and rates

(b) Multi-year SINEX Solutions for ITRF/EOP/ICRF

- Generation of multi-year combined solutions from weekly solutions
- Treatment of non-linear site motion etc.

4. Validation of Solutions

(a) Validation of Weekly SINEX Solutions

(b) Validation of Multi-year SINEX Solutions

Systematic Effects

General Modeling Consistency (IERS Conventions 2003):

- Solid Earth and pole tides
- Subdaily ERP ocean tide model; IAU2000 precession/nutation
- Ocean loading, atmospheric loading
- Subdaily geocenter variations
- Troposphere mapping functions

Antennas and Environment (easily reaching 1cm or more):

- Antenna phase center variations (PCV) of receiver antennas
- Antenna phase center variations of satellite antennas
- Multipath effects, environment (e.g. snow), equipment changes

Orbit modeling and parameterization:

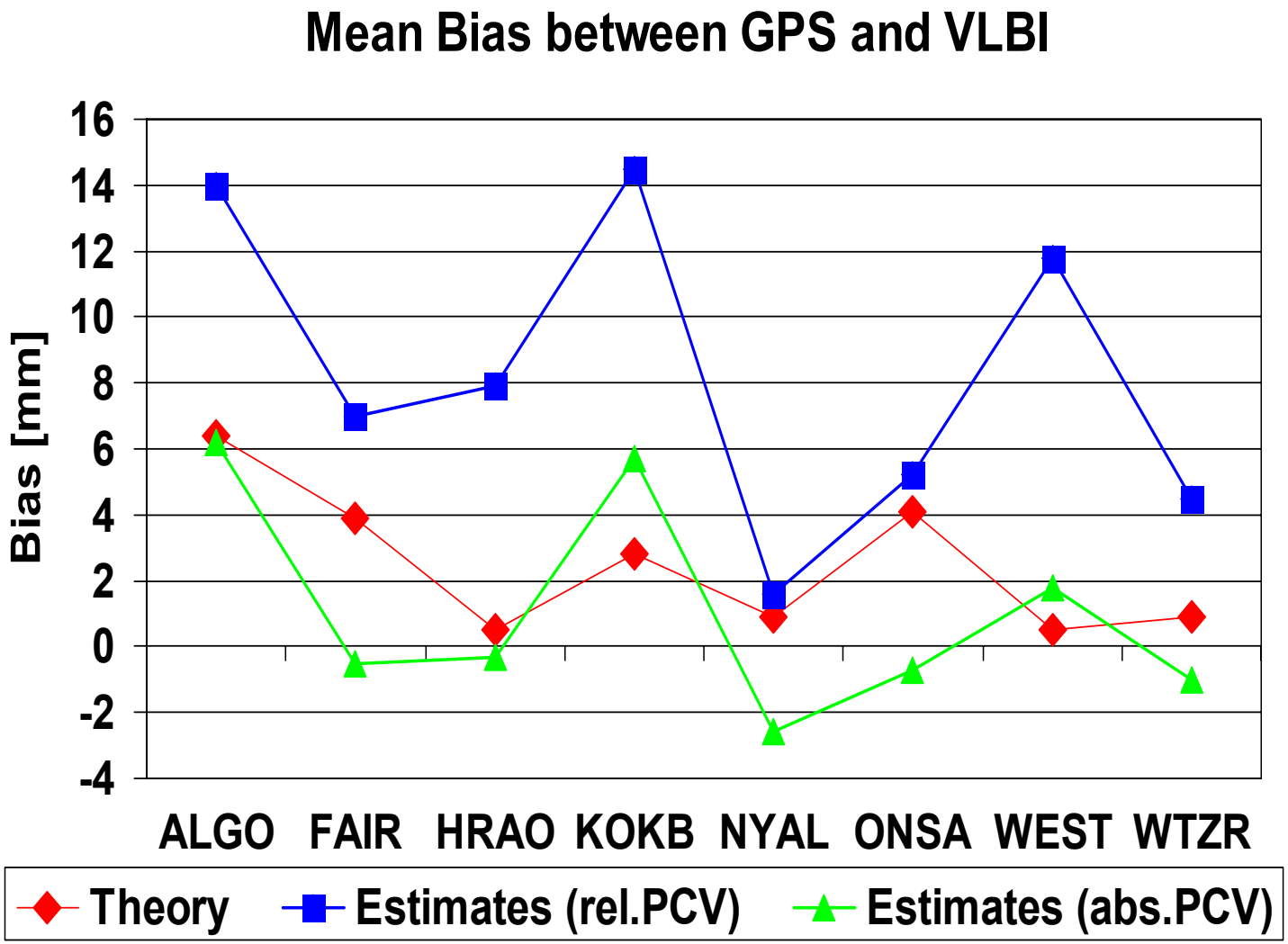
- Systematic effects in geocenter variations; SLR-GPS orbit bias of 5cm
- Systematic effects in LOD and nutation rates

