Federal Agency for
Cartography and Geodesy

Precise Point Positioning at BKG

Axel Rülke and BKG colleagues

NKG Summer School 2016, 29.08.-01.09.2016, Båstad, Sweden

Outline

GNSS Real Time Infrastructure

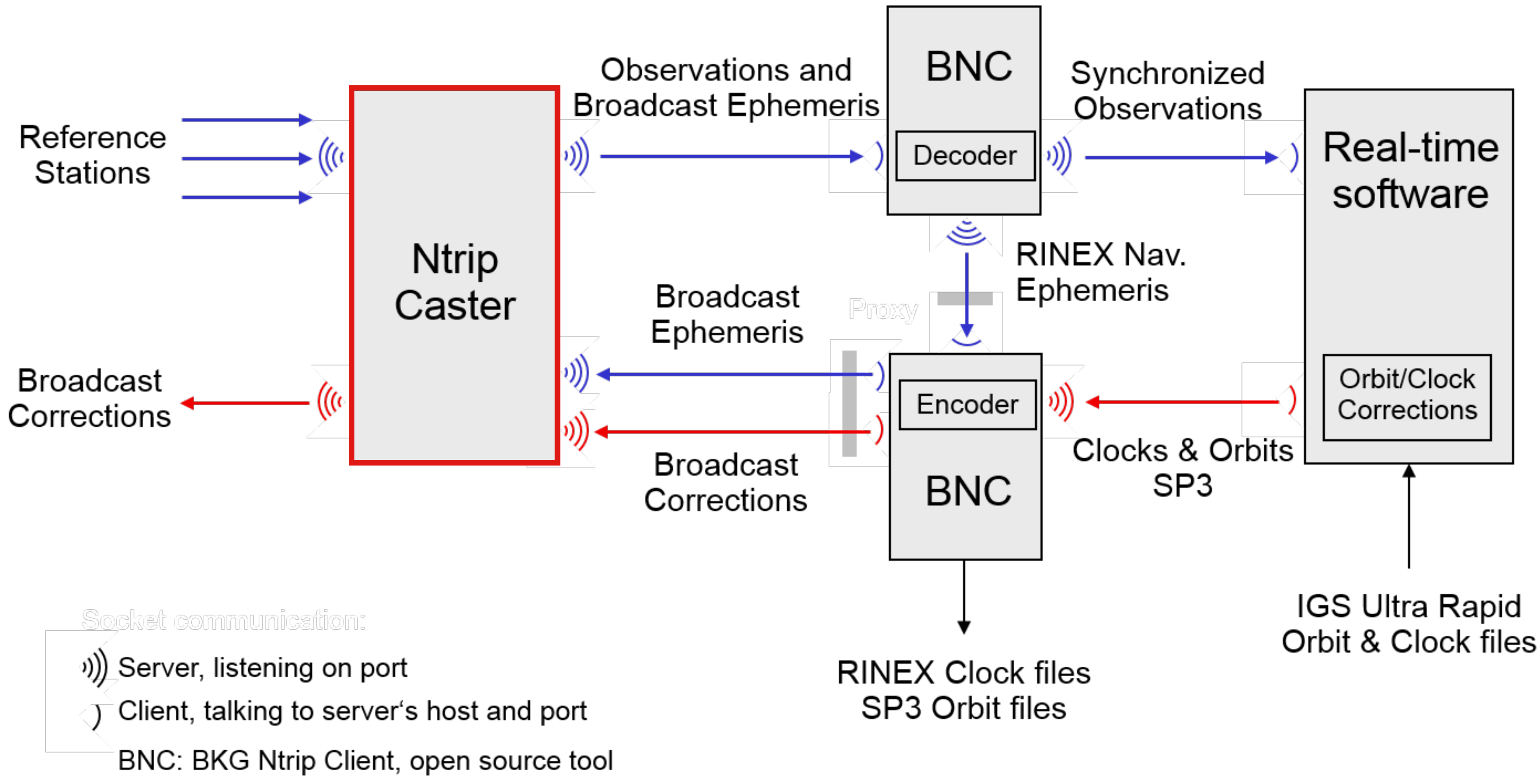
GNSS Standardisation

Real Time Positioning with GNSS

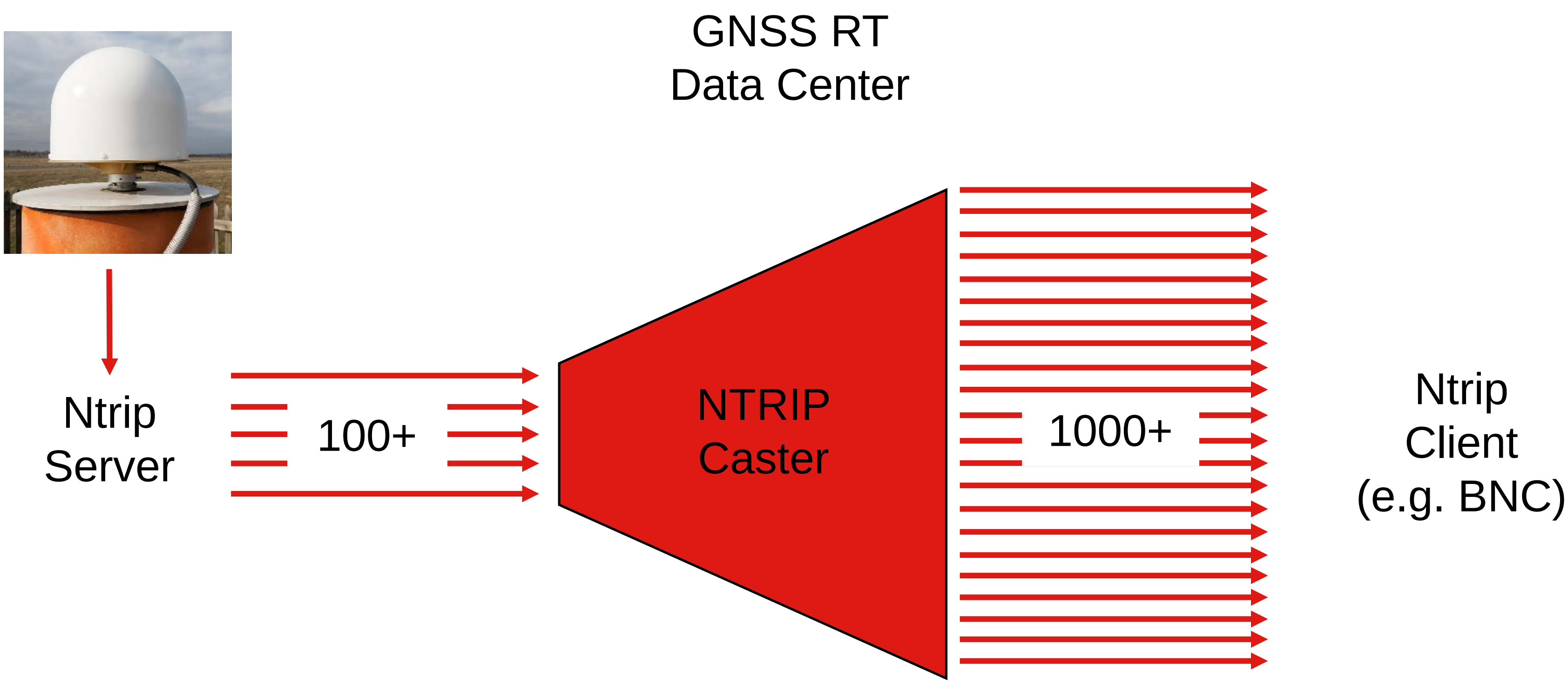
Real Time Service at International GNSS Service

Example Application at Sea

Processing Chain @ BKG



Ntrip Caster



Stream providers and users are not in contact

Source Table
igs-ip.net

File Edit View History Bookmarks Tools Help

HotSpot | http://igs-ip.net/

igs-ip.net

Most Visited | Intranet BKG | Anwesenheit | New Tab | SPIEGEL ONLINE | Coordinates | Inside GNSS | GPS World

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Source Table
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```

NTRIP Caster source-table

- CASrecord = Caster entry
- NETrecord = Network entry (e.g. SKL holdings)
- STRrecord = Source entry
- Data field content separated by “;”

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Source Table
Metadata handling

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STR;CHUR0;Churchill;RTCM 3.0;1004(1),1006(15),1008(15);2;GPS;IGS;CAN;
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STR;COCO0;Cocos_Island;RTCM 3.2;1019(1),1020(1),1033(1),1077(1),1087(1),
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1004, 1006: Conventional GPS observations
1008: Antenna information
1019: GPS Ephemeris, 1020 GLONASS Ephemeris
1033: Receiver, Antenna
1077, 1087, 1097, 1117, 1127: MSM-7 observations GPS, GLONASS, Galileo, QZSS, BDS
1057, 1058, 1063, 1064: GPS, GLONASS orbit + clock corrrrections

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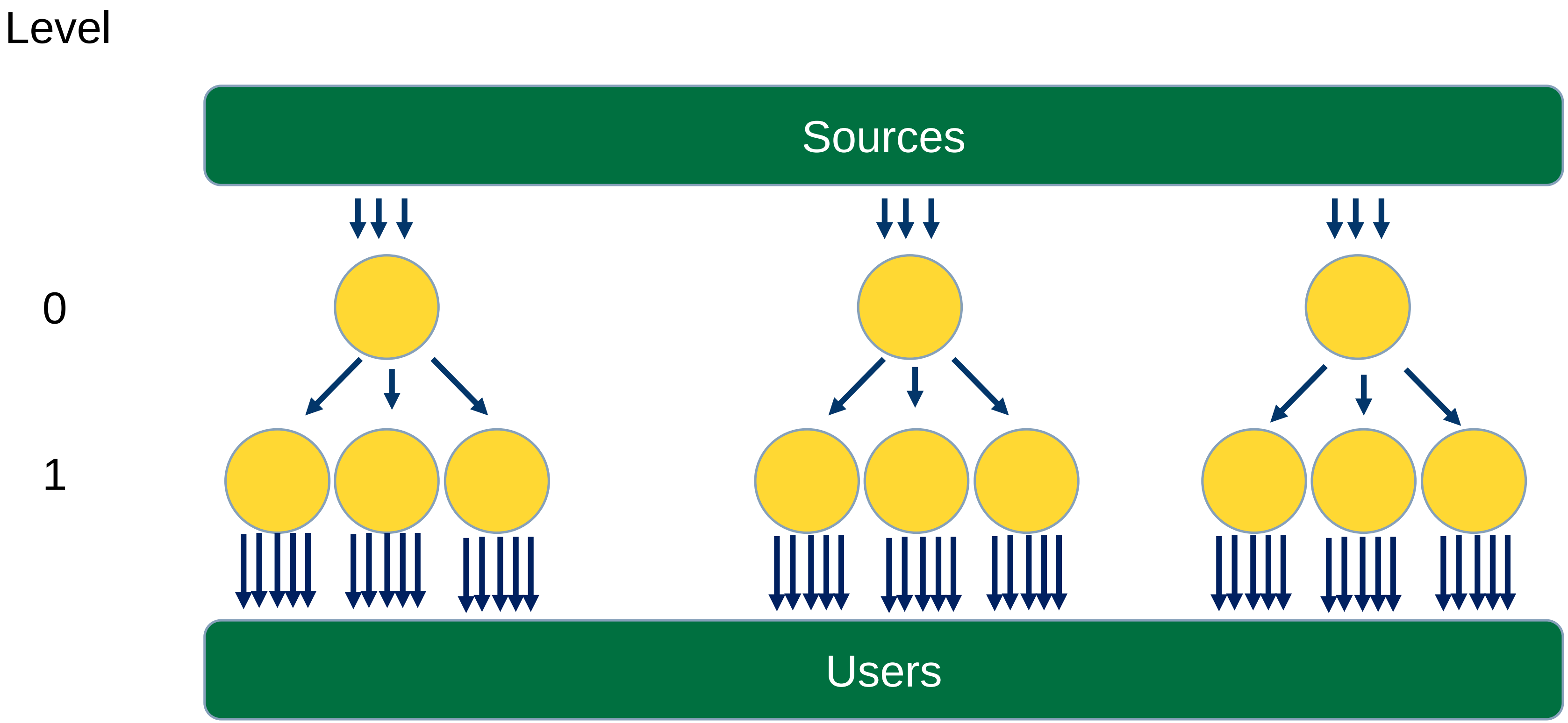
Caster hierarchy



Each caster adds approximately 0.2 .. 0.3 s of latency

Outline

GNSS Real Time Infrastructure

GNSS Standardisation

Real Time Positioning with GNSS

Real Time Service at International GNSS Service

Example Application at Sea

GNSS Standardisation


RTCM 10403.2
RTCM Paper 104-2013-SC104-STD
with Amendment 1
RTCM Paper 151-2013-SC104-STD
with Amendment 2
RTCM Paper 228-2013-SC104-STD

