Identification and Mitigation of GNSS Errors

Position Paper

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ERRO Session

09:00	Hugentobler	Position paper
09:15	Gendt	Consistency of IGS products
09:30	Slabinski	Systematic errors of IGS Rapid orbits
09:45	Urschl	SLR validation of GNSS orbits
10:00	Sleewaegen	GPS/Galileo receivers and observables
10:15	Ray	Systematic errors in GPS position estimates
10:30	*Coffee break*	
11:00	Larson	Modified sidereal filtering
11:15	Böhm	Atmospheric mapping functions
11:30	Discussion	
12:00	*Lunch break*	

Topics

- Effects that may corrupt GNSS signals or induce undesirable contributions to GNSS analysis results, as well as mitigation of such effects.

- Effects that are of serious magnitude, that obscure genuine geophysical signals, that degrade the reference frame stability.

- Quality and consistency of IGS products, in particular for precise point positioning.

- Procedures promising the most precise and least biased results.

Topics

- It is likely that significant technique-related errors are sometimes misinterpreted as geophysical signals.

- IGS should take a stronger role in identifying the sources of GNSS errors and in finding strategies to mitigate their effects.

- Topics cover a very broad range and interfere with topics in other sessions.

- All aspects of GNSS geodesy are potentially involved, from field observations through data analysis and interpretation...

Significant input of Jim Ray is acknowledged

In the Field...

- **Far-field and site multipath**
  - local environmental effects, trees, snow, rain water, etc.
  - may average out over 24h-sessions but important for high time-resolved studies

    $\rightarrow$ Larson, van der Marel, Wübbena

- **Near-field and internal multipath**
  - antenna mounting, cable connections, etc.
  - may be important source of systematic positioning errors
  - little known

- **Radio frequency interference**
  - e.g., station KYVW [Larson et al, *J. Geophys. Res.*]

Snow on Antenna

Coordinate repeatability of HOHT

17/02/06 14:53
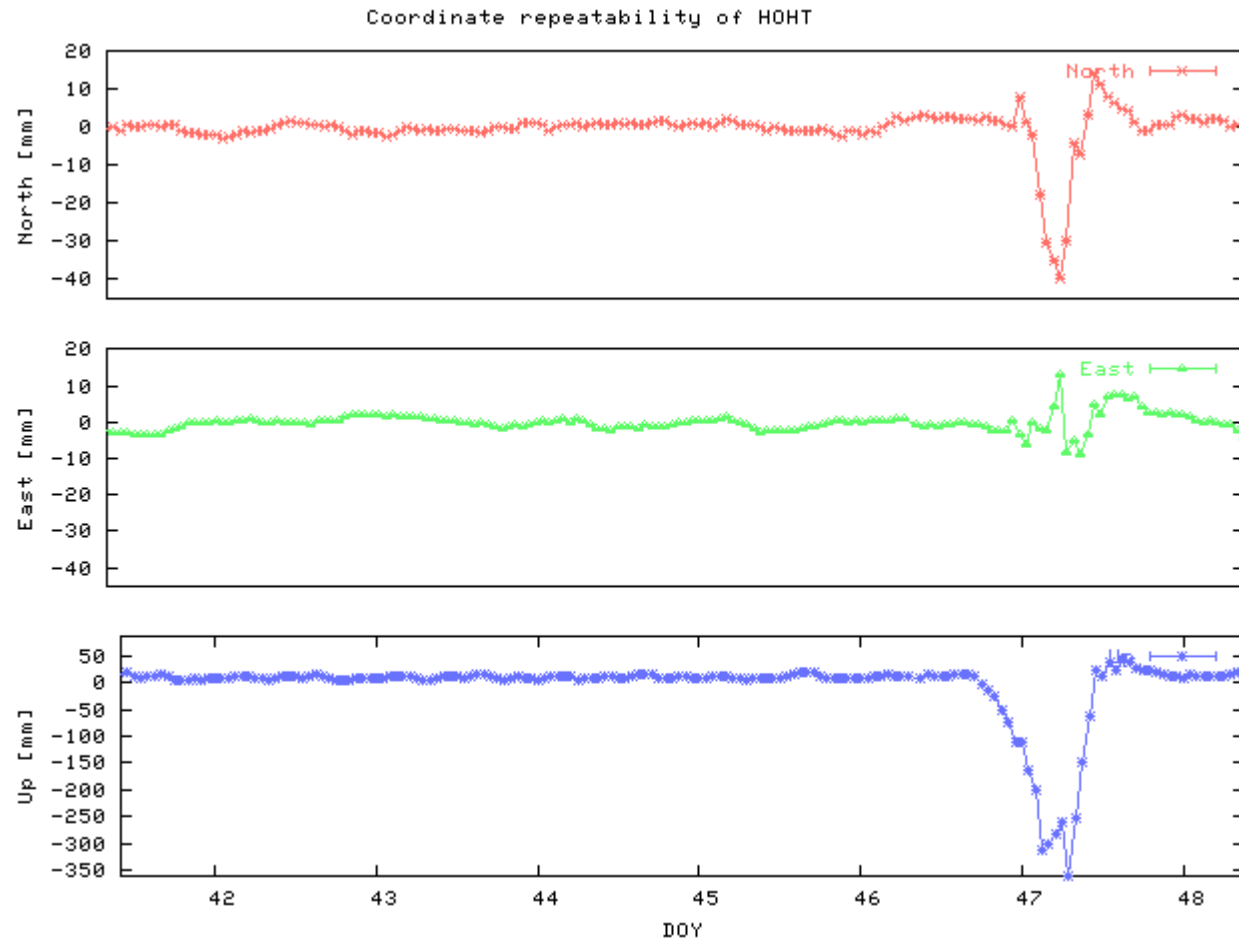
Elmar Brockmann, swisstopo