Comparison of GPS & VLBI Troposphere

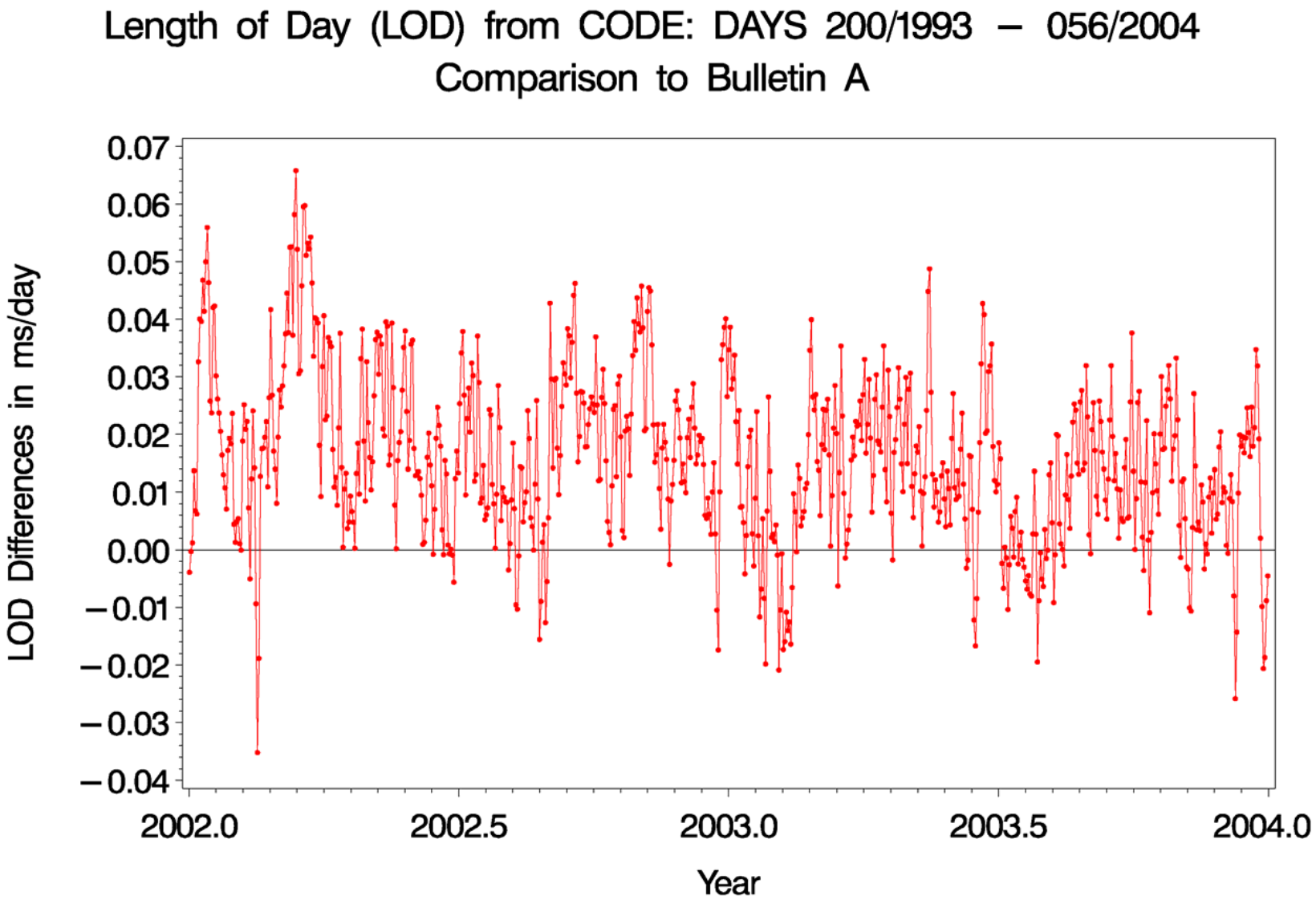
Station	ΔHeight (local tie) [m]
ALGO	23.11
FAIR	13.08
HRAO	1.54
KOKB	9.24
NYAL	3.07
ONSA	13.71
WEST	1.75
WTZR	3.10

