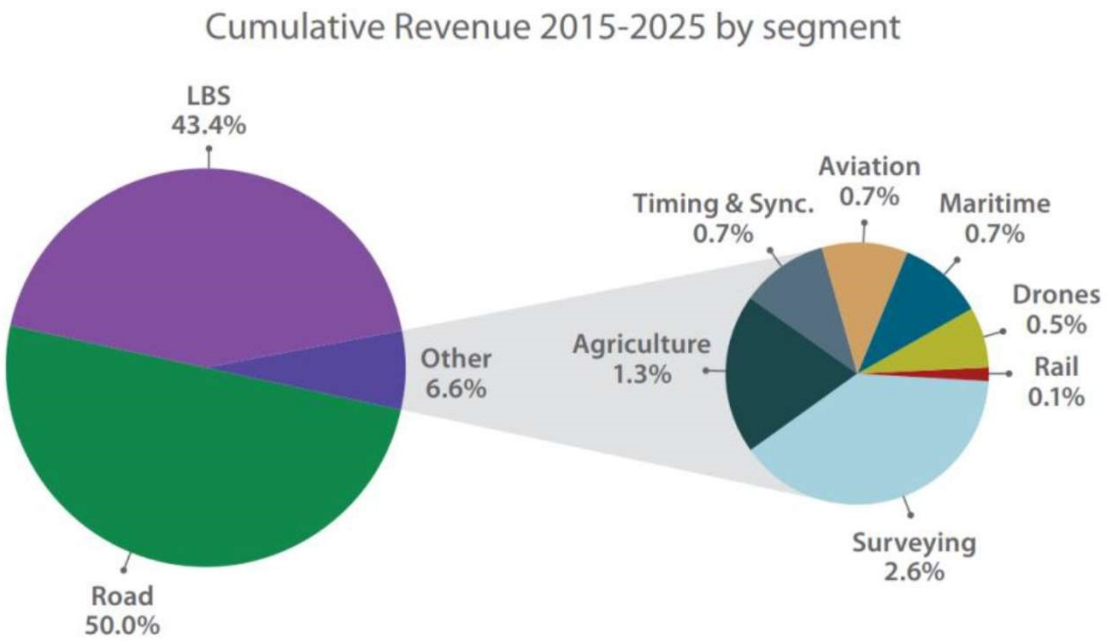
Geosoft OÜ

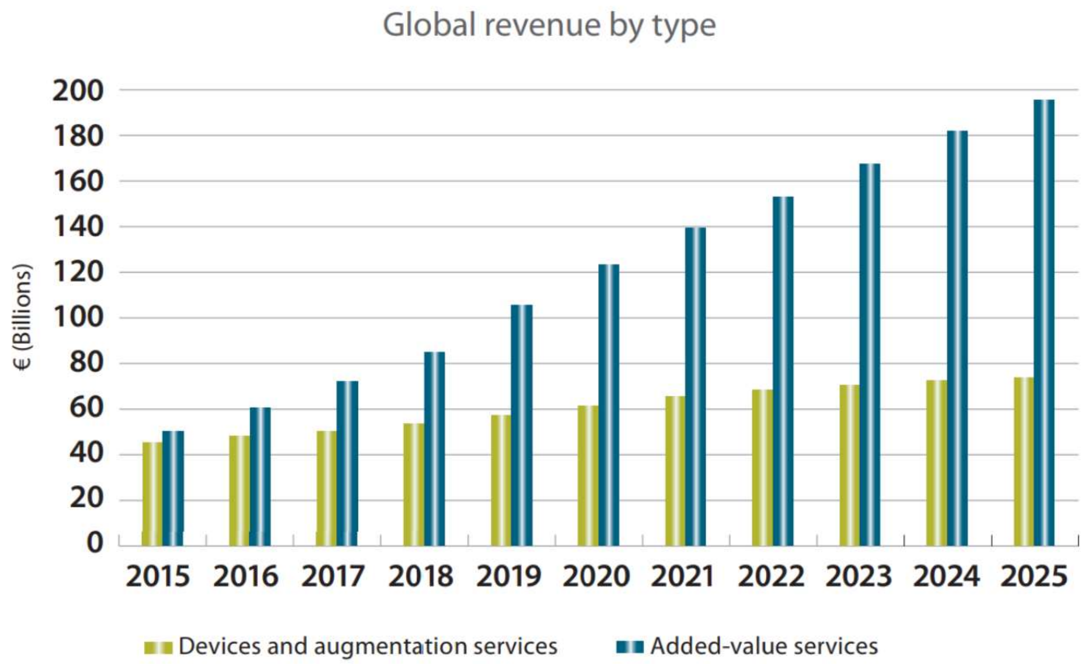
Hugo Toll

Riga, June 7-th, 2019

GNSS Applications

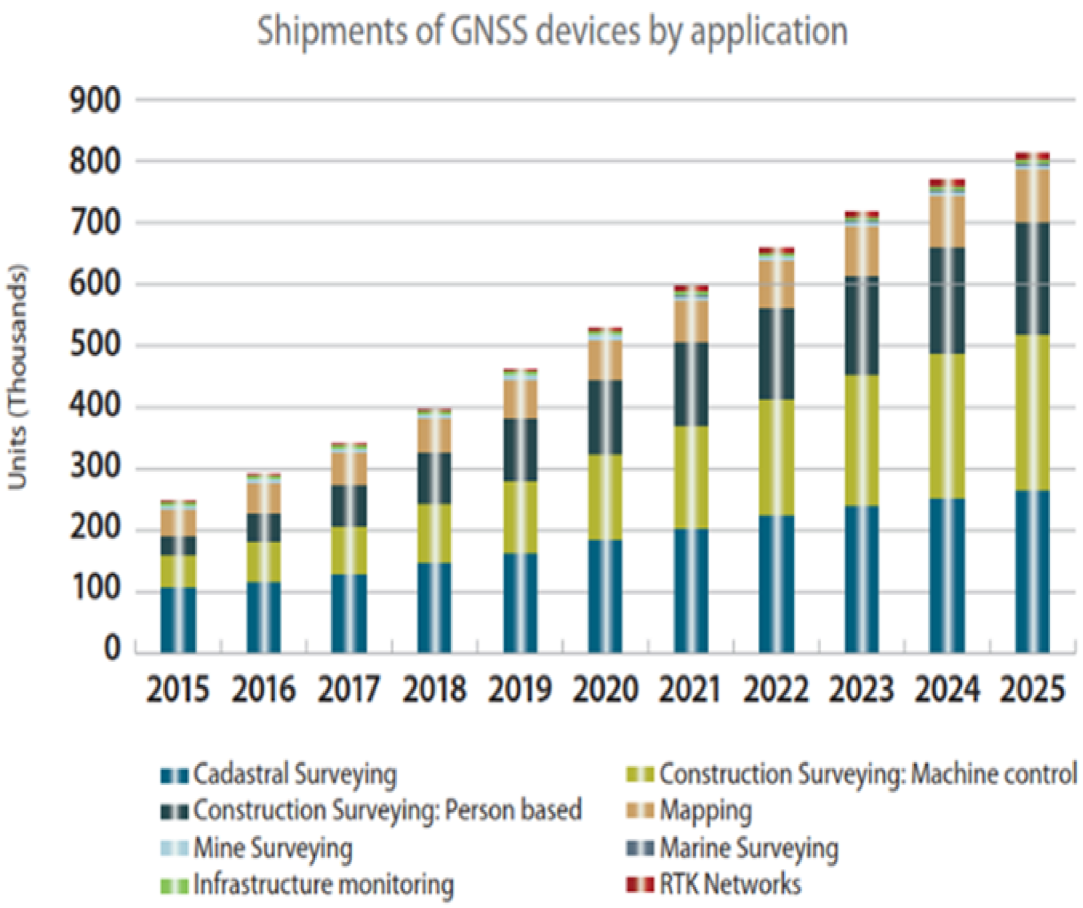
GNSS markets 2015-2025

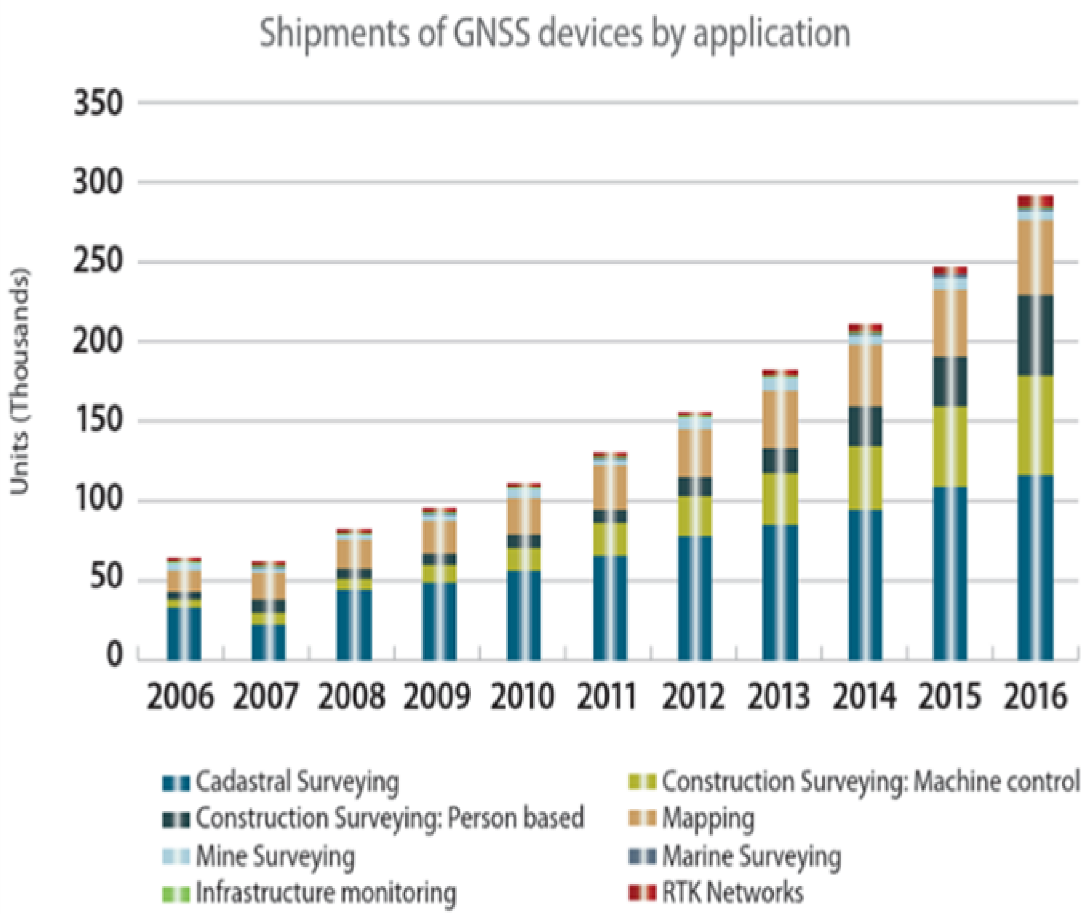




Data GSA Market Report 2017

GNSS Survey Markets





Data GSA Market Report 2017

Full constellation

	GPS	Glonass	QZSS	BeiDou	Galileo	Together
First launch	1978	1982	2010	2007	2011	
Fully operational	1995	2011	??	2020	2018	
Number of satellites	31	25	7	35	30	135
Current status	31 operational	24 operational 1 in flight test phase	2 operational 1 in test phase	15 operational 6 GEO 6 IGSO 3 MEO	15 operational 2 in test phase	87