In the Field...

- ## Radome effects and antenna calibrations
  - to what extent can repeatable calibrations be made accurately?
  - can the use of radomes be further discouraged? or
  - is there a radome design that is widely usable?

    $\rightarrow$ ABSA Schmid

- ## Correlations between geodetic results and observation errors
  - significant technique-related errors may sometimes be misinterpreted as geophysical effects

    $\rightarrow$ Ray

Absolute Antenna Phase Patterns

RMS of daily solutions

In the Field...

- Tracking data amount and quality
    - across the IGS network, variations of tracking data amount and quality are still quite large
    - consistent tracking of "unhealthy" satellites is still not standard
    - tracking problems are particularly pronounced with respect to GLONASS satellites

Tracking Data Amount

GPS   GLONASS

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drej  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24     G26 G27 G28 G29 G30   R01 R02 R03 R04 R05 R06 R07 R08 R17 R18 R19 R20 R21 R22       JPS LEGACY
dubo  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            AOA SNR-8000 ACT
dwh1  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16     G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30   R01 R02 R03 R04 R05 R06 R07 R08 R17 R18 R19 R20 R21 R22 R24  JPS LEGACY
ebre  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            TRIMBLE NETRS
fair  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH UZ-12
ffmj  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24     G26 G27 G28 G29 G30   R01 R02 R03 R04 R05 R06 R07 R08 R17 R18 R19 R20 R21 R22       JPS LEGACY
flin  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            AOA BENCHMARK ACT
glps  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH Z-XII3
glsv  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            TRIMBLE 4000SSI
gode  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH UZ-12
gold  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH Z-XII3
gope  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30   R01 R02 R03 R04 R05     R07 R08 R17         R20 R21 R22       ASHTECH Z18
grac  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30       R02 R03 R04 R05     R07 R08 R17     R19 R20 R21 R22       ASHTECH Z18
gras  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH UZ-12
graz  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            TRIMBLE NETRS
guam  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH Z-XII3
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harb  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            TRIMBLE 4000SSI
helg  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24     G26 G27 G28 G29 G30   R01 R02 R03 R04 R05 R06 R07 R08 R17 R18 R19 R20 R21 R22       TPS EUROCARD
hers  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH Z-XII3
hert  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30       R02 R03 R04 R05     R07 R08 R17         R20 R21 R22       ASHTECH Z18
hlfx  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21     G23 G24 G25 G26 G27 G28 G29 G30                                                            AOA BENCHMARK ACT
hob2  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH UZ-12
hofn  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            TRIMBLE 4000SSI
holb  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            LEICA CRS1000
hrao  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH Z-XII3
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ieng  G01 G02 G03 G04 G05 G06 G07     G09 G10         G14 G15 G16     G18 G19     G21 G22 G23     G25     G27         G30                                                            ASHTECH Z-XII3T
iisc  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23     G25 G26 G27 G28 G29 G30                                                            ASHTECH Z-XII3
irkm  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH UZ-12
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kit3      G02     G04 G05 G06 G07         G10             G15         G18         G21             G26             G29 G30                                                            AOA SNR-8000 ACT
kokb  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH UZ-12
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mac1  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH UZ-12
mad2  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30                                                            ASHTECH Z-XII3T
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mas1  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24     G26 G27 G28 G29 G30                                                            ASHTECH Z-XII3
mat1  G01 G02 G03 G04 G05 G06 G07 G08 G09 G10 G11 G13 G14 G15 G16 G17 G18 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30   R01 R02 R03 R04 R05 R06 R07 R08 R17 R18 R19 R20 R21 R22       ASHTECH Z18
...   ..
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In the Satellites...