Theory: ΔHeight = 10m

→ ΔZD ≈ 3mm



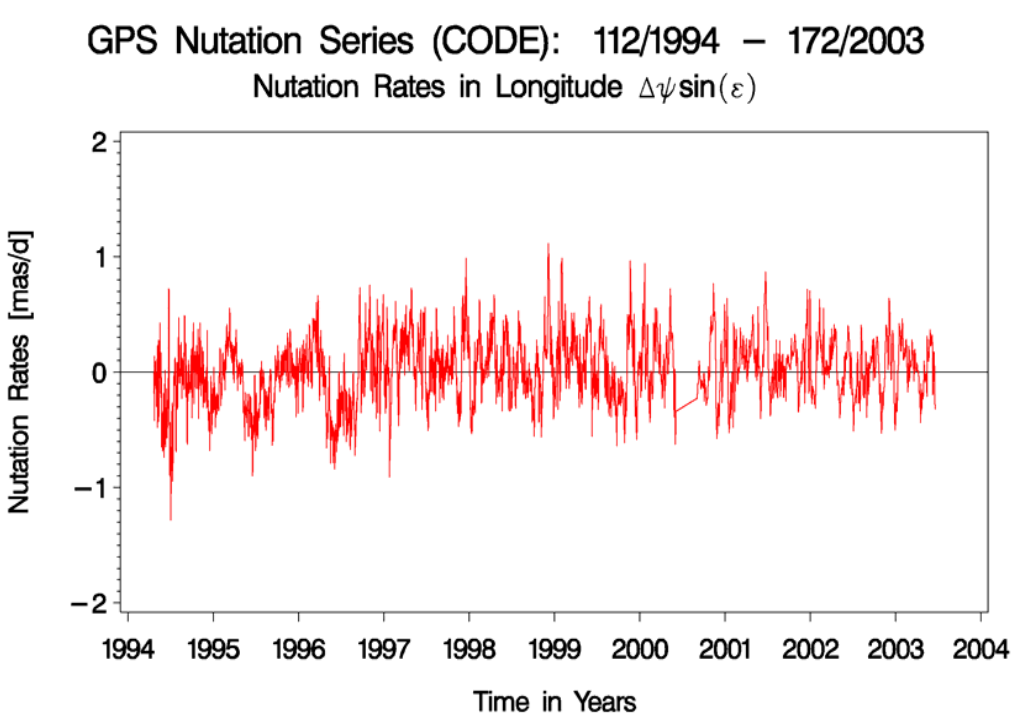
Systematic Effects: LOD

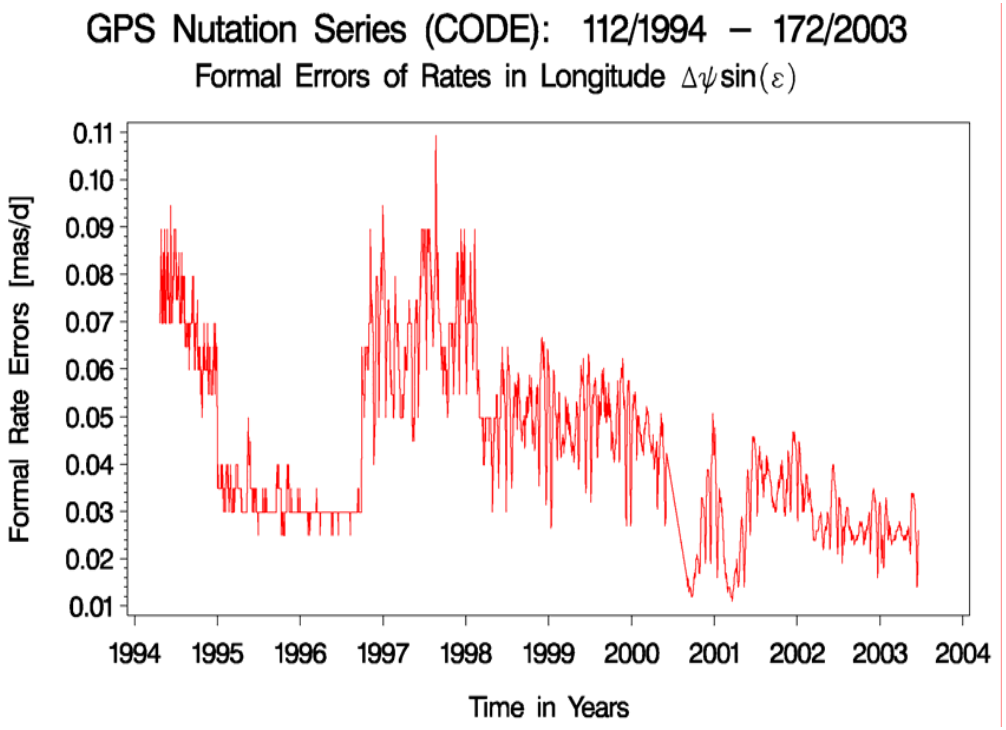


Systematic Effects: Nutation

GPS nutation rates in longitude:

- systematic effects due to orbit modeling and parameterization
- visible in the values and the formal errors



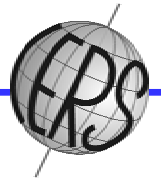


Reduction of Systematic Effects

Statement 1: All systematic effects in the technique-specific results have to be eliminated or reduced to the extent possible for an IERS inter-technique combination to be successful.

- **Not only internal consistency is important, but also absolute accuracy**
- **We should try to come as close as possible to the point, where ITRF coordinates are as consistent as the realization of the ITRF by the individual techniques (e.g., IGS00, ...)**
- **Each technique has its own systematic biases to care about**