https://www.gps.gov/systems/gps/space/

Satellite Signals in Network RTK in 1998

Table 3.5-91 GPS Signal ID mapping

Signal ID in Signal Mask (DF395)	Frequency Band	Signal	GPS signal RINEX code	Comments/Notes
1				Reserved
2	L1	C/A	1C	
3	L1	P	1P	
4	L1	Z-tracking or similar	1W	
5-7				Reserved
8	L2	C/A	2C	
9	L2	P	2P	
10	L2	Z-tracking or similar	2W	
11-14				Reserved
15	L2	L2C(M)	2S	
16	L2	L2C(L)	2L	
17	L2	L2C(M+L)	2X	
18-21				Reserved
22	L5	I	5I	
23	L5	Q	5Q	
24	L5	I+Q	5X	
25-29				Reserved
30	L1	L1C-D		
31	L1	L1C-P		
32	L1	L1C-(D+P)		

Satellite Signals Today

Table 3.5-91 GPS Signal ID mapping

Signal ID in Signal Mask (DF395)	Frequency Band	Signal
1		
2	L1	C/A
3	L1	P
4	L1	Z-tracking or similar
5-7		
8	L2	C/A
9	L2	P
10	L2	Z-tracking or similar
11-14		
15	L2	L2C(M)
16	L2	L2C(L)
17	L2	L2C(M+L)
18-21		
22	L5	I
23	L5	Q
24	L5	I+Q
25-29		
30	L1	L1C-D
31	L1	L1C-P
32	L1	L1C-(D+P)

Table 3.5-100 GALILEO Signal ID mapping

Signal ID in Signal Mask (DF395)	Frequency Band	Signal		
1				
2	E1	C no data		
3	E1	A		
4	E1	B I/NAV OS/CS/SoL		
5	E1	B+C		
6	E1	A+B+C		
7				
8	E6	C		
9	E6	A		
10	E6	B		
11	E6	B+C		
12	E6	A+B+C		
13				
14	E5B	I		
15	E5B	Q		
16	E5B	I+Q		
17				
18	E5(A+B)	I	8I	
19	E5(A+B)	Q	8Q	
20	E5(A+B)	I+Q	8X	
21				Reserved
22	E5A	I	5I	
23	E5A	Q	5Q	
24	E5A	I+Q	5X	
25–32				Reserved

Table 3.5-108 BeiDou Signal ID Mapping

Signal ID in Signal Mask (DF395)	Frequency Band	Signal
1		
2	B1	I
3	B1	Q
4	B1	I+Q
5-7		
8	B3	I
9	B3	Q
10	B3	I+Q
11-13		
14	B2	I
15	B2	Q
16	B2	I+Q
17-32		

Table 3.5-105 QZSS Signal ID Mapping

Signal ID in Signal Mask (DF395)	Frequency Band	Signal
1		
2	L1	C/A
3-8		
9	LEX	S
10	LEX	L
11	LEX	S+L
12-14		
15	L2	L2C(M)
16	L2	L2C(L)
17	L2	L2C(M+L)
18-21		
22	L5	I
23	L5	Q
24	L5	I+Q
25-29		
30	L1	L1C(D)
31	L1	L1C(P)
32	L1	L1C(D+P)

Table 3.5-97 GLONASS Signal I

Signal ID in Signal Mask (DF395)	Frequency Band	Signal	GLONASS signal RINEX code
1			
2	G1	C/A	1C
3	G1	P	1P
4-7			
8	G2	C/A	2C
9	G2	P	2P
10-32			

Table 3.5-109. IRNSS Signal ID

Signal ID in Signal Mask (DF395)	Frequency Band	Signal	IRNSS signal RINEX code
1..7			
8	S	A SPS	9A
9	S	B RS (D)	9B
10	S	C RS (P)	9C
11	S	B+C	9X
12-21			
22	L5	A SPS	5A
23	L5	B RS (D)	5B
24	L5	C RS (P)	5C
25	L5	B+C	5X
26-32			