- Inter-modulation biases
  - how to handle these biases within the IGS?
  - soon more complicated with new GPS, Galileo, Glonass signals
  - do we have to expect intra-system biases?

    $\rightarrow$ REPR Schaer

- New signals and carrier phase biases
  - usually absorbed into clocks
  - with more signals more possibilities to form ionosphere-free linear combinations
  - necessary to solve for more than one clock when mixing different type of ionosphere-free linear combinations?
  - generate more than one clock for PPP applications?

In the Receivers...

- **Inter-modulation biases, new signals**
  - similar problems with new signals and inter-modulation biases for receivers
  - problem already for GLONASS

    $\rightarrow$ Poster Dach

- **Relative performance of different signal observables**
  - how do, e.g., C1 and P1 compare?

In the Orbits...

- **Orbit modeling deficiencies**
  - orbit modeling parameters, in particular radiation pressure parameters may correlate with geodetic parameters
  - e.g., observability of geocenter affected
  - is GNSS capable of reliably measuring geocenter motions?

- **y-Shift of orbits**
  - described by [Springer, 1999]
  - are such shifts still present and what is their cause?

- **SLR validation**
  - indicates orbit modeling problems

$\rightarrow$ Urschl

Geocenter: Dependence on RPR Model

CODE Geocenter Coordinates (3-daily)
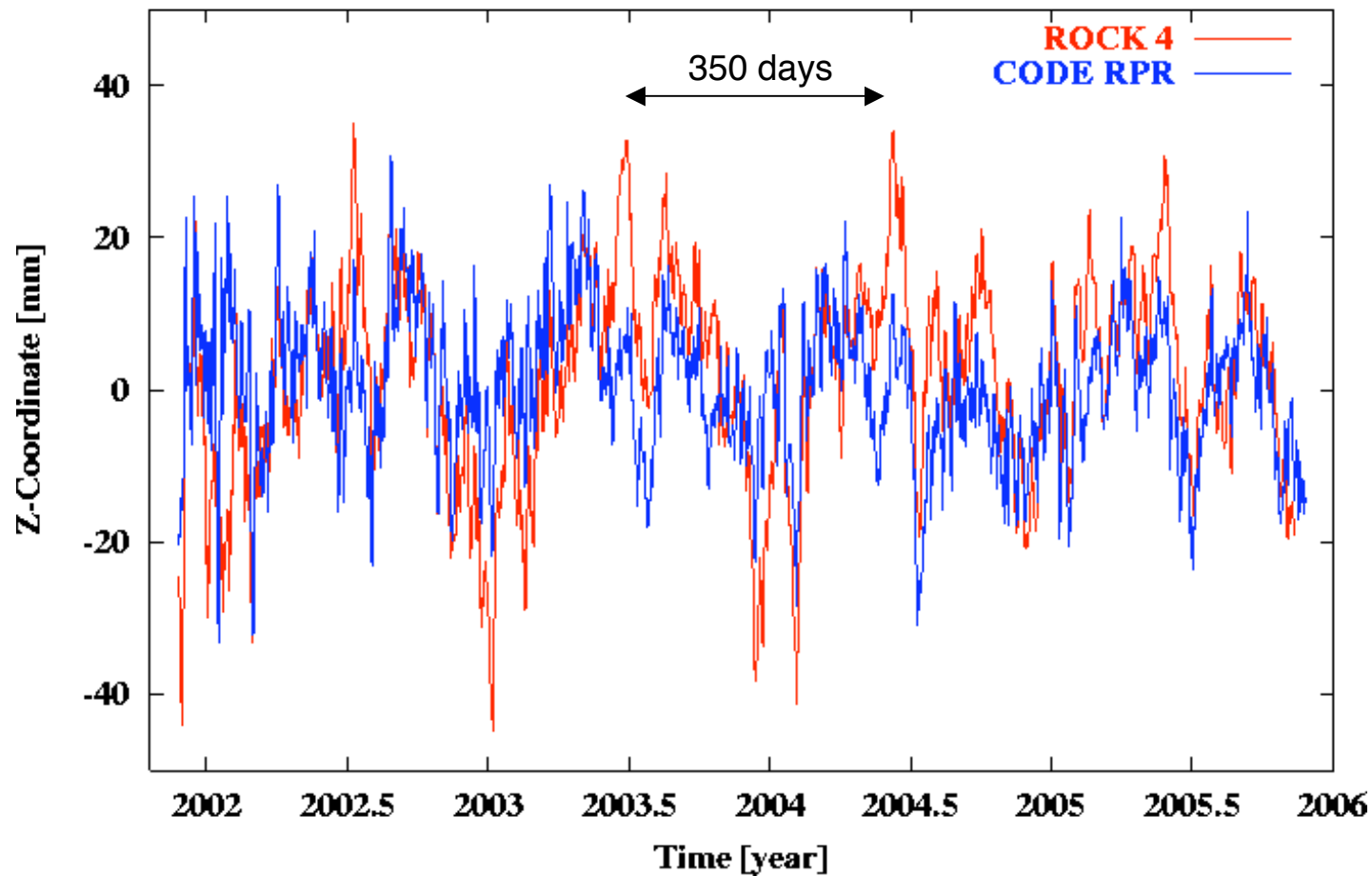
y-Shift of Orbits
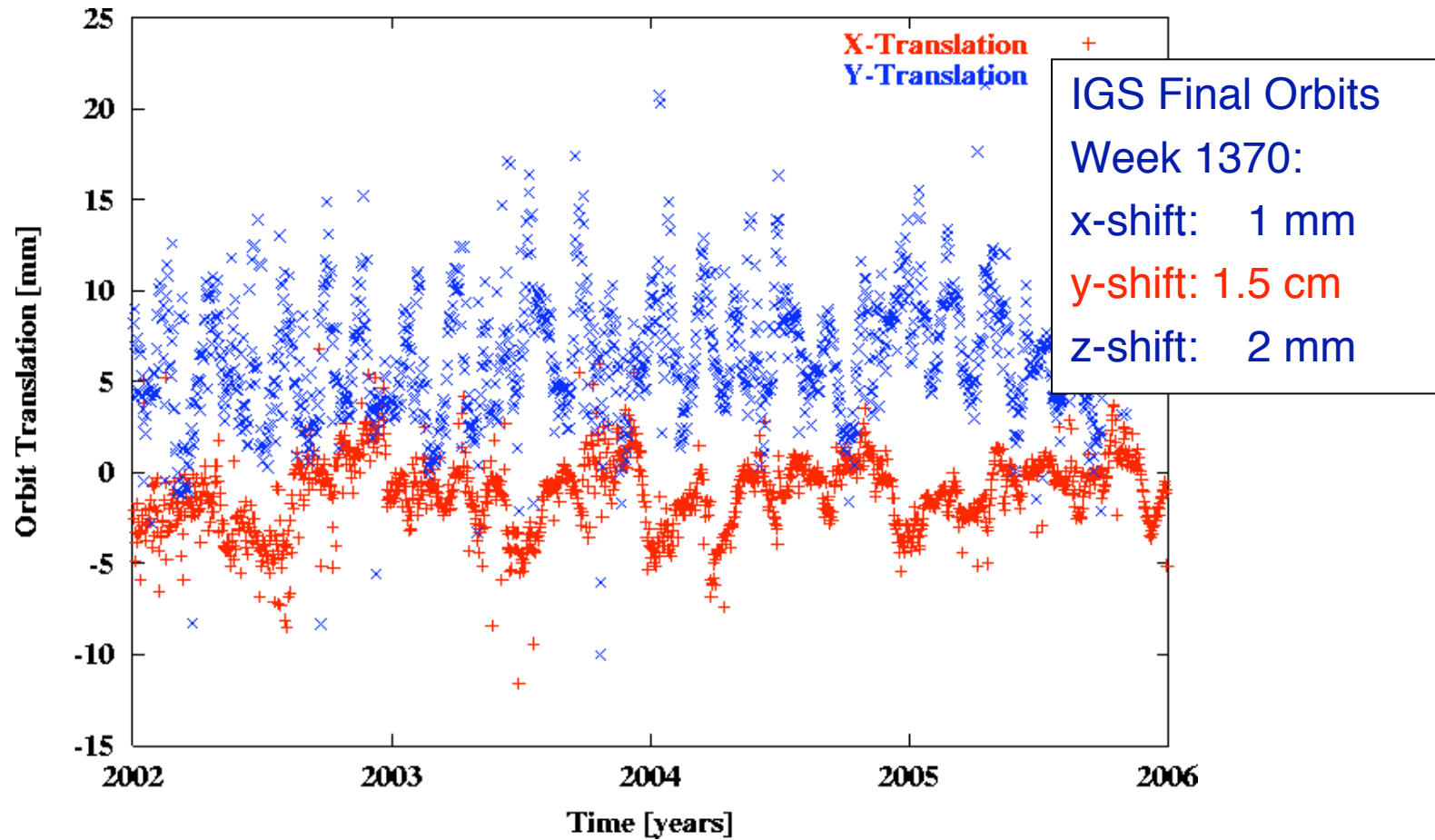
In the Frame...