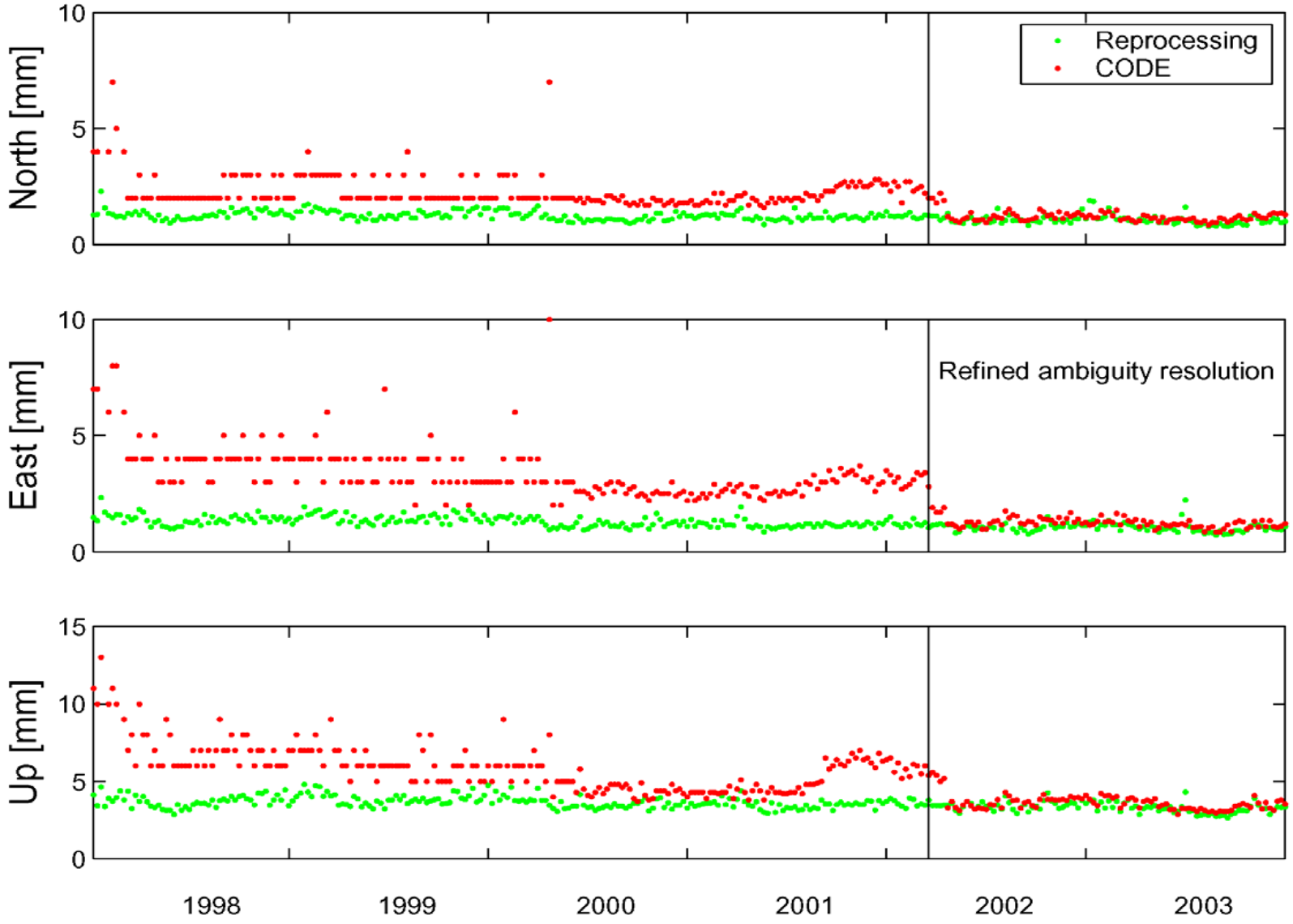
Reprocessing Capability