Even more signals will come for GLONASS (CDMA) and BeiDou

Galileo Tracking

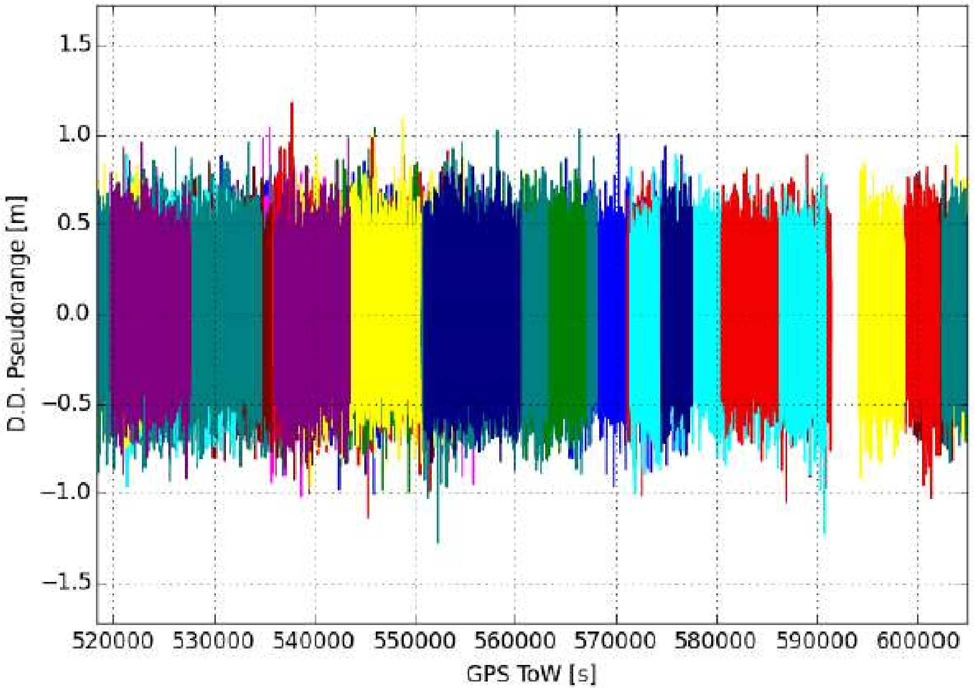
Table 3.5-100 GALILEO Signal ID mapping

Signal ID in Signal Mask (DF395)	Frequency Band	Signal	GALILEO signal RINEX code	Comments/Notes
1				Reserved
2	E1	C no data	1C	
3	E1	A	1A	
4	E1	B I/NAV OS/CS/SoL	1B	
5	E1	B+C	1X	
6	E1	A+B+C	1Z	
7				Reserved
8	E6	C	6C	
9	E6	A	6A	
10	E6	B	6B	
11	E6	B+C	6X	
12	E6	A+B+C	6Z	
13				Reserved
14	E5B	I	7I	
15	E5B	Q	7Q	
16	E5B	I+Q	7X	
17				Reserved
18	E5(A+B)	I	8I	
19	E5(A+B)	Q	8Q	
20	E5(A+B)	I+Q	8X	
21				Reserved
22	E5A	I	5I	
23	E5A	Q	5Q	
24	E5A	I+Q	5X	
25–32				Reserved

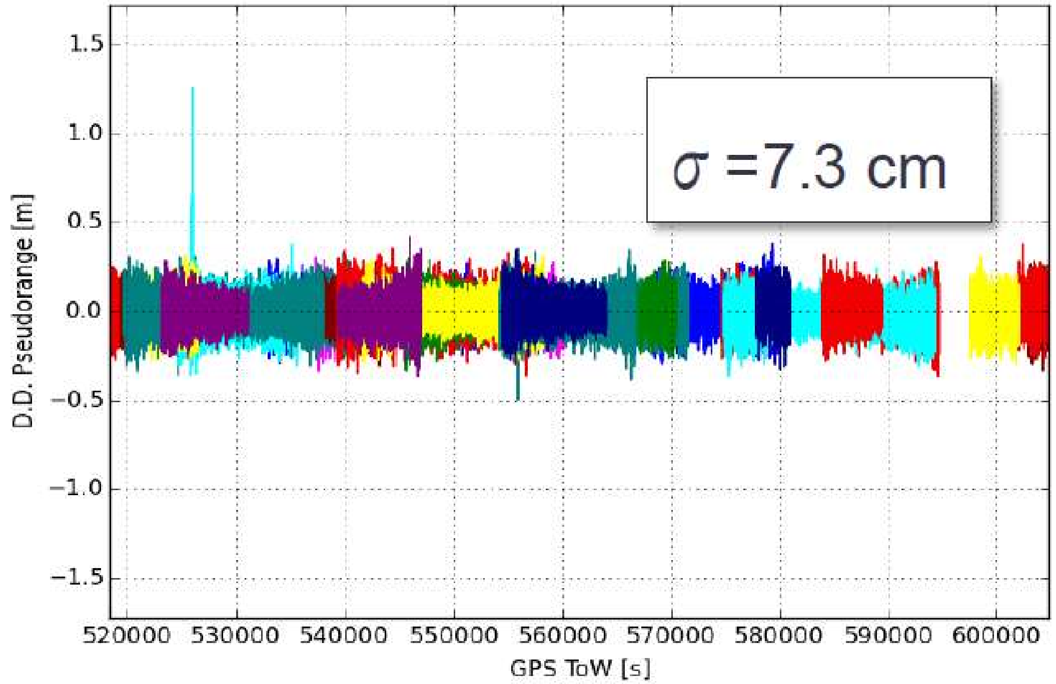
- Pilot and Data signals
- Combined signals are best performing
- AltBOC vs. separate E5A and E5B tracking