- Distribution and quality of reference sites

  – overall quality of IGS reference network decreasing

  – how can the impact of inevitable changes at reference sites be minimized?

- Effect of antenna change

  – soon antennas replaced by Galileo-capable antennas

  – how a change should be performed to guarantee minimum effect on estimation of station position and velocity?

- Co-location

  – how to handle multiple antennas, and antenna sharing?

  – should more than one antenna be included into solution for reference sites?

In Combined Multi-GNSS Solutions...

- Improvements with GPS + Galileo + GLONASS

  – will GPS + Galileo give improved results over Galileo alone?

  – are inter-system systematic errors so significant that multi-GNSS combinations will give degraded results?

  $\rightarrow$ Poster Bruyninx

GPS+GLONASS

Baseline Onsala-Wetzell (920 km)
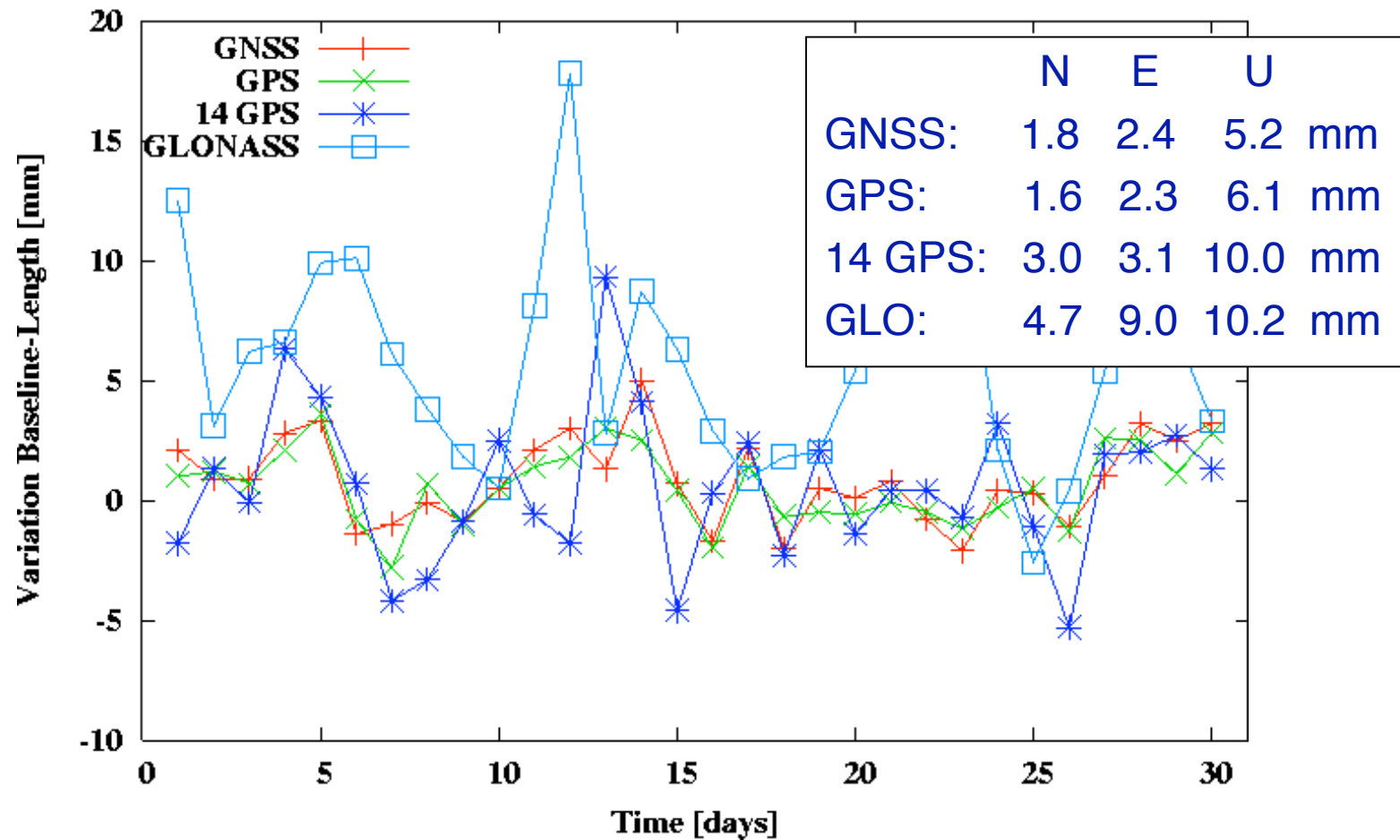
In the Geodetic Results...

- **New models**
  - how do new models for solid Earth, ocean, atmospheric tidal variations, subdaily EOPs, nutation improve geodetic results?

- **Non-tidal loading**
  - what to do with non-tidal loading?
  - can we continue to neglect it at the observation level?

- **Loading signals**
  - is there evidence of aliasing into longer-period signals?
  - extraction of loading signals from geodetic results

- **Seasonal height variations**
  - are they of geophysical origin or caused by technique-specific errors/problems?