RTCM

RTCM STANDARD 10403.2

DIFFERENTIAL GNSS
(GLOBAL NAVIGATION SATELLITE SYSTEMS)
SERVICES – VERSION 3

DEVELOPED BY
RTCM SPECIAL COMMITTEE NO. 104

NOVEMBER 7, 2013

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Web Site: http://www.rtcm.org

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RTCM Special Committee 104 (RTCM-SC104)

- Committee to develop open international standards on DGNSS
- Working groups
  - GLONASS (Alexei Zinoviev)
  - Galileo (Hans-Jürgen Euler)
  - QZSS (Rui Hirokawa)
  - BeiDou (Shao Wei Han)
  - State Space (Gerhard Wübbena)
  - RINEX (Ken MacLeod)
  - Biases (Ken MacLeod)
  - …
- Procedure
  1. Proposal
  2. Interoperability test (3 independent software implementations and testing)
  3. CDV (Committee draft for vote)

GNSS Standardisation Observations

- Intention to generate GNSS observables in a universal manner
- Ability to support all GNSS and their signals that are available today & future

Multi Signal Messages (MSM) are designed to cover the following:

  - maximum compatibility with RINEX-3
  - universality for all existing and future GNSS signals
  - compactness of presentation
  - no ambiguity in interpretation
  - simplicity of generation/decoding
  - flexibility and scalability

GNSS Standardisation Observation messages

RTCM

	Conventional messages	Multi Signal Messages
Constellations	GPS, GLONASS, (SBAS)	GPS, GLONASS, GALILEO, …
Signals	1 signal per frequency (either C/A or P(Y) on L1/L2)	Multiple signals per frequency, → all RINEX v3 signals
Observation Types	▪ Pseudo-Range ▪ Carrier-Phase ▪ C/N0	▪ Pseudo-range ▪ Carrier Phase ▪ C/N0 ▪ Doppler
Resolution	Pseudorange: 20 mm Carrier Phase: 0.5 mm C/N0: 0.25 dB Hz	Pseudorange: ~0.6 mm Carrier Phase: ~0.14 mm C/N0: 0.1 dB Hz Doppler: 0.1 mm/s

GNSS Standardisation
Observation messages

Constellation	Conventional	MSM
GPS	1001-1004	1071-1077
GLONASS	1009-1012	1081-1087
Galileo		1091-1097
SBAS		1101-1107
QZSS		1111-1017
BDS		1121-1127

- Full RINEX 3 capability with MSM7!
- Availabilty of MSM observation messages at http://mgex.igs-ip.net (software converted)
- Receiver generated MSM messages at normal caster (e.g. http://igs-ip.net)

GNSS Standardisation Navigation Messages

RTCM

Constellation	Message #	Proposal?
GPS	1019	
GLONASS	1020	
Galileo F/Nav	1045	
Galileo I/Nav	1046	
SBAS	1043	x
QZSS	1044	
BDS	63	x

Outline

GNSS Real Time Infrastructure

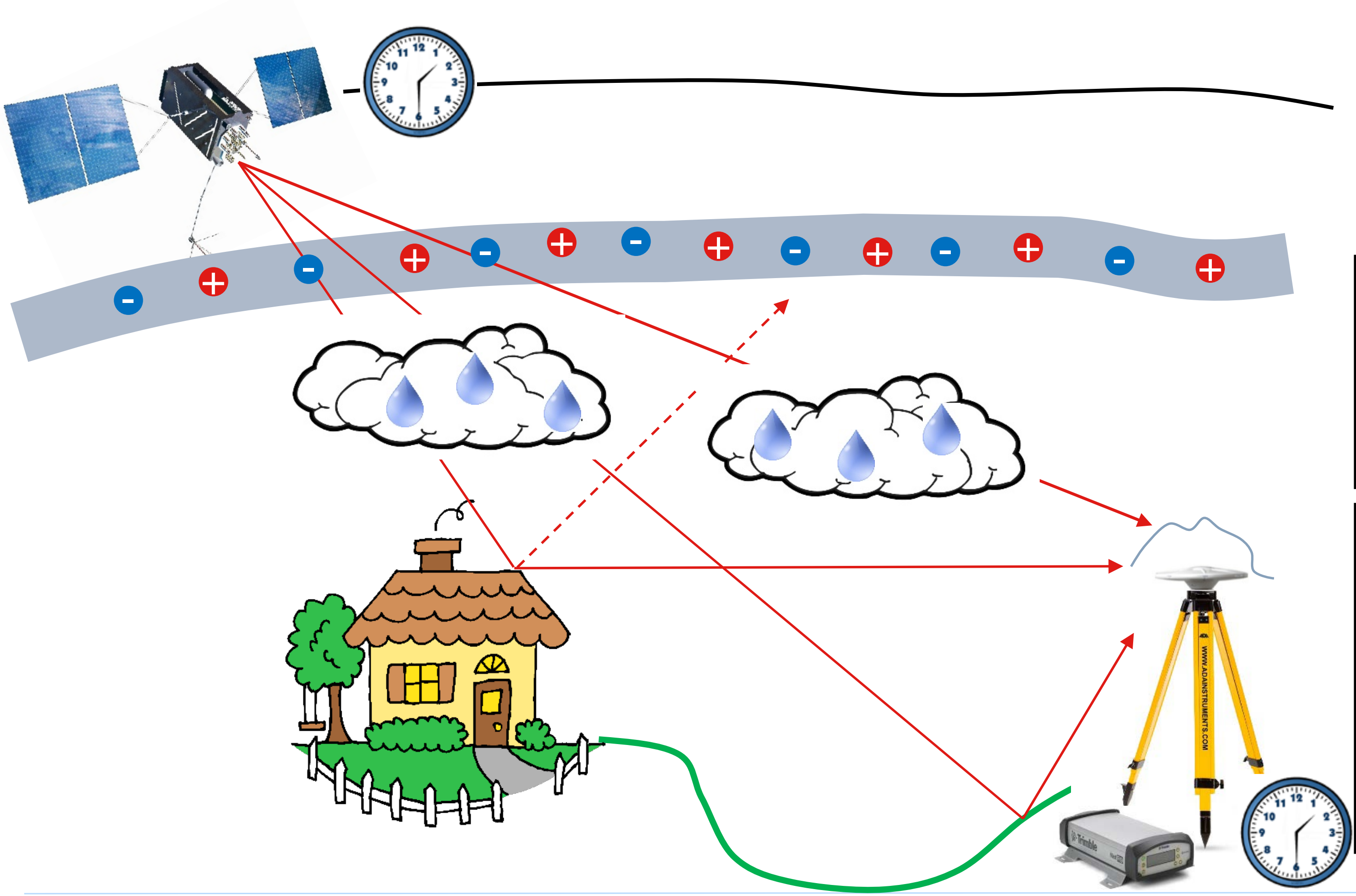
GNSS Standardistation

Real Time Positioning with GNSS

Real Time Service at International GNSS Service

Example Application at Sea

Realtime Positioning with GNSS
GNSS Error Sources



Satellite
Orbit error
Clock error
Biases

Atmosphere
Ionosphere
Troposphere

Antenna
Receiver
Receiver Clock
PCV
Multipath
Biases

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Realtime Positioning with GNSS Observation Space Representation

Sum of GNSS errors per station, GNSS, frequency / signal

- Distance dependent errors are derived from and combined with reference station observations
- RTK networking with current RTCM standards: VRS,FKP,..
  - RTK service uses network of reference stations
  - RTK rover uses reference station observations and RTK corrections

Disadvantages:

- only satellites / signals tracked within the RTK network are usable
- no reduction of reference station dependent errors
- update rate of the corrections depends on component with highest dynamics (satellite clock, ionosphere)
- limited spatial validity of corrections
- Bandwith with additional GNSS/satellites/signals
- Bi-directional communication needed

Realtime Positioning with GNSS
State Space Representation

State Space Representation (SSR) approach has significant **advantages** compared to the oberservation space representation used for RTK applications:

- High reduction of reference station dependent errors through high redundancy within the network
- Independent from single reference stations
- More realistic physical models for individual errors enables better modeling and interpolation
- Update rate can be optimized for different state parameters
- Scalability of accuracy and hence of the derived services
- Broadcasting of parameters possible (Uni-directional communication)

→ Precise Point Positioning applications (PPP)

Realtime Positioning with GNSS
State Space Representation

The main **disadvantage** is the higher standardization and implementation effort

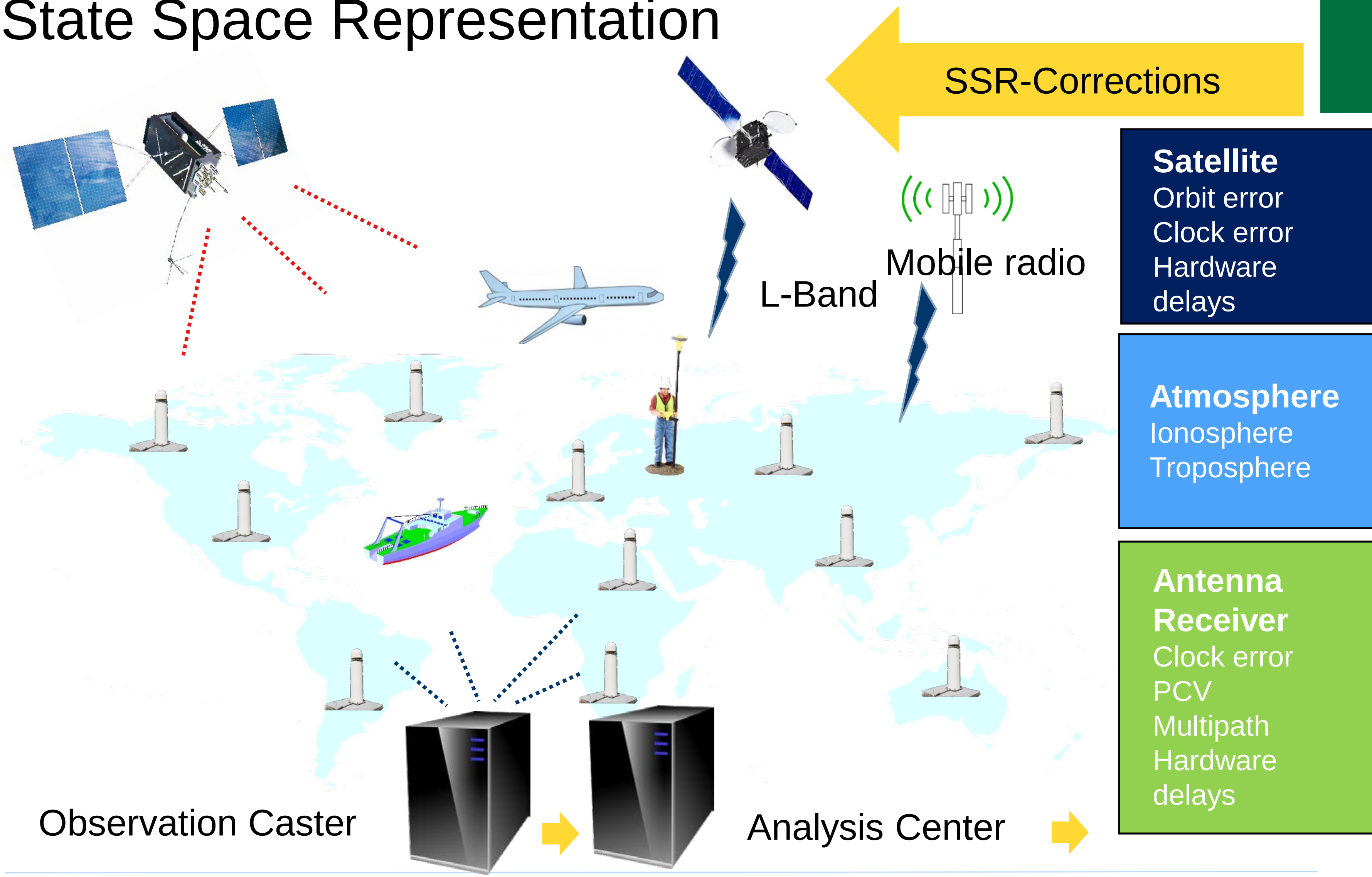
- site displacements (solid earth/pole tides, ocean/atmospheric loading)
- phase wind up effect, antennae PCO/PCV
- higher order ionosphere effects
- standardization of troposphere correction models

→ IERS Conventions are the reference for standardization

Examples for PPP services:

- Trimble RTX, Fugro, Veripos etc.
- IGS supports correction data based on open standards as a „best effort“ solution of a community with scientific background