Noise on Pseudoranges on GPS L5

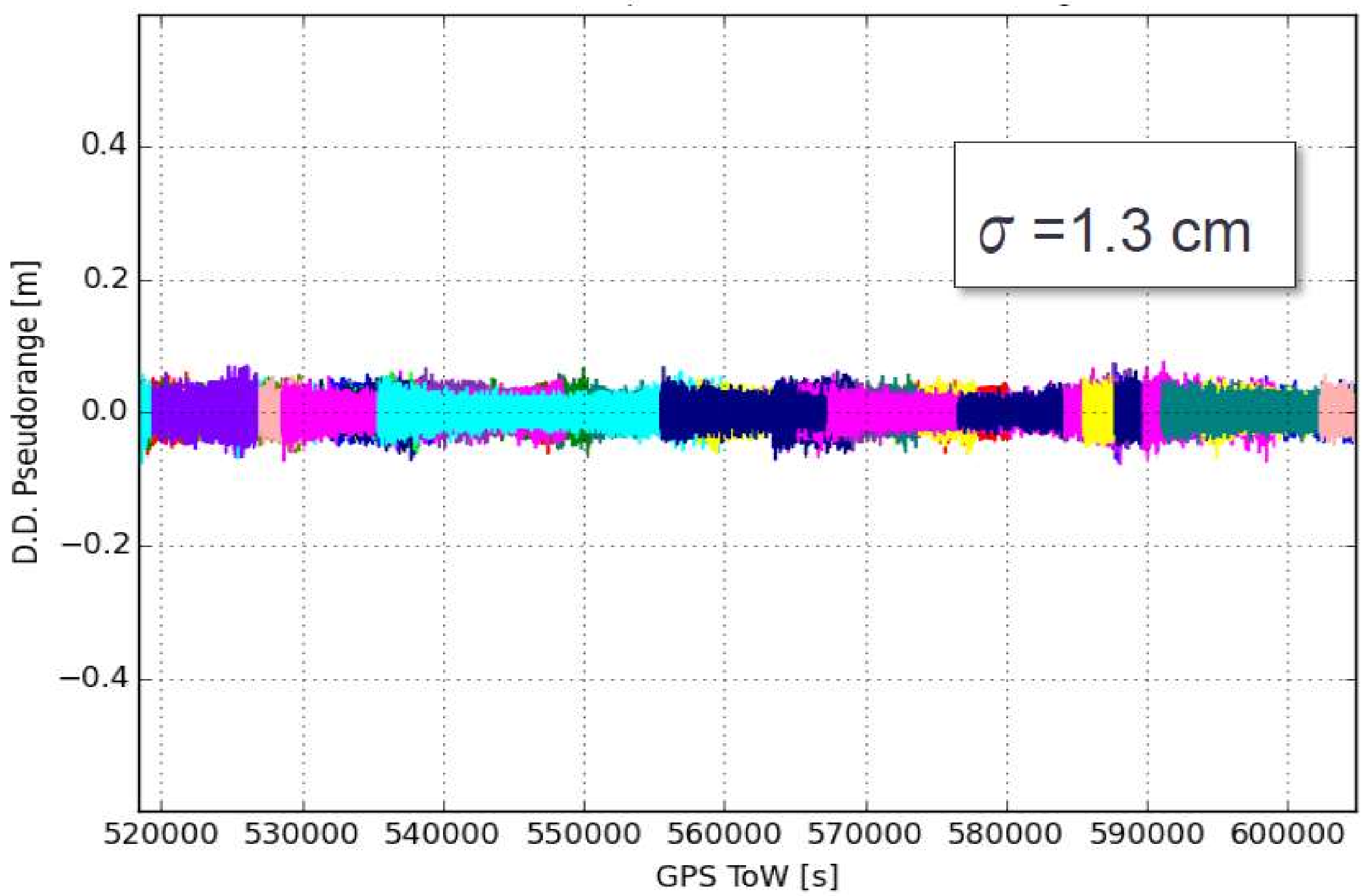
C/A L1



GPS L5

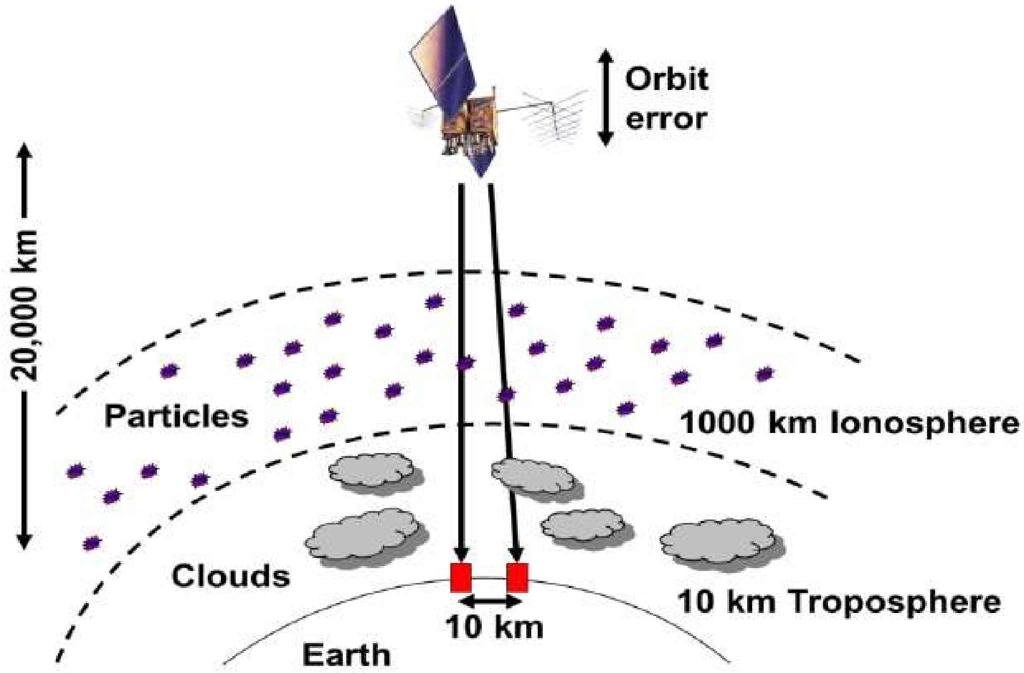


Noise on Pseudoranges on Galileo E5 AltBOC



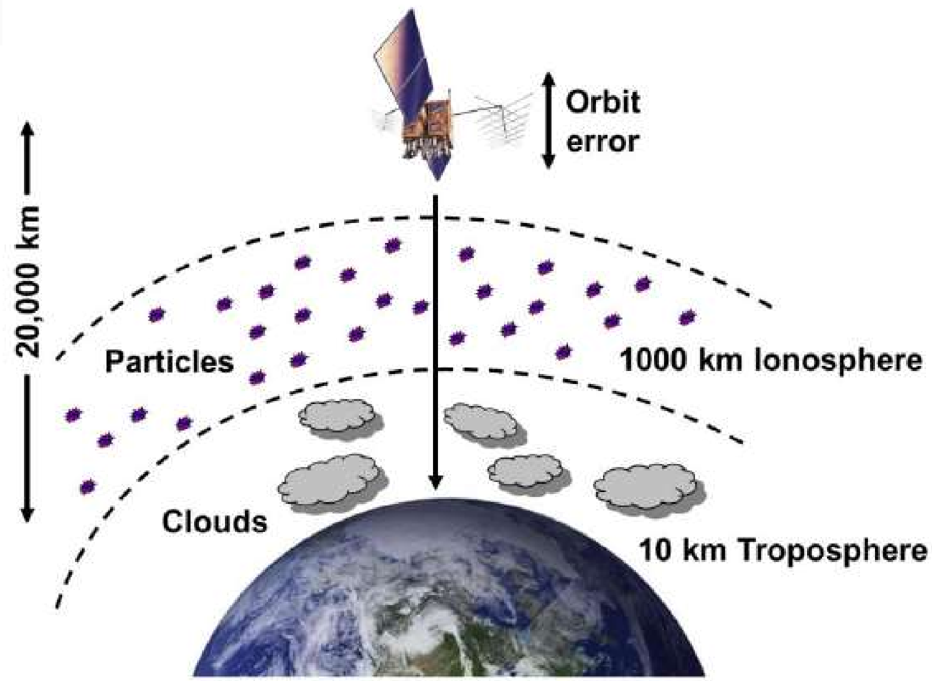
- Importance of pseudoranges increases in RTK and network RTK
- Pseudorange biases need to be handled properly

Differential GNSS (e.g. RTK)



Errors	Effect on Position
Satellite Position (orbit)	< 1 ppm = 10 mm on 10 km