OT Loading: Simple Model - Hardisp

● RMS 4 mm
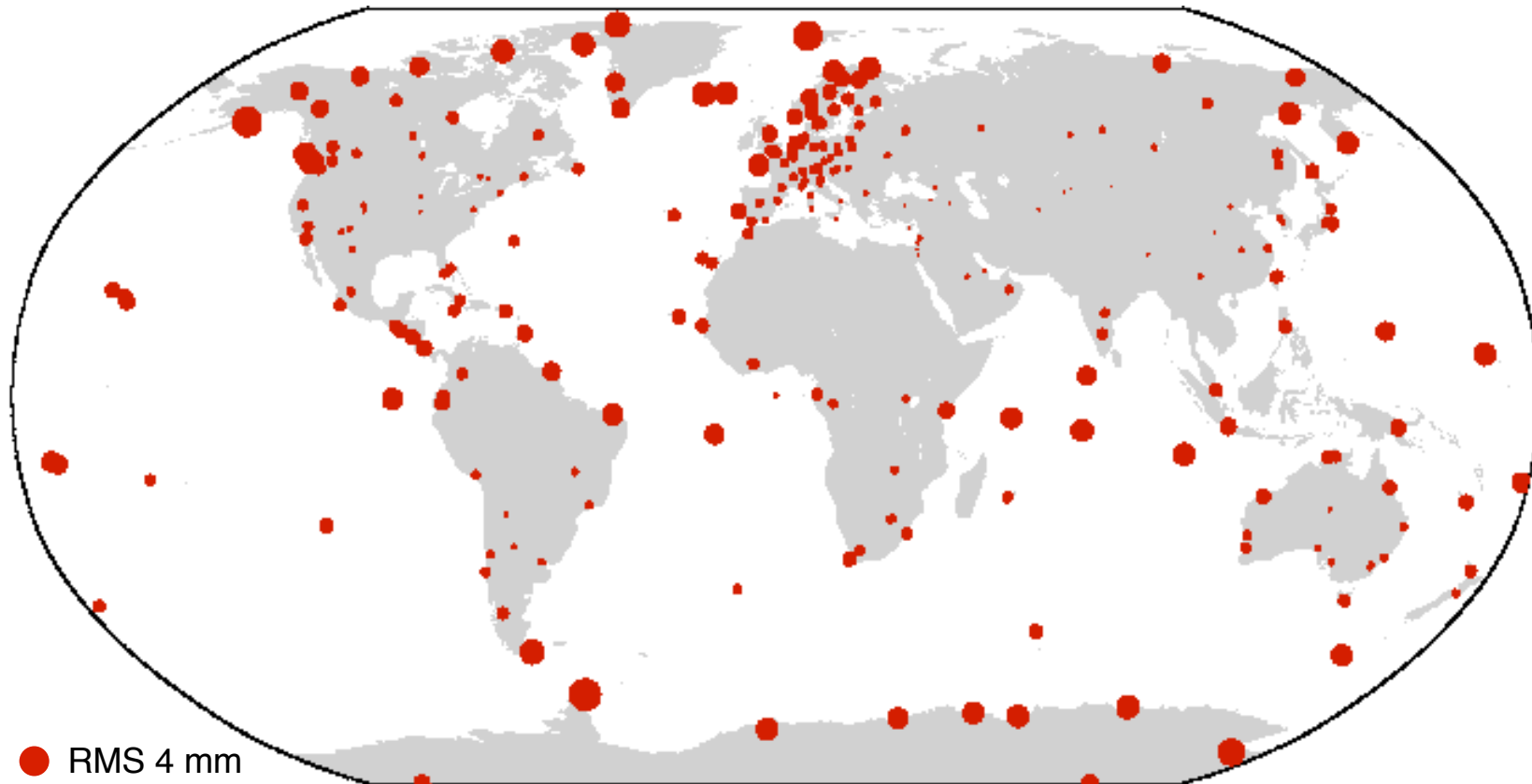
hardisp: Duncan Agnew (UCSD)

In the IGS Products...

- Combination
  - is the multi-AC combination approach still the best for IGS?
  - "large" differences between "best" and "worst" AC

- Consistency, Precise Point Positioning
  - how to improve consistency?
  - consistency of individual AC orbits and clocks contributions
  - consistency of IGS products, in particular for PPP
  - how to reduce analysis noise?
  - what is the consistency of user software with IERS/IGS conventions?