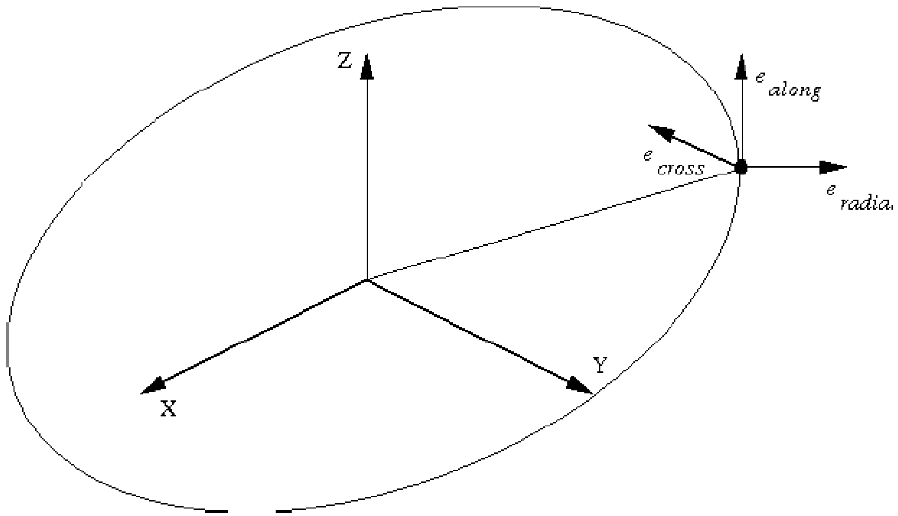
State Space Representation



State Space Representation
Orbit corrections

Orbit corrections refer to broadcast orbits → bandwith reduction

$$X_{orbit} = X_{broadcast} - \delta X$$



X_{orbit}	Corrected satellite position
$X_{broadcast}$	satellite position computed according to the respective GNSS ICD
δX	satellite position correction

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State Space Representation
Orbit corrections

Orbit corrections

- are defined radial, along-track and cross-track

$$\delta X = \begin{bmatrix} e_{radial} & e_{along} & e_{cross} \end{bmatrix} \delta O$$

- consist of correction and velocity correction term

$$\delta O = \begin{bmatrix} O_{radial} \\ O_{along} \\ O_{cross} \end{bmatrix} + \begin{bmatrix} \dot{O}_{radial} \\ \dot{O}_{along} \\ \dot{O}_{cross} \end{bmatrix} (t - t_0)$$

t .. time

t_0 .. reference time obtained from SSR orbit correction message

$\delta O_i, \delta \dot{O}_i$ .. orbit correction term from SSR orbit message; i = {radial, along, cross}

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State Space Representation
Clock corrections

Clock corrections refer to broadcast clocks

- clock correction terms: C0, C1, C2 polynomial coefficients
- reduces bandwidth

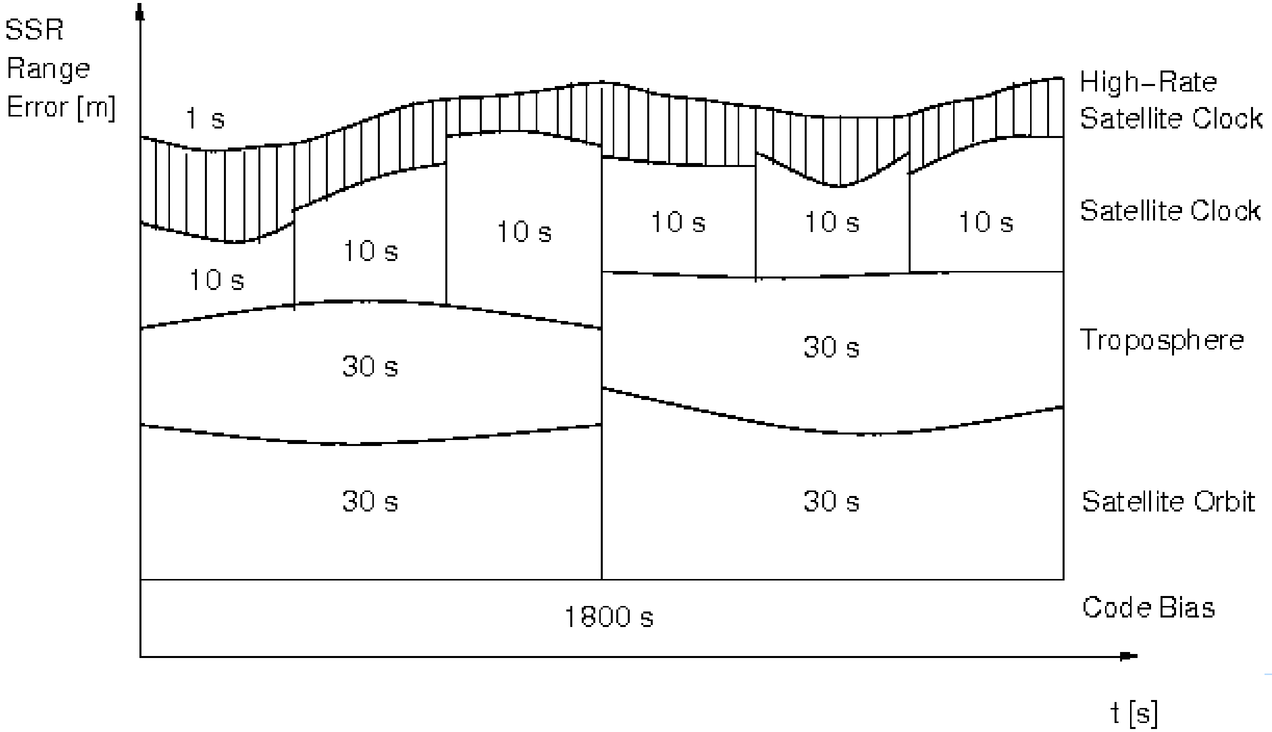
$$t_{satellite} = t_{broadcast} - \frac{\delta C}{c}, \quad \text{with} \quad \delta C = C_0 + C_1(t - t_0) + C_2(t - t_0)^2$$

$t_{broadcast}$ … satellite time computed according to corresponding GNSS ICD
$t_{satellite}$ … satellite time corrected by SSR clock correction message,
δC … clock correction obtained from SSR clock correction message.
t … time
t_0 … reference time obtained from SSR clock correction message
C_0, C_1, C_2 … polynomial coefficients from SSR clock correction message
c … velocity of light

- High rate clock (in addition to polynomial clock: higher update rate)
- Satellite code biases (absolute correction term for every signal and tracking mode)

State Space Representation
Basic concept

- SSR messages support different update rates, accuracy requirements
- additional SSR message types adds additional resolution/position accuracy
- SSR update interval and GNSS epoch time define changes of parameters and ensure consistency of data



State Space Representation Status

RTCM

Satellite
Orbit error
Clock error
Hardware delays

Atmosphere
Ionosphere
Troposphere

Antenna
Receiver
Clock error
PCV
Multipath
Hardware delays

		G	R	E	C	J	S
1	Satellite orbit error	✓	✓	●	●	●	●
	Satellite clock error	✓	✓	●	●	●	●
	Hardware Delay (CODE biases)	✓	✓	●	●	●	●
2	Hardware Delay (Phase biases)	●	●	●	●	●	●
	Ionosphere (VTEC)	●					
3	Ionosphere (STEC)	✗					
	Troposphere	✗					
4	Compression	✗					

Standardization, SSR RTCM-SC104

System / RTCM SSR Message (* proposed)	GPS	GLONASS	Galileo	SBAS	QZSS	BDS
Orbits	1057	1063	1240*	1246*	1252*	1258*
Clocks	1058	1064	1241*	1247*	1253*	1259*
Code Biases	1059	1065	1242*	1248*	1254*	1260*
Combined Orbits and Clocks	1060	1066	1243*	1249*	1255*	1261*
VTEC	1264*					
Phase Biases	1265*	1266*	1267*	1268*	1269*	1270*

Outline

GNSS Real Time Infrastructure

GNSS Standardisation

Real Time Positioning with GNSS

Real Time Service at International GNSS Service

Example Application at Sea

IGS Real-Time-Service

IGS INTERNATIONAL GNSS SERVICE **http://rts.igs.org**

- IGS – a voluntary federation of over 200 self-funding agencies, universities, and research institutions in more than 100 countries
- 2002: Development of a IGS Real-Time-Service starts
- 2005..2007:
  - Development of NTRIP basics
- 2007..2012:
  - Pilot Project
  - MSM to be compatible with RINEX 3
  - Joined RTCM
  - Plan of action (PPP→Service)
- April 2013: Launch of IGS RT-Service
- today: three product streams: IGS01, IGS02, IGS03

Infrastructure

Obervation Casters

BKG: **http://igs-ip.net**

IGS CB: **http://igscb.jpl.nasa.gov:2101**

CDDIS: **https://cddis-caster.gsfc.nasa.gov/**

MGEX-Caster @ BKG: **http://mgex.igs-ip.net**

Product Casters

BKG: **http://products.igs-ip.net/**

Pulled products at other casters available

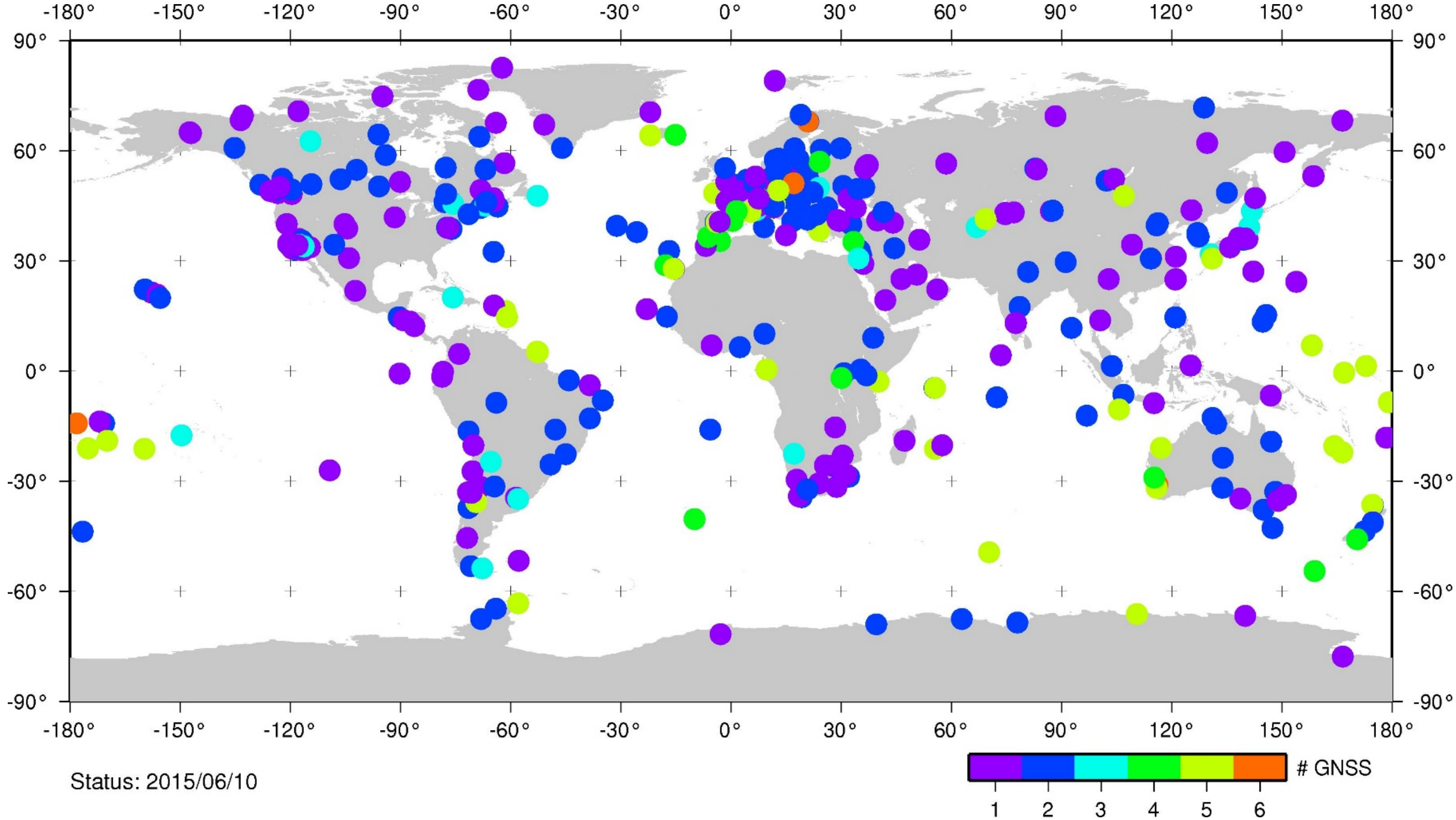
Registration

BKG: **http://register.rtcm-ntrip.org/cgi-bin/registration.cgi**

IGS-CB: **https://cddis-casterreg.gsfc.nasa.gov/DataCasterRegistrationForm.html**