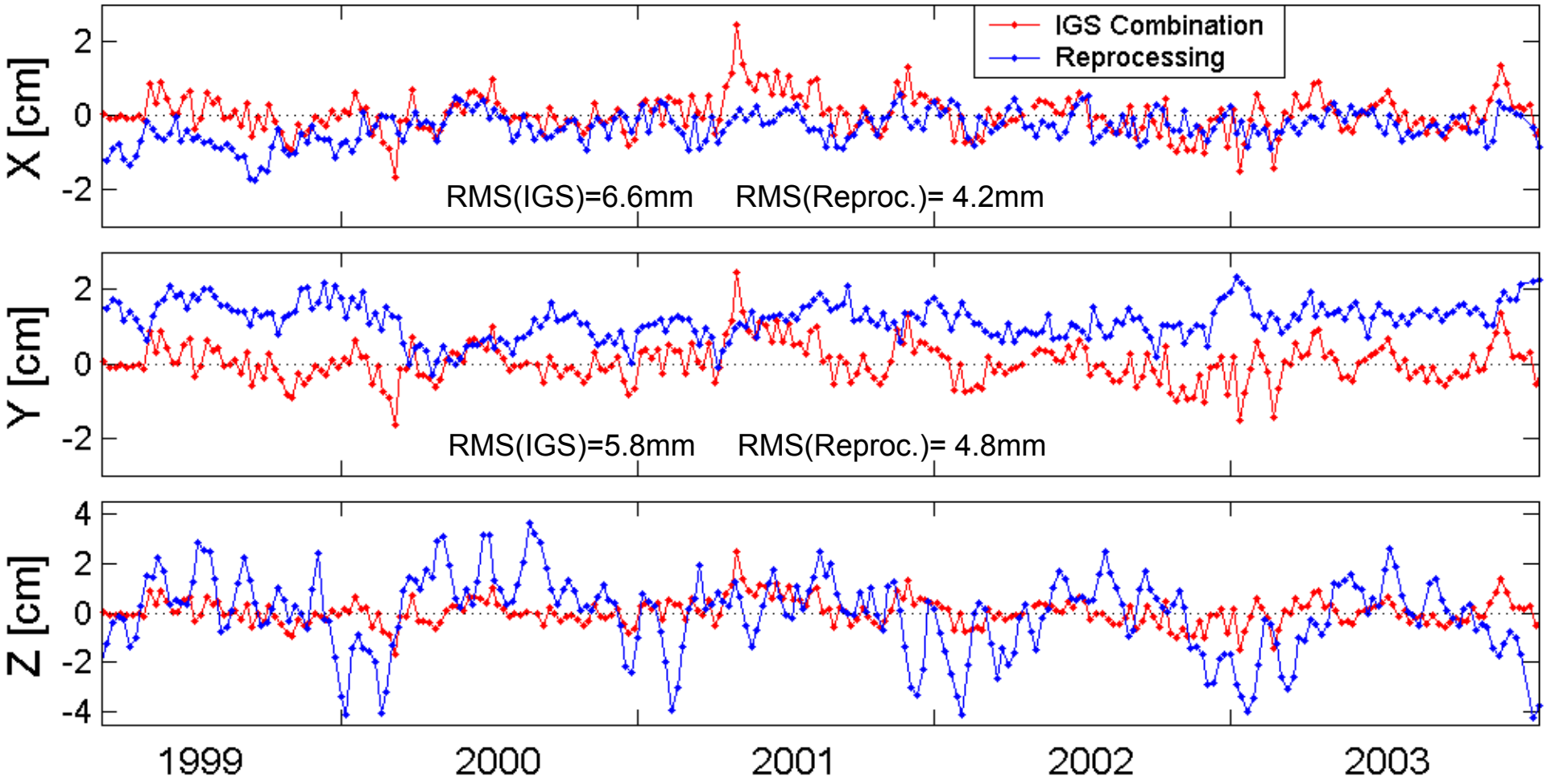
Importance of reprocessing:

- **Inhomogeneous** old time series with inconsistent modeling → quality, consistency and long-term stability cannot be guaranteed
- Upgrades of solution series to **new standards** in modeling and parameterization are necessary (e.g. orbit parameterization)
- Improvements in **processing strategies** (e.g. ambiguity resolution for GPS) should be exploited for the entire time series
- GPS: effects of **reference frame changes** cannot be fully removed (GPS week 1143: ITRF97 → ITRF2000)
- Examples: switch to **IERS Conventions 2003** or introduction of **absolute antenna PCV** in GPS → reprocessing necessary
- IERS requires most up-to-date and consistent time series of products from all techniques (e.g., for IERS2005 products)

Reprocessing: Coordinate Repeatability



Reprocessing: Geocenter



Reprocessing Capability

Statement 2: Development of reprocessing capabilities must be an important goal for all techniques in the near future

- Most other techniques already have such capabilities (VLBI, SLR, DORIS(?), LLR)
- Some or most of the Analysis Centers should reach a status, where they can periodically (e.g., once a year) reprocess the entire global dataset available to the technique
- Associate Analysis Centers might join the effort (?)
- IGS: strategy required on how to improve products of the past (new submissions, new combinations, …)

Consistency of AC and of Combined Products

Troposphere Zenith Delays:

- Systematic and quite large differences between individual ACs
- Indicates inconsistencies in modeling
- Effects heavily correlated with the station height and the global scale
- Try to understand these effects, not just remove them
- Troposphere zenith delay product not consistent with core products

Geocenter, Scale and LOD:

- Quite large systematic offsets and variations exist in these quantities
- They make a rigorous combination difficult

Statement 3: Despite the consistency already reached, the Technique Services should strive for further consistency between AC solutions and between combined products

Conclusions

- IERS is on the way to a **rigorous combination** of its products (IERS CPP, IERS2005).
- **Systematic effects** have to be understood and removed to the extent possible before a successful combination can be done.
- **Reprocessing capabilities** are important to contribute official consistent long-term series to the IERS.
- The **consistency between ACs** as well as the **consistency between products** of one technique should further be improved.
- **Work together with the IERS** to obtain a set of rigorously combined IERS products, which will be beneficial to all space geodetic techniques.