$\rightarrow$ Gendt

PPP: Consistency

PPP With Different Products, with Helmert
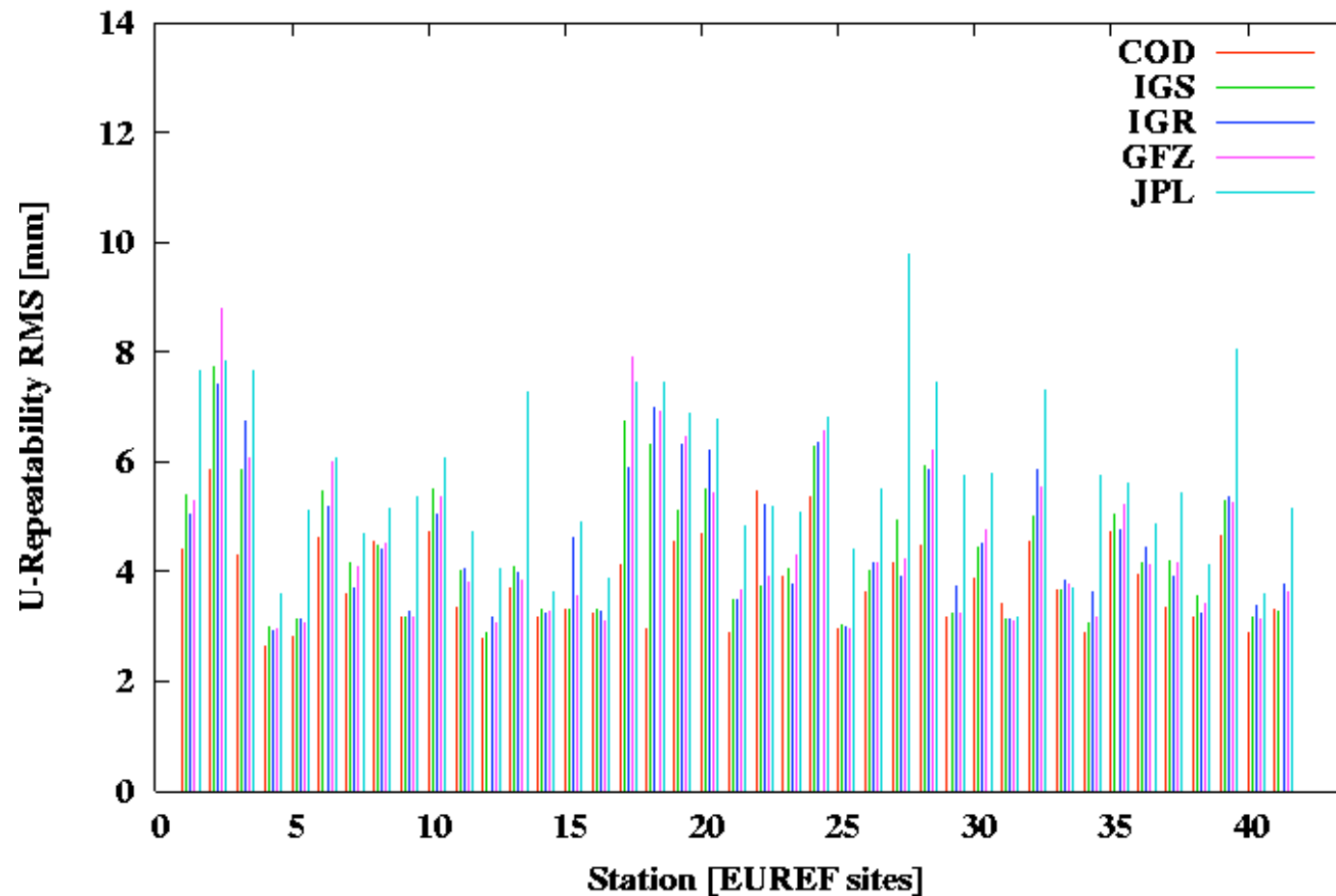
Recommendations

- IGS should stimulate research leading to a better understanding of the different error sources and technique-related problems,

- in particular of not well understood effects such as near-field and internal multipath and their mitigation.

- This may be done by organizing dedicated workshops or sessions at assemblies such as AGU or EGU or preparing a Journal of Geodesy Special Issue, inviting a wider community for participation.

- Improve consistency between AC products and of combined IGS products, in particular for precise point positioning.

End

Recommendations

Recommendation 1:

- IGS should stimulate research leading to a better understanding of the different error sources and technique-related problems,in particular of not well understood effects such as near-field and internal multipath and their mitigation.

- Possibilities are the organization of dedicated workshops or sessions at assemblies such as AGU or EGU or the preparation of a Journal of Geodesy Special Issue, inviting a wider community for participation.

Recommendations

Recommendation 2:

- Improve consistency between AC products and of combined IGS products, in particular for precise point positioning.

- As a first step ACs shall fill an analysis questionnaire that gives a detailed description of the analysis.

- Consistency with respect to used IERS Conventions has to be verified.

- Recommendation of Bern concerning consistency of orbits and clocks with ITRF shall be implemented by all ACs.

Questions

- Has the interface to receiver manufacturers to be intensified?

- Are common tracking standards necessary?

- Implementation of GMF as fast as possible?

- Should the geocenter be constrained to zero or to OTL CMC for the generation of the products?

- Proposal of Jim on use of OTL CMC?

- Enable relativistic travel time correction together with switch to APCV?

Geocenter: Influence on Site Positions

Geocenter: Influence on Site Positions

Datum definitions: no-net rotation only v.s. no-net rotation and translation

Geocenter: Influence on Site Positions

Geocenter: Influence on Site Positions