IGS-Network
452 Stations

www.igs.org



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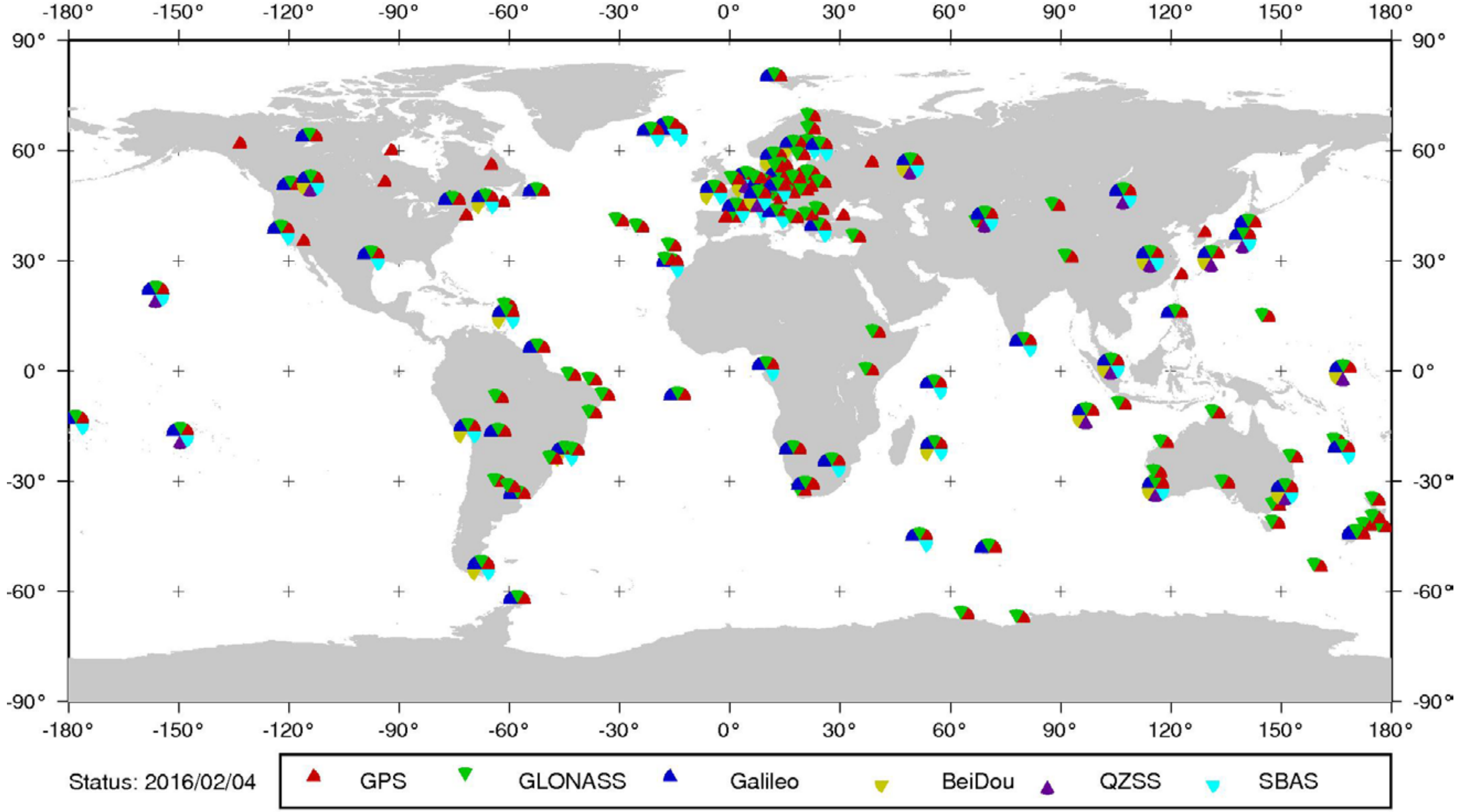
RT-Station Network

IGS INTERNATIONAL GNSS SERVICE

igs-ip.net
mgex.igs-ip.net



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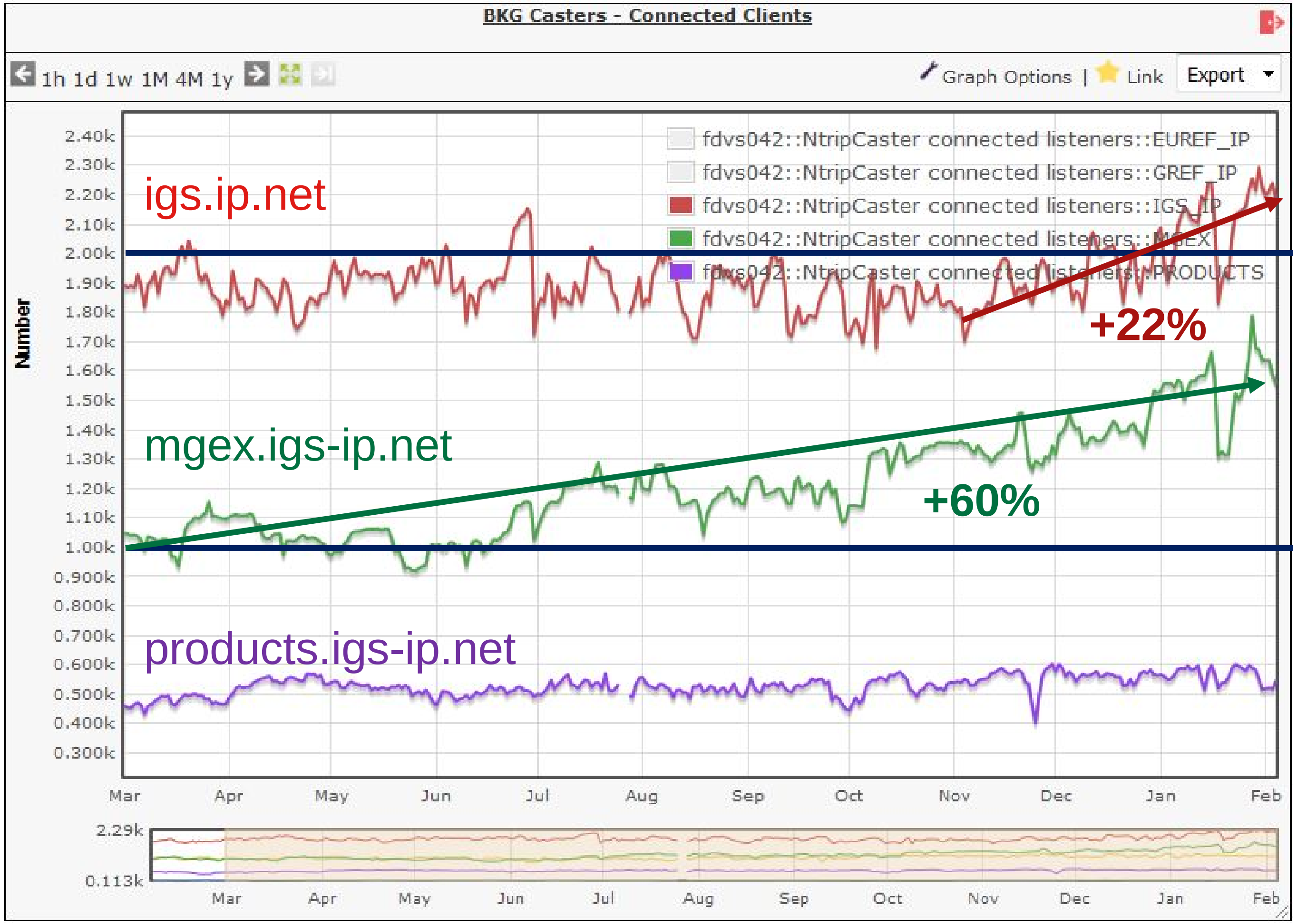
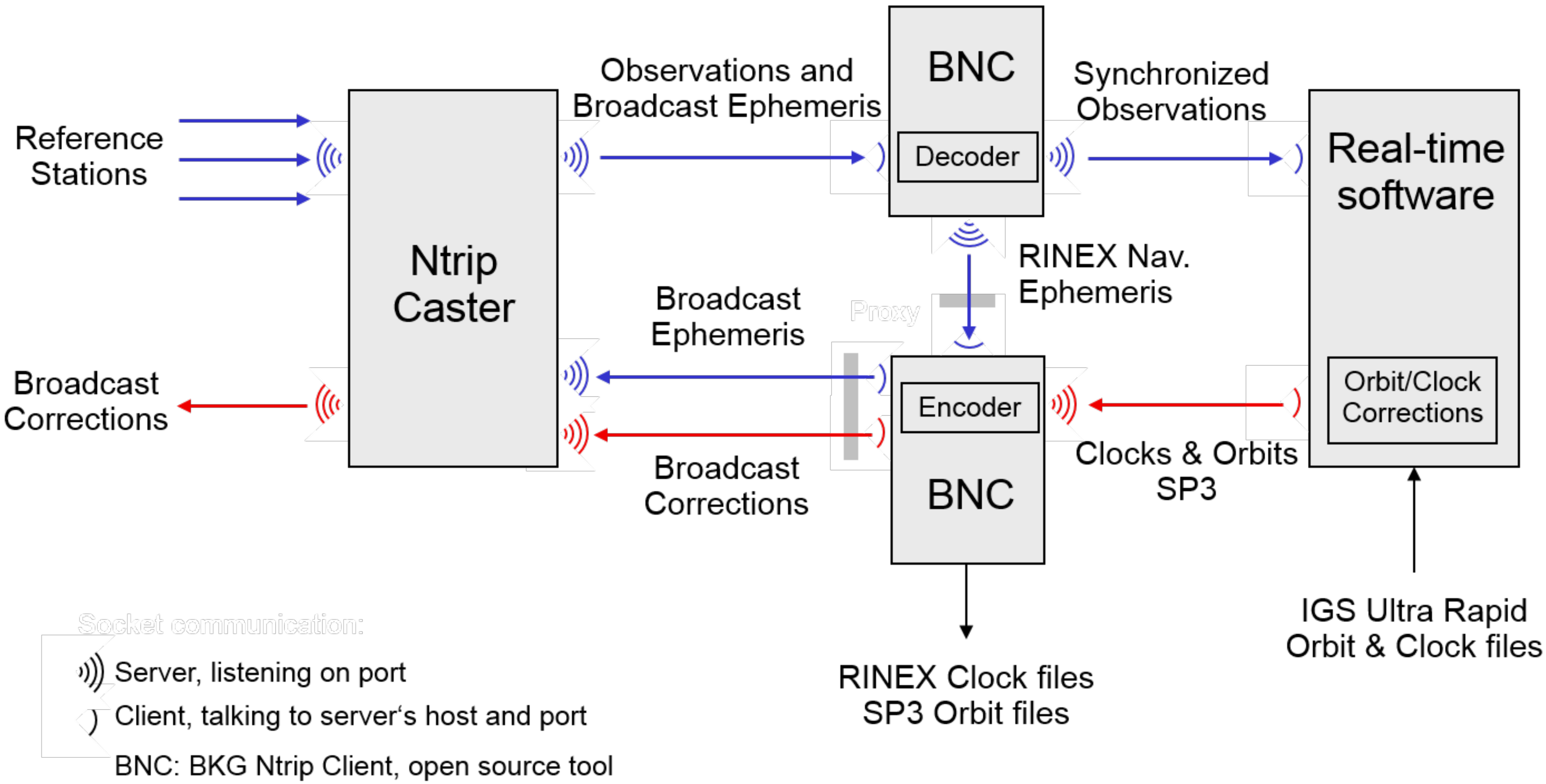
Connected clients at BKG casters