Satellite clock	None (cancels out)
Atmosphere model errors	~1 ppm

Introducing RTX Technology



Errors	Effect on Position
Satellite orbit	~ 1 cm
Satellite clock	~ < 1 cm
Ionosphere	Iono-free combination L1/L2
Troposphere	estimated < 10 cm (height)

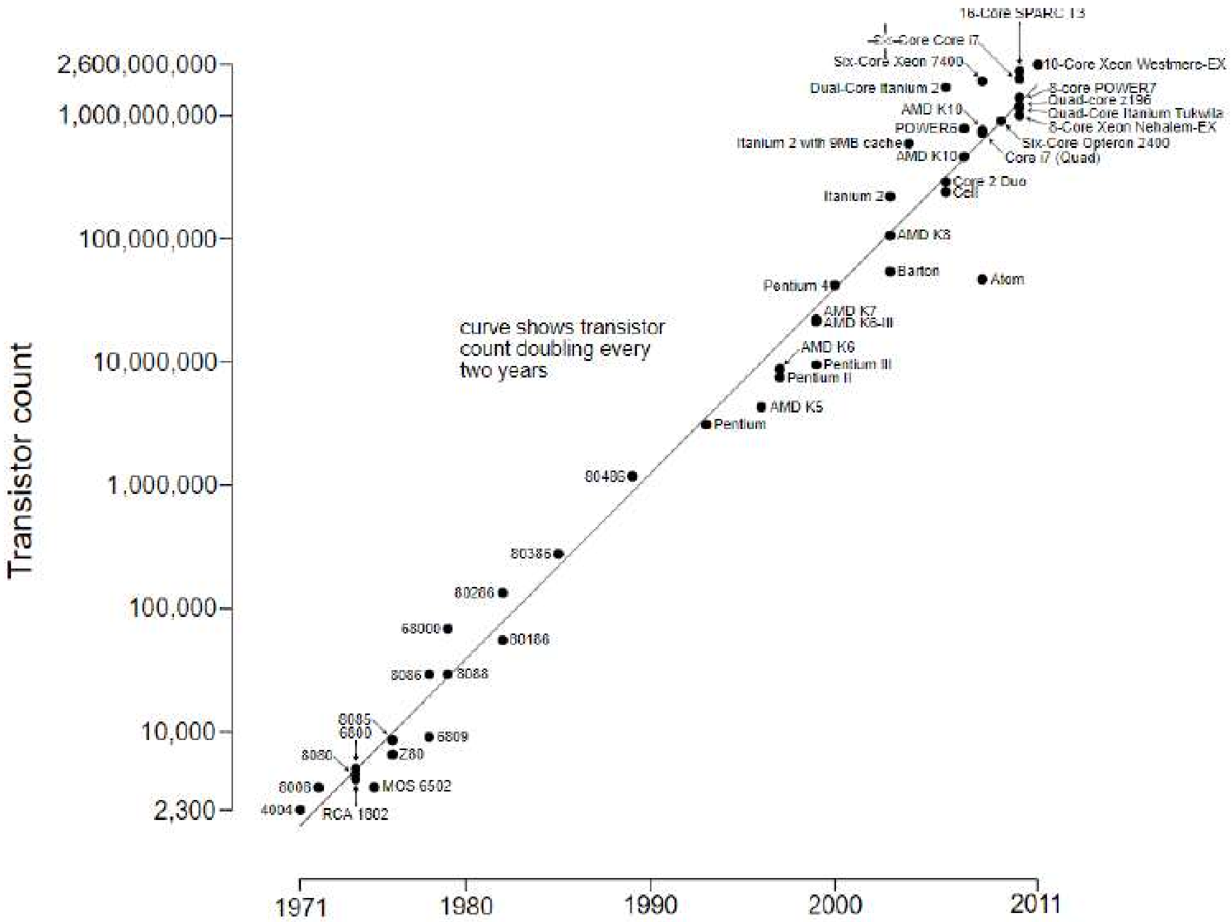
Problem: CPU Increase in RTN Server

- Increase of satellites and signals
- More stations desired in larger networks
- Leads to an increase in unknowns in Least Squares Estimation