Processing Chain @ BKG

IGS INTERNATIONAL GNSS SERVICE



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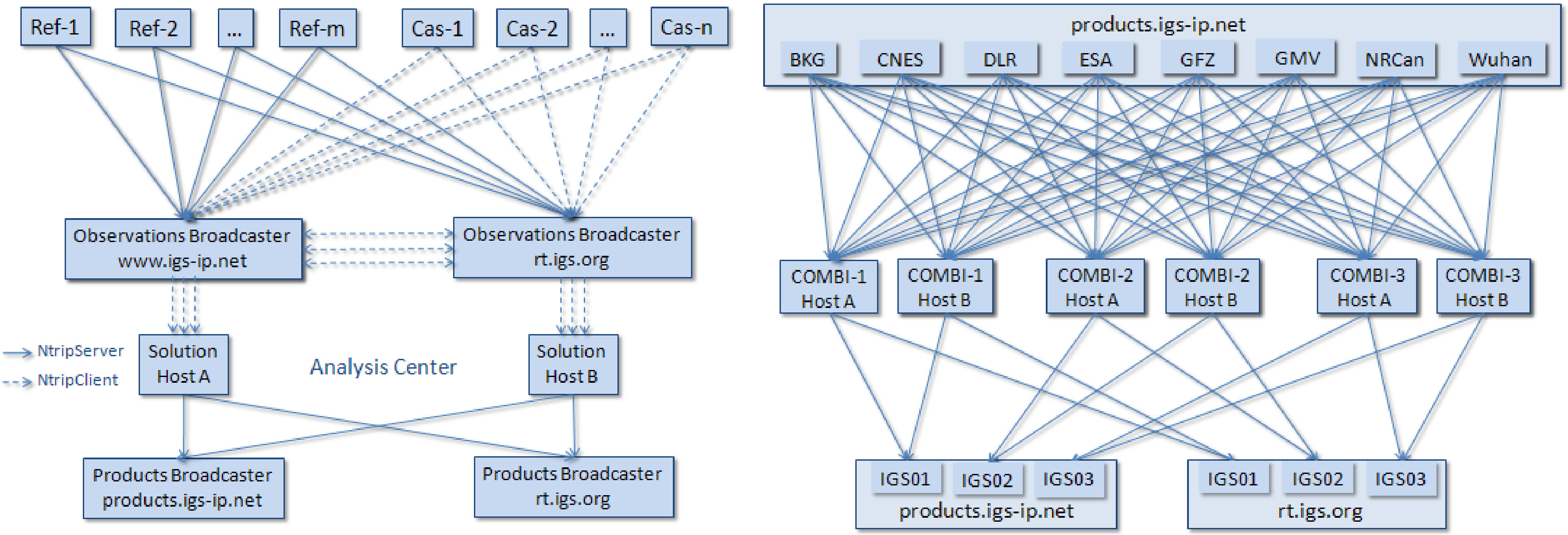
IGS RT-Processing Scheme



IGS ACs

Federal Agency for Cartography and Geodesy, Germany

ESOC Darmstadt, Germany

Natural Resources, Ottawa, Canada

Helmholtz Center Potsdam, GFZ German Research Center for Geosciences, Potsdam, Germany

Centre National D‘Études Spatiales, Toulouse, France

GMV, Madrid, Spain

Deutsches Zentrum für Luft- und Raumfahrt, Oberpfaffenhofen, Germany

Wuhan University, Wuhan, China

IGS-RTS: Products

AC	Mountpoints with Message Types and Update Rates
BKG	CLK00/10 (CoM/APC): **1057(60),1058(5)** CLK01/11 (CoM/APC): **1057(60),1058(5)**,1063(60),1064(5)
CNES	CLK90/91 (CoM/APC): 1059(5),**1060(5)**,1065(5),1066(5),1264(56),1265(10) CLK92/93 (CoM/APC): 1059(5),**1060(5)**,1065(5),1066(5),1242(5),1243(5),1261(5), 1264(60),1265(15)
DLR	CLK20 (APC): 1059(5),**1060(5)** CLK21 (APC): 1059(10),**1060(10)**,1066(10)
ESA	CLK52/53 (CoM/APC): 1059(1815),**1060(5)**
GFZ	CLK70/71 (CoM/APC): **1060(5)**
GMV	CLK80/81 (CoM/APC): 1059(5),**1060(5)**,1066(5)
NR Can	CLK22 (APC): 1059(5),**1060(5)**
Wuhan	CLK15/16 (CoM/APC): 1059(5),**1060(5)**

GPS Orbits and Clocks

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IGS-RTS: Products

AC	Mountpoints with Message Types and Update Rates
BKG	CLK00/10 (CoM/APC): **1057(60),1058(5)** CLK01/11 (CoM/APC): **1057(60),1058(5)**,**1063(60),1064(5)**
CNES	CLK90/91 (CoM/APC): 1059(5),**1060(5)**,1065(5),**1066(5)**,1264(56),1265(10) CLK92/93 (CoM/APC): 1059(5),**1060(5)**,1065(5),**1066(5)**,1242(5),1243(5),1261(5), 1264(60),1265(15)
(DLR)	CLK20 (APC): 1059(5),**1060(5)** CLK21 (APC): 1059(10),**1060(10)**,**1066(10)**
ESA	CLK52/53 (CoM/APC): 1059(1815),**1060(5)**
GFZ	CLK70/71 (CoM/APC): **1060(5)**
GMV	CLK80/81 (CoM/APC): 1059(5),**1060(5)**,**1066(5)**
NR Can	CLK22 (APC): 1059(5),**1060(5)**
Wuhan	CLK15/16 (CoM/APC): 1059(5),**1060(5)**

GPS Orbits and Clocks

GLONASS Orbits and Clocks

Federal Agency for Cartography and Geodesy

IGS-RTS: Products

IGS INTERNATIONAL GNSS SERVICE

AC	Mountpoints with Message Types and Update Rates
BKG	CLK00/10 (CoM/APC): **1057(60),1058(5)** CLK01/11 (CoM/APC): **1057(60),1058(5)**,**1063(60),1064(5)**
CNES	CLK90/91 (CoM/APC): 1059(5),**1060(5)**,1065(5),**1066(5)**,1264(56),1265(10) CLK92/93 (CoM/APC): 1059(5),**1060(5)**,1065(5),**1066(5)**,1242(5),**1243(5)**,**1261(5)**, 1264(60),1265(15)
DLR	CLK20 (APC): 1059(5),**1060(5)** CLK21 (APC): 1059(10),**1060(10)**,**1066(10)**
ESA	CLK52/53 (CoM/APC): 1059(1815),**1060(5)**
GFZ	CLK70/71 (CoM/APC): **1060(5)**
GMV	CLK80/81 (CoM/APC): 1059(5),**1060(5)**,**1066(5)**
NR Can	CLK22 (APC): 1059(5),**1060(5)**
Wuhan	CLK15/16 (CoM/APC): 1059(5),**1060(5)**

GPS Orbits and Clocks

GLONASS Orbits and Clocks

Galileo Orbits and Clocks

BDS Orbits and Clocks

Federal Agency for Cartography and Geodesy

IGS-RTS: Products

AC	Mountpoints with Message Types and Update Rates
BKG	CLK00/10 (CoM/APC): **1057(60),1058(5)** CLK01/11 (CoM/APC): **1057(60),1058(5)**,**1063(60),1064(5)**
CNES	CLK90/91 (CoM/APC): **1059(5)**,**1060(5)**,**1065(5)**,**1066(5)**,**1264(56)**,**1265(10)** CLK92/93 (CoM/APC): **1059(5)**,**1060(5)**,**1065(5)**,**1066(5)**,**1242(5)**,**1243(5)**,**1261(5)**, **1264(60)**,**1265(15)**
DLR	CLK20 (APC): **1059(5)**,**1060(5)** CLK21 (APC): **1059(10)**,**1060(10)**,**1066(10)**
ESA	CLK52/53 (CoM/APC): **1059(1815)**,**1060(5)**
GFZ	CLK70/71 (CoM/APC): **1060(5)**
GMV	CLK80/81 (CoM/APC): **1059(5)**,**1060(5)**,**1066(5)**
NR Can	CLK22 (APC): **1059(5)**,**1060(5)**
Wuhan	CLK15/16 (CoM/APC): **1059(5)**,**1060(5)**

GPS Orbits and Clocks

GLONASS Orbits and Clocks

Galileo Orbits and Clocks

BDS Orbits and Clocks

CODE Biases

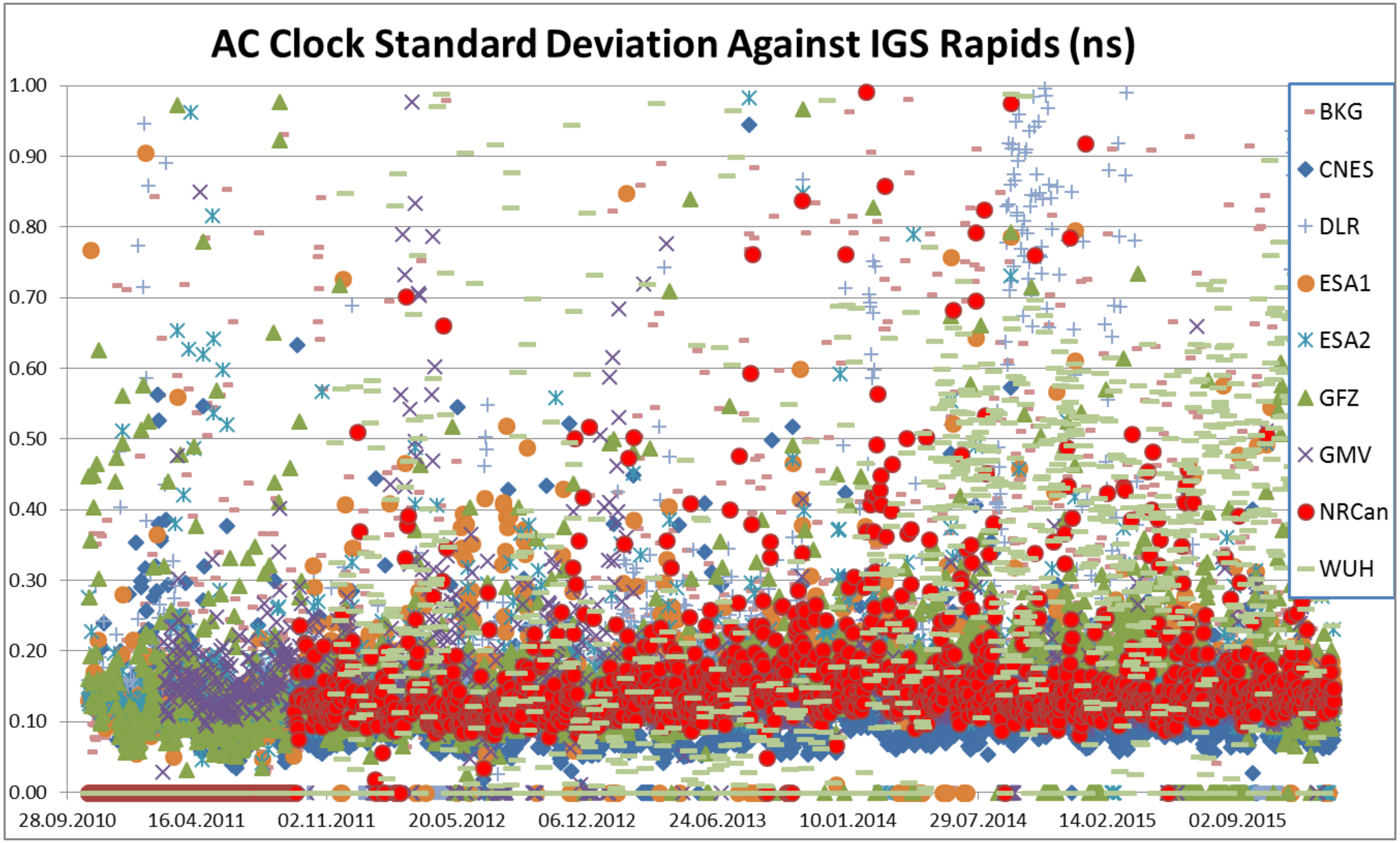
Phase Biases

VTEC

IGS RT Products

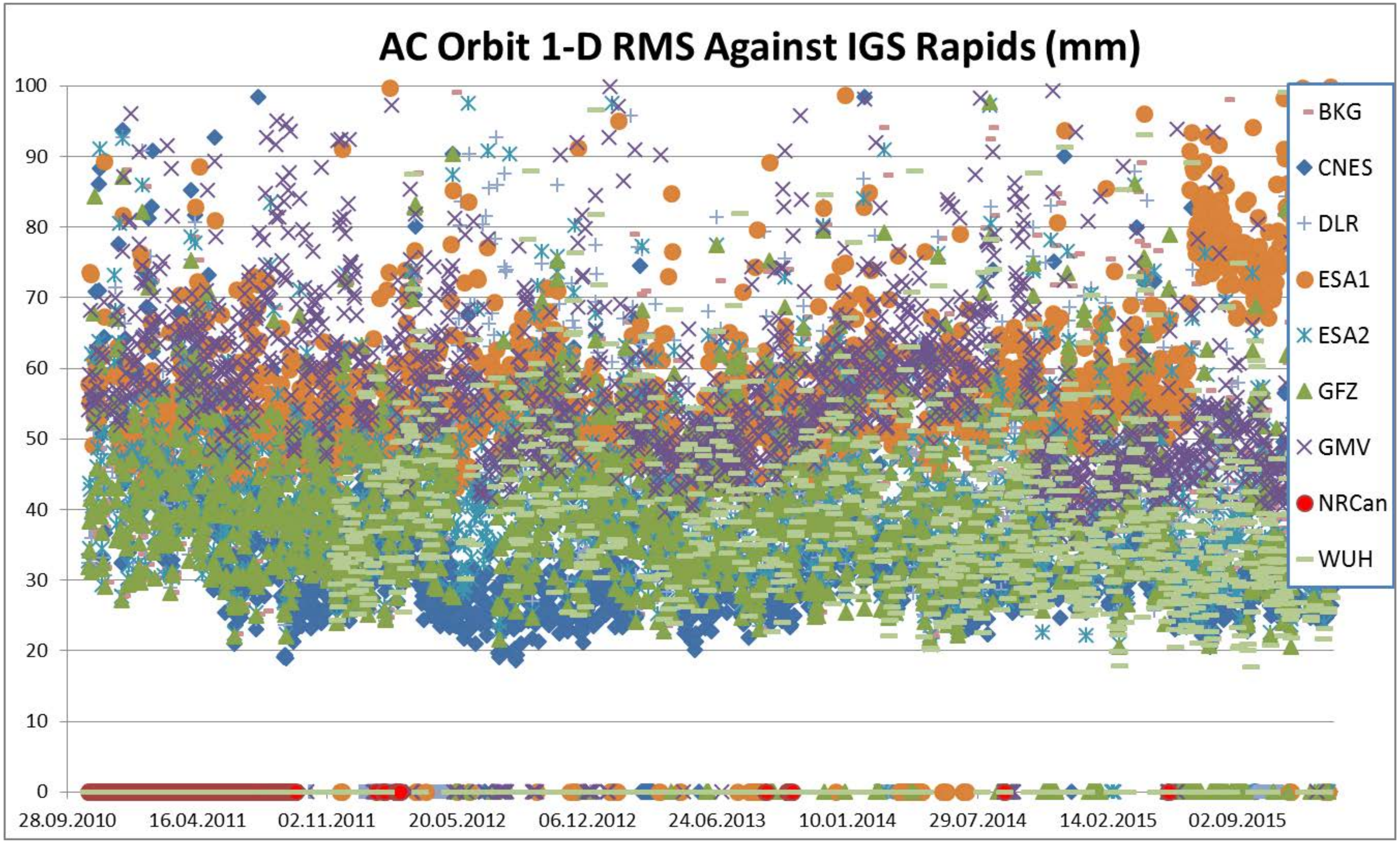
Stream	Description	RTCM-Messages	RP	CC/Soft-ware
IGS01 IGC01	GPS only orbit / clock correction, orbit: average value from all contributions clock: weighted average	1059(5),1060(5)	APC CoM	ESOC/ RETINA
IGS02 IGC02	GPS only orbit / clock correction, Kalman filter combination orbit: extracted from one specific AC clock: estimated using clocks from individual ACs as pseudo observations	1057(60), 1058(10), 1059(10)	APC CoM	BKG / BNC
IGS03 IGC03	GPS + GLONASS same procedure as for IGS02/IGC02	1057(60), 1058(10), 1059(10), 1063(60), 1064(10), 1065(10)	APC CoM	BKG / BNC

IGS RT Products Performance GPS - clocks



IGS RT Products Performance
GPS - Orbits

IGS INTERNATIONAL GNSS SERVICE



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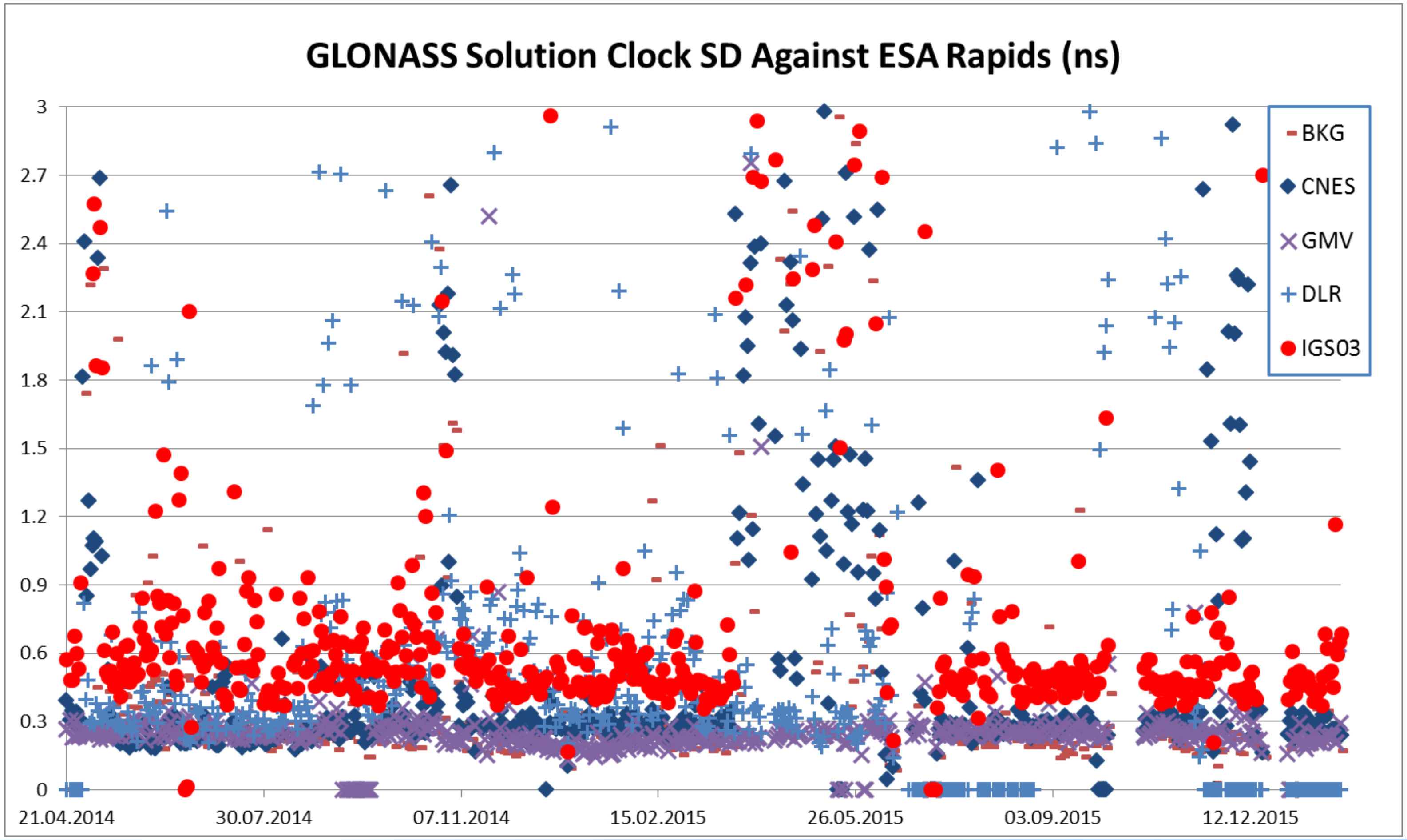
IGS RT Products Performance GLONASS - Clocks



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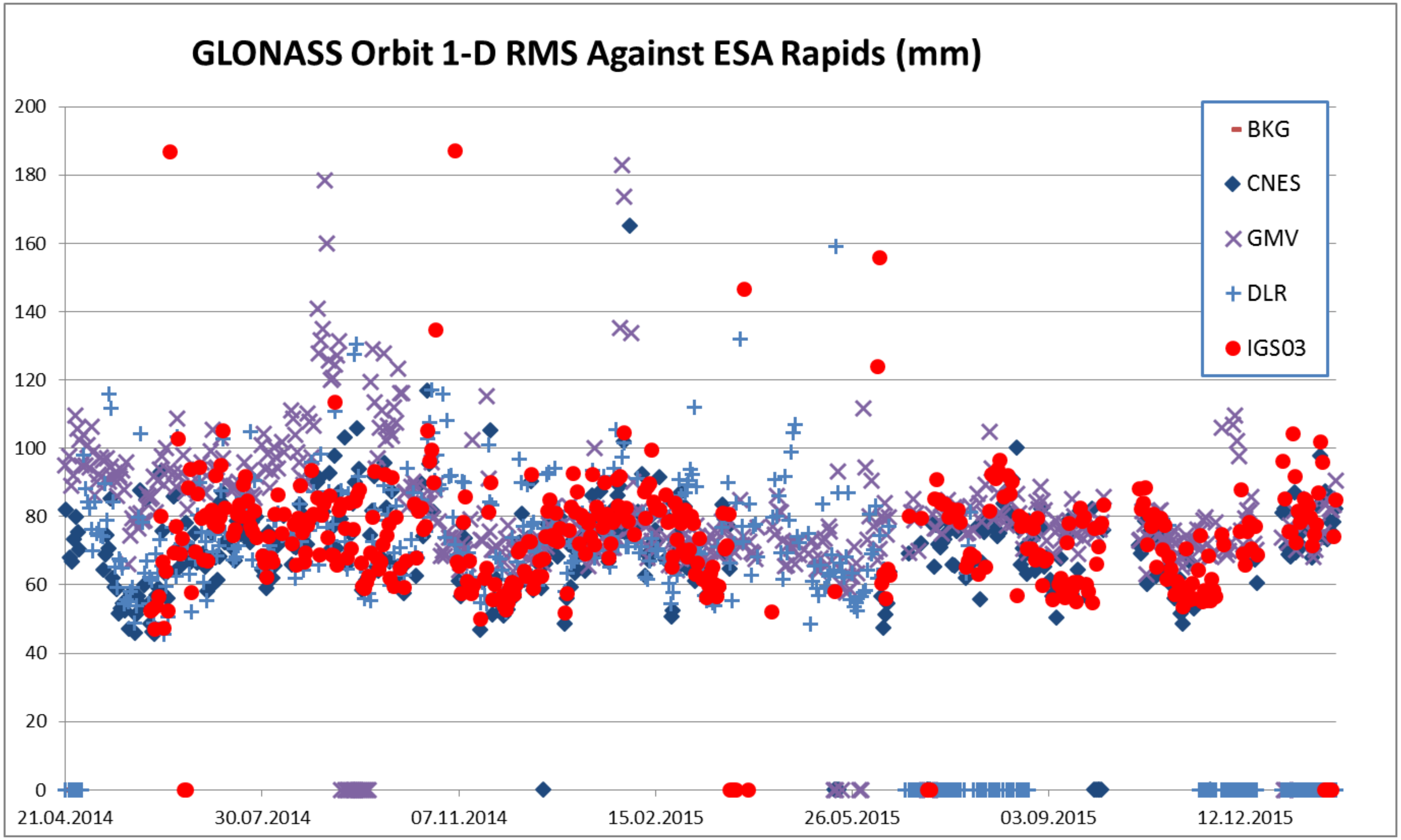
IGS RT Products Performance
GLONASS - Orbits

IGS INTERNATIONAL GNSS SERVICE



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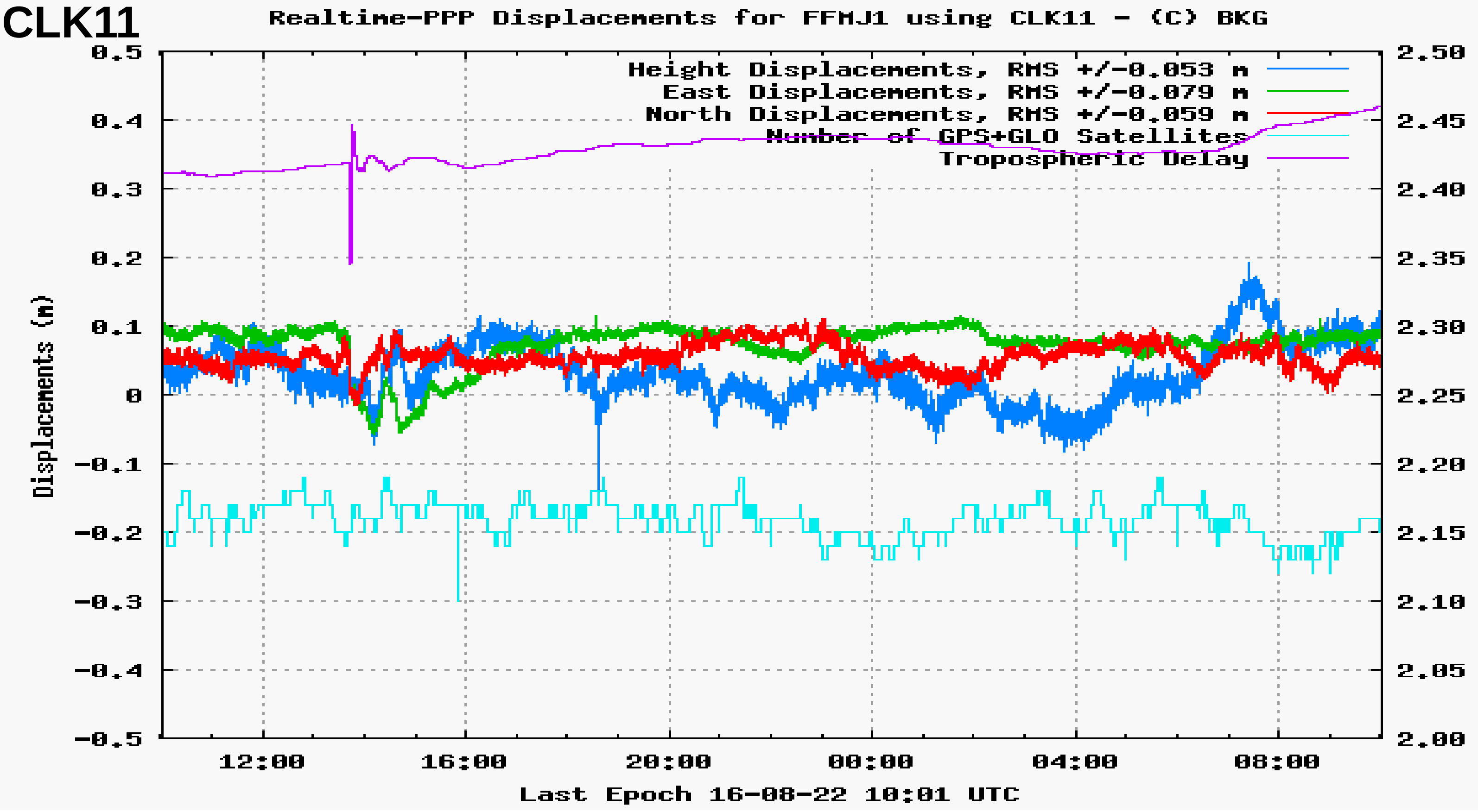
IGS RT Products Performance
PPP Products