Year	Constellation	Stations	Sats	Signals	Unknowns	CPU Scale Factor	Reduced CPU by RTX
1998	GPS	100	8	2	1700	1	1×10^{-4}
2005	GPS+GLN	100	20	2	4300	14	14×10^{-4}
2017	All (EU)	100	40	3	12100	361	3.61×10^{-2}
2017	All (APAC)	100	50	3	15100	693	6.93×10^{-2}
2020	All	500	50	4	100500	207158	8.21

- One way of handling CPU load is to introduce absolute positioning and ambiguity resolution instead of differential.

Moore‘s Law on Microprocessor Count



- Number of transistors in an Integrated Circuit is doubled approximately every two years
- 10 nm is the current distance between transistors
- Natural limit: the size of an atom?

Decentralization of processing with RTX

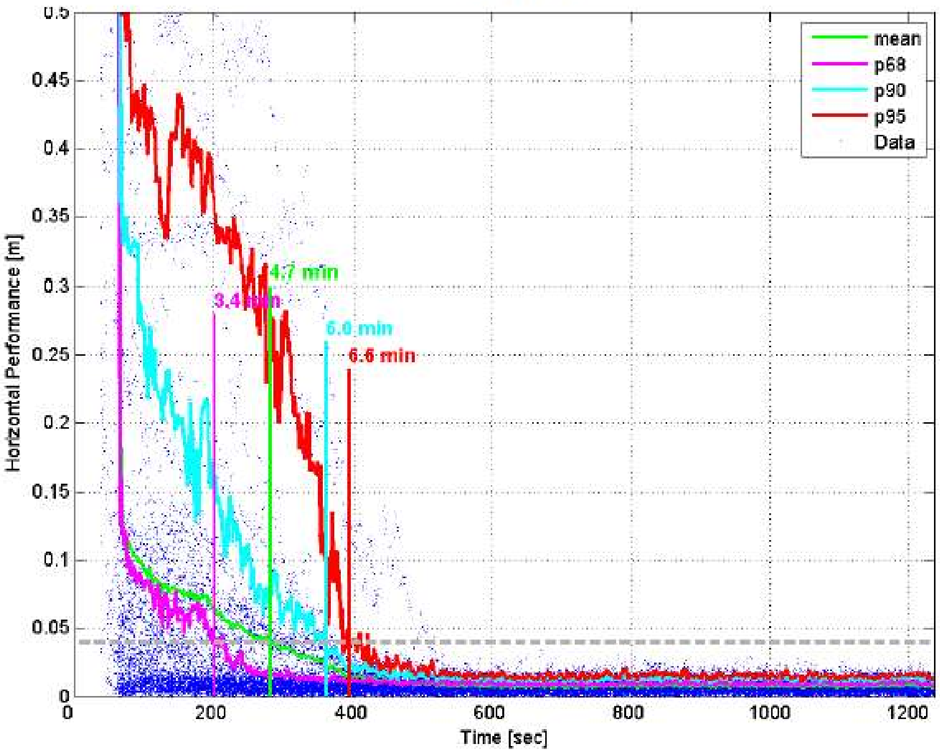
- RTX runs on one station and solves
  - all carrier phase ambiguities
  - all visible signals
- No interdependency between stations
- Scalable with the number of satellites
  - (immune against tracking of different signals, “sparse GNSS”)
- Computation distributable to various PCs and the Cloud

Why RTX

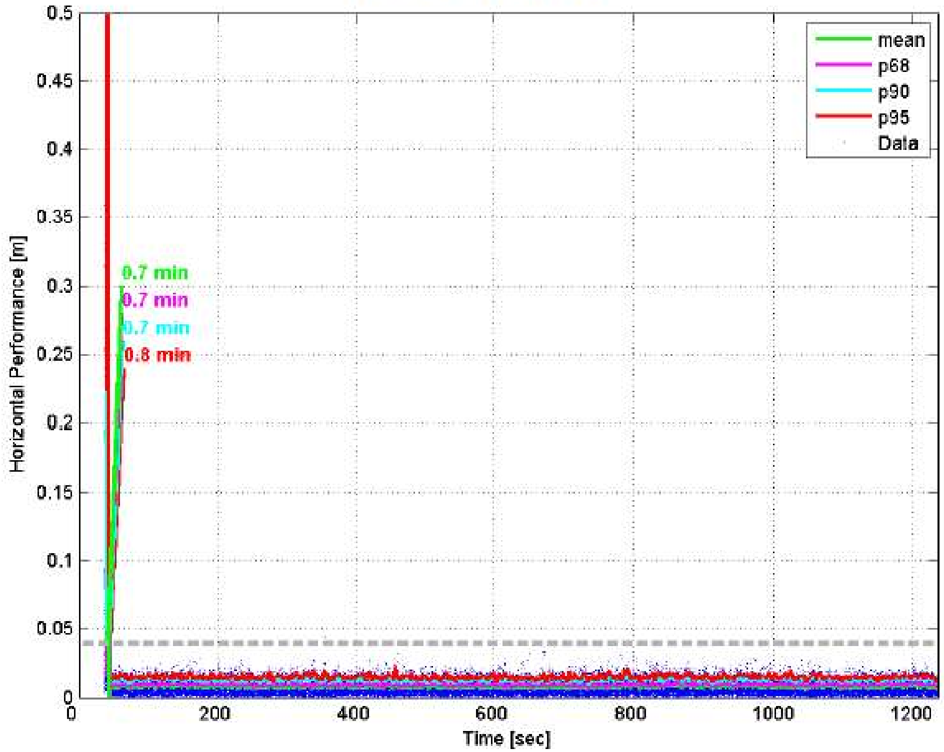
- What if we had a
- –satellite position and clock information accurate to one centimeter?
- –service with all satellite systems and signals (GPS,GLO,GAL,BDS,QZSS including third frequencies)?
- –system reliably computing absolute ambiguities?
- –correction, which would provide a very high integrity level of 10-6per hour (equivalent to one error in 120 years)?
- –availability of RTX: >99.999% (measured over the past years equivalent to 5.25 minutes downtime per year)?
- –server, which processes >500 stations on a single server PC?