CLK11



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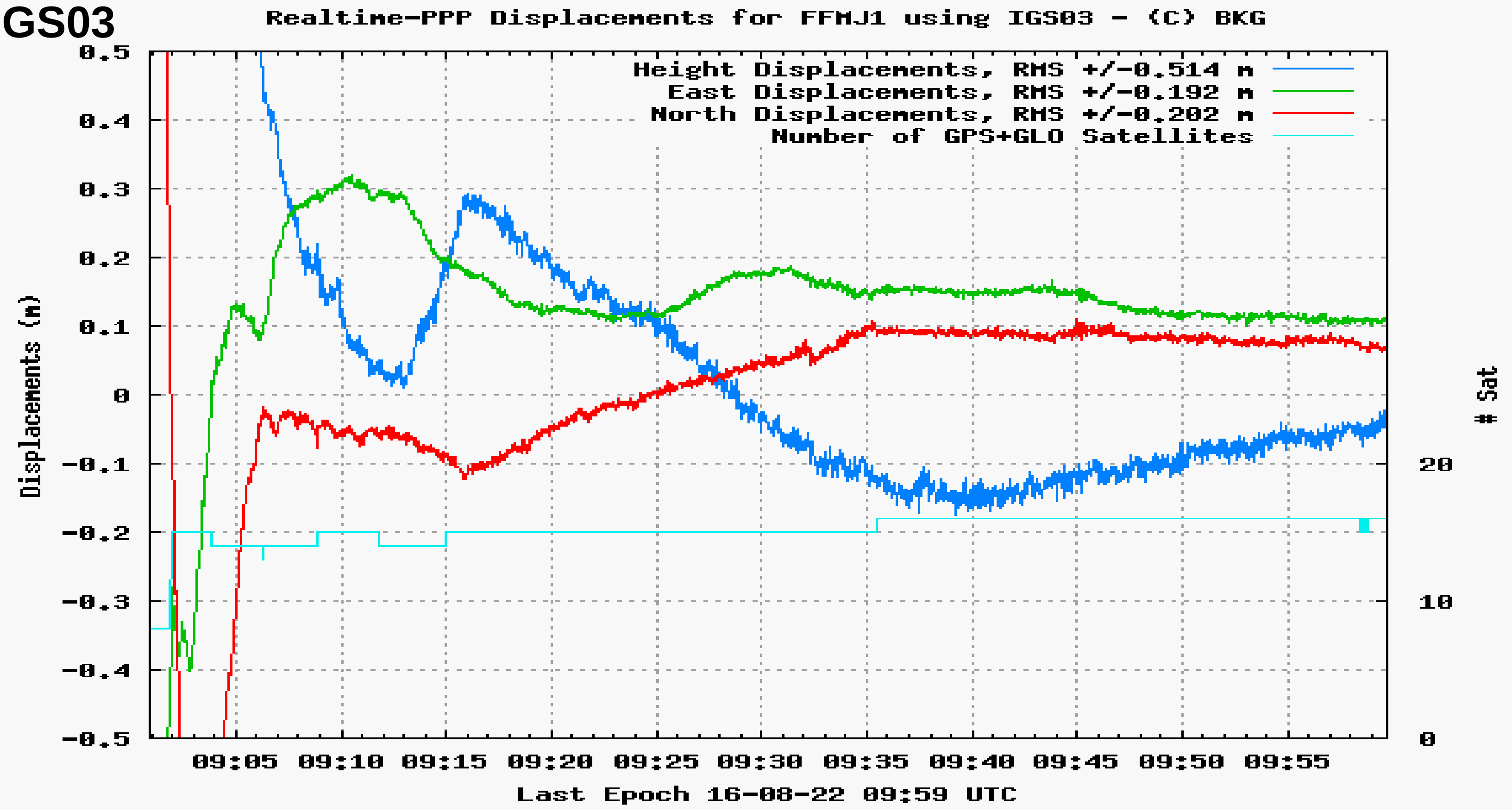
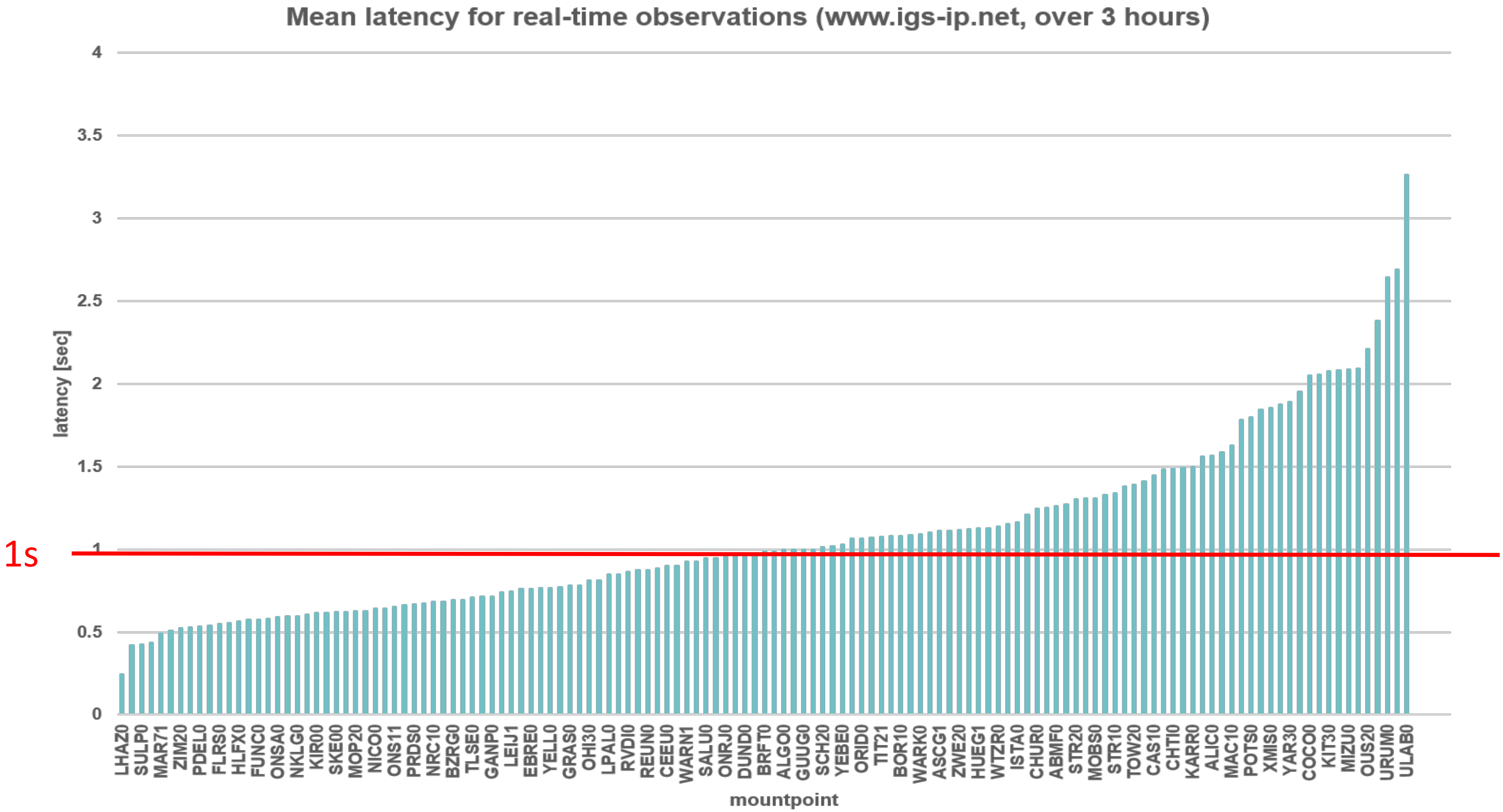
IGS RT Products Performance
PPP Results: Convergence Time

IGS03



IGS RT Products Performance
Latency Observations

IGS INTERNATIONAL GNSS SERVICE



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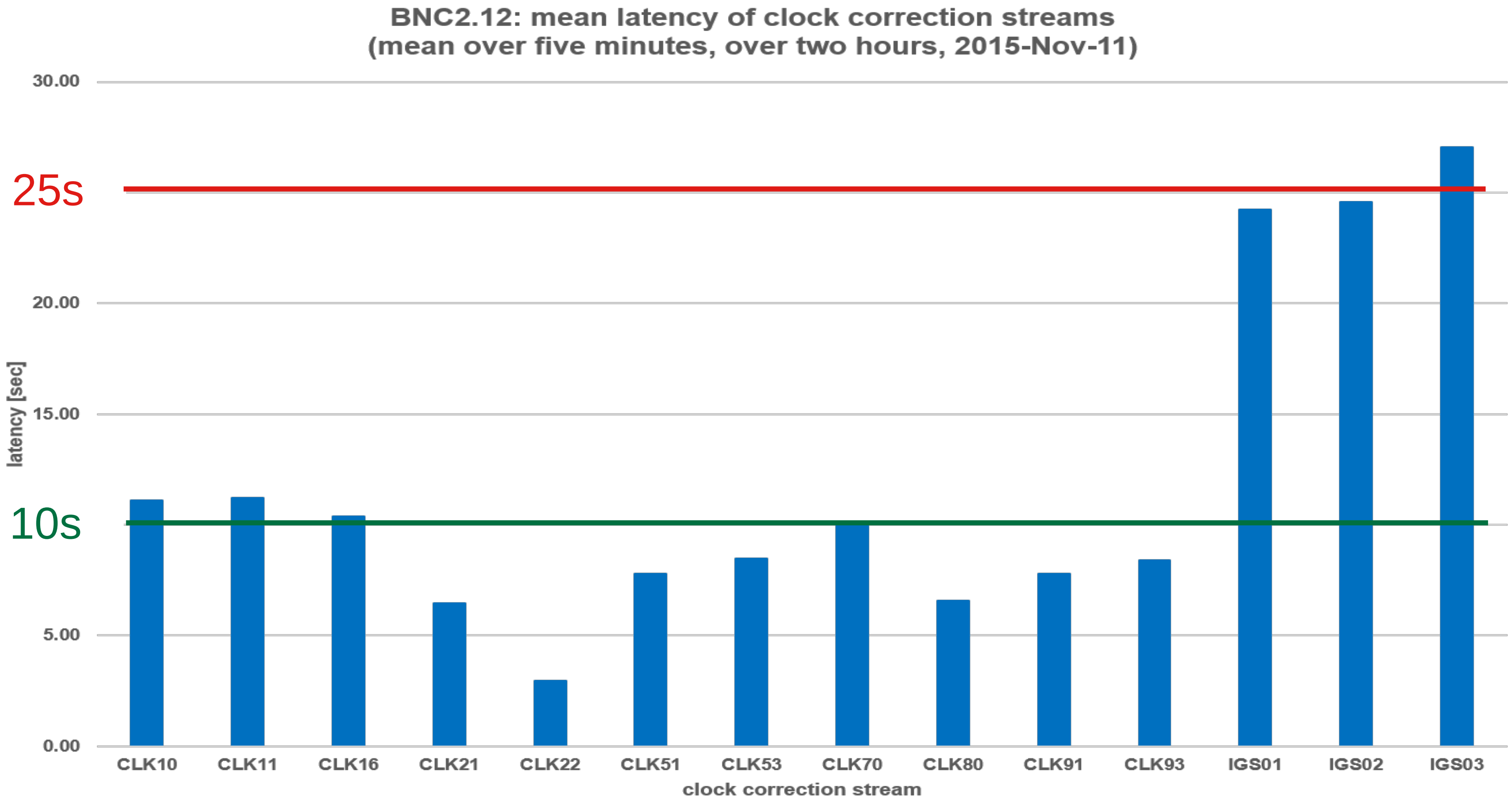
IGS RT Products Performance
Latency Correction data streams



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Outline

GNSS Real Time Infrastructure

GNSS Standardistation

Real Time Positioning with GNSS

Real Time Service at International GNSS Service

Example Application at Sea

Finalising Surveys for the Baltic Motorways of the Sea (FAMOS)

Question:
Where am I and how much water is underneath my ship?

To answer the question:
- Sea floor needs to be mapped
- Vessel vertical and horizontal position has to be known
- Reliable zero has to be defined
- All information must be easily available to the navigator.

Positioning requirement: +- 10 cm vertically at sea

Co-financed by the European Union
Connecting Europe Facility

SWEDISH MARITIME ADMINISTRATION
Bundesamt für Kartographie und Geodäsie
GFZ Helmholtz Centre Potsdam
NLS FINNISH GEOSPATIAL RESEARCH INSTITUTE FGI
DTU
Geodatastyrelsen Danish Geodata Agency
SSPA
SMHI
BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE
LANTMÄTERIET
TALLINN UNIVERSITY OF TECHNOLOGY
LIETUVOS SAUGIOS LAIVYBOS ADMINISTRACIJA
Liikennevirasto

Federal Agency for Cartography and Geodesy

DENEB cruise 2016

Two coactive VSAT-antennas

Foto: Gunter Liebsch

DENEB cruise 2016

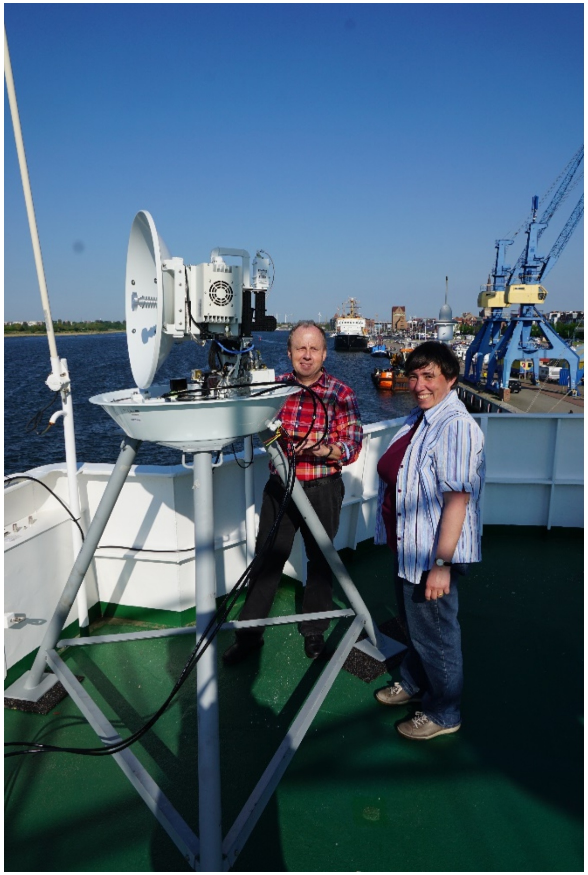
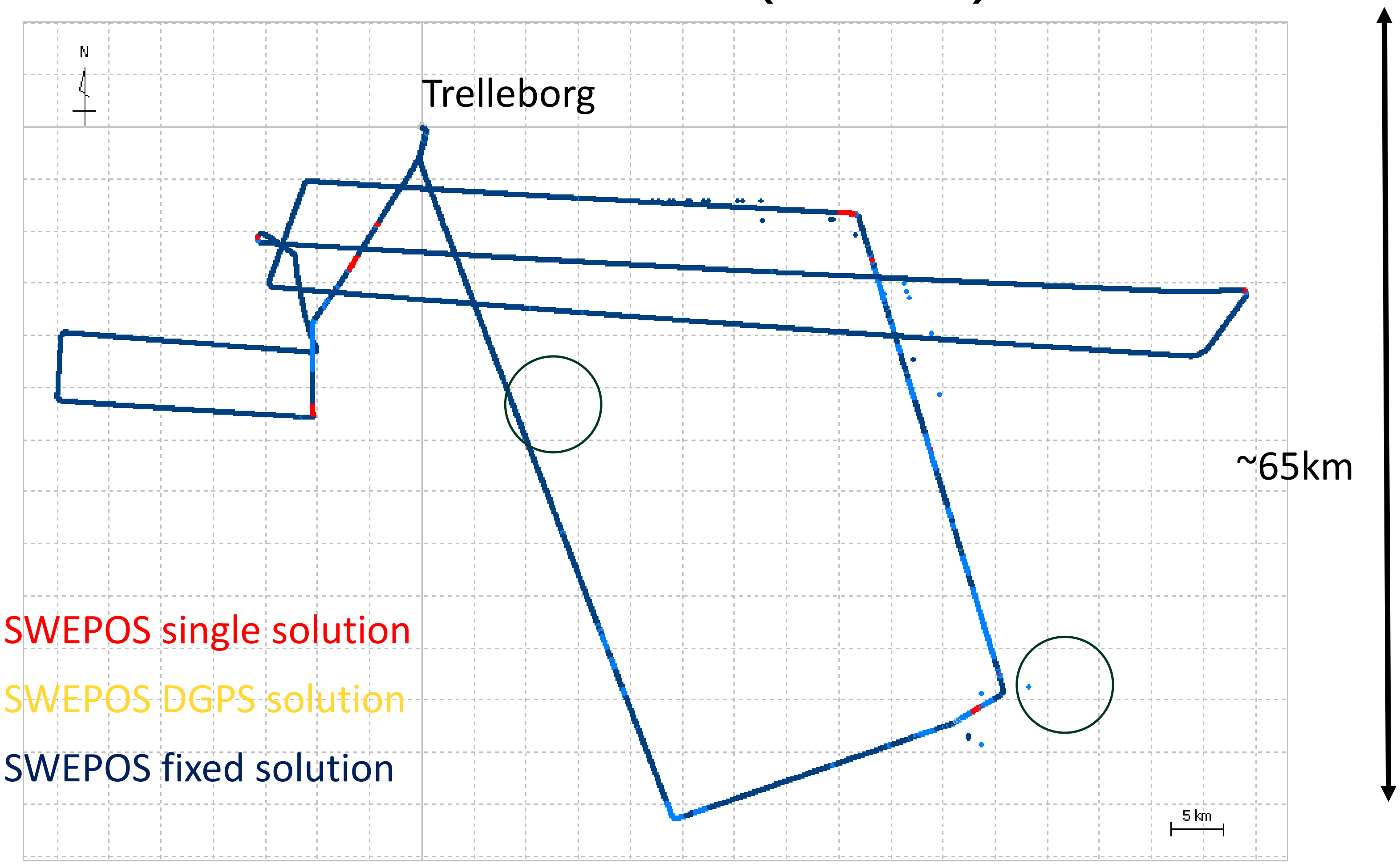


Foto: Gunter Liebsch

Foto: Gunter Liebsch

Very Preliminary results
SWEPOS/RTK vs. BNC/PPP (CLK11)



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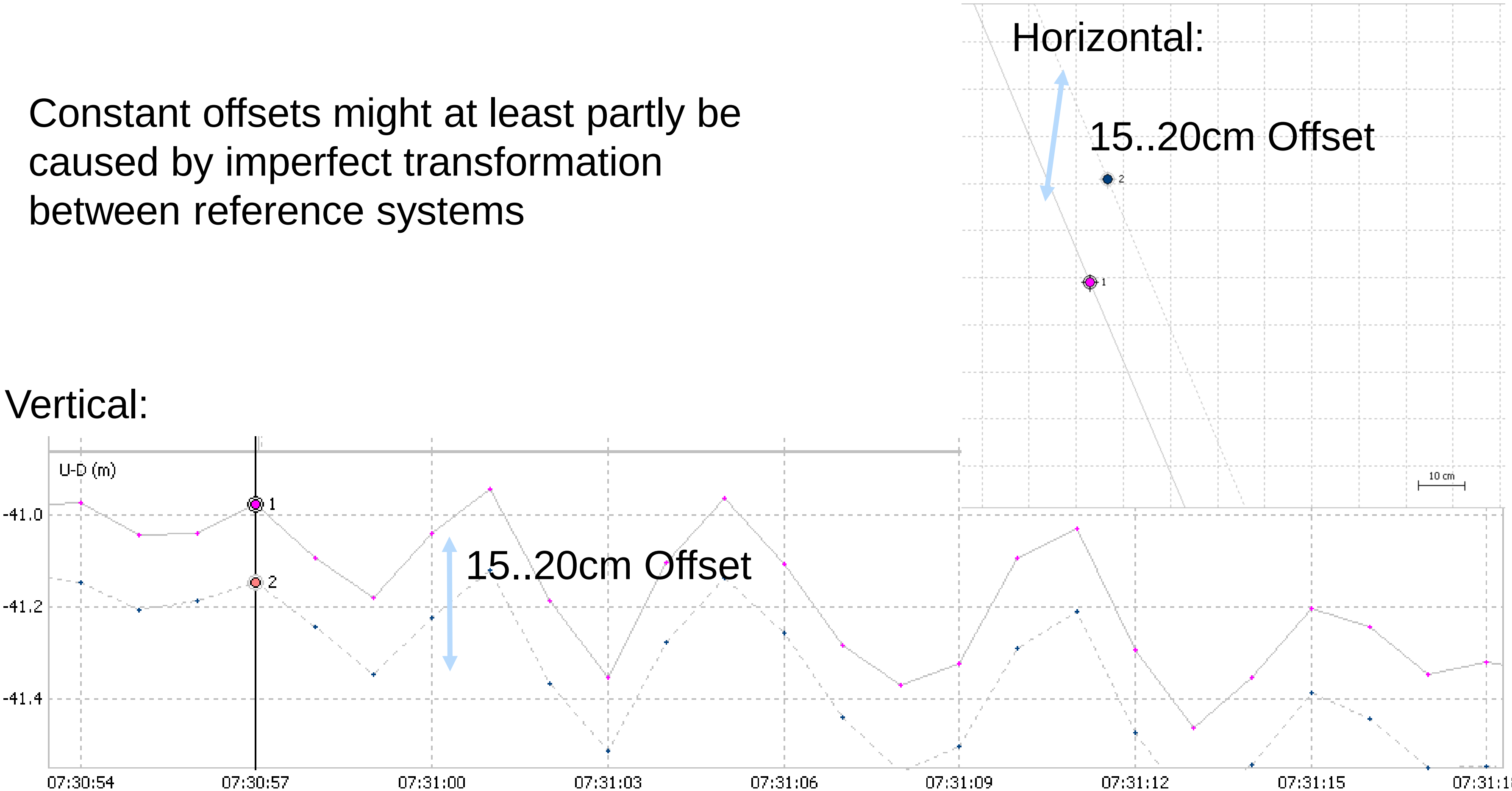
Cartography and Geodesy

Very Preliminary:
SWEPOS/RTK vs. BNC/PPP (CLK11)

Constant offsets might at least partly be caused by imperfect transformation between reference systems

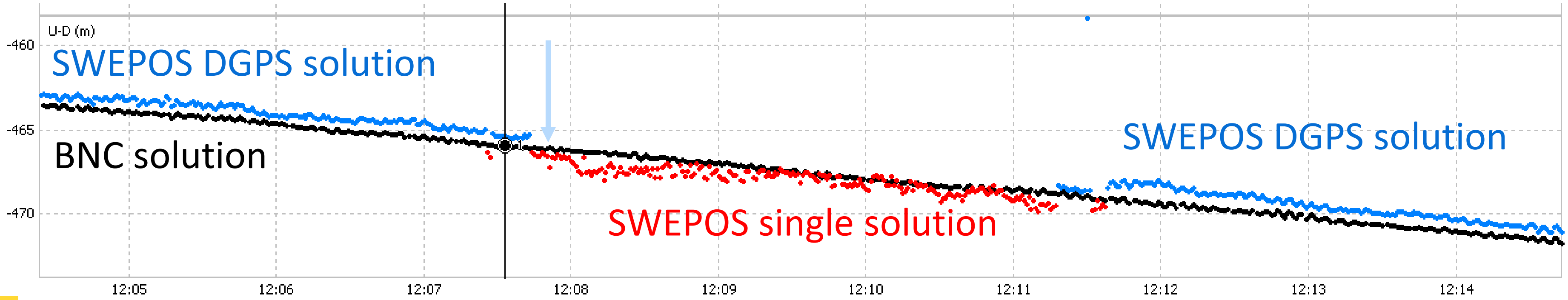
Horizontal:

Vertical:



Very Preliminary: SWEPOS/RTK vs. BNC/PPP (CLK11)

Vertical Component



1m drop of SWEPOS while solution changes from DGPS to SPP

approx. 10 minutes

… but there are other situations, where PPP/BNC behaves strange. This needs closer evaluation.

Thank you for your kind attention!

Contact:

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60598 Frankfurt, Germany

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