Horizontal RTX and RTX-Fast (October 1, 2017)

RTX

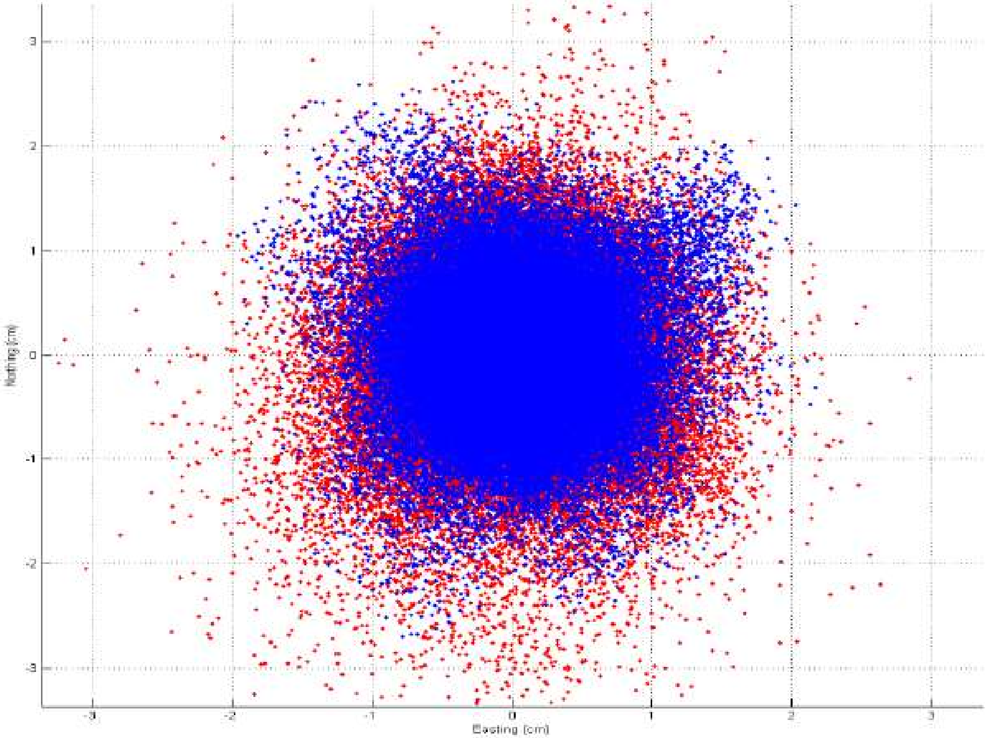


RTX-Fast



Typical Performance of VRS vs. RTX-Fast

- VRS (1.5 cm 95%)
- RTX (1.8 cm 95%)



- RTX-Fast can serve as a backup for VRS
- Major differences caused by station spacing
- VRS is superior in height
- RTX is working in ITRF or in e.g. ETRF89 (14 parameter transformation)

Baseline – post processing or RTK

GNSS errors at the rover

GNSS errors for the reference station

Residual errors in differential GNSS

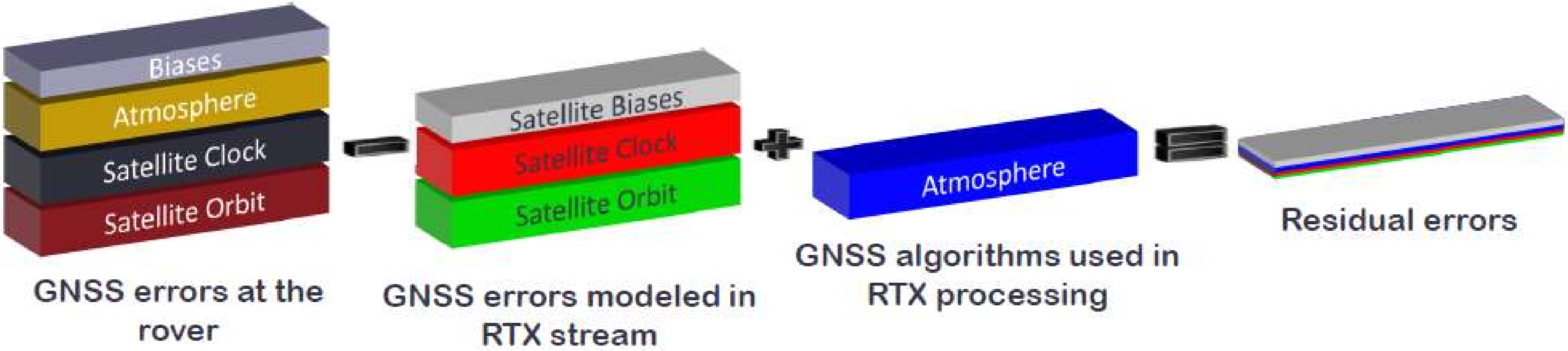
Network support - VRS

GNSS errors at the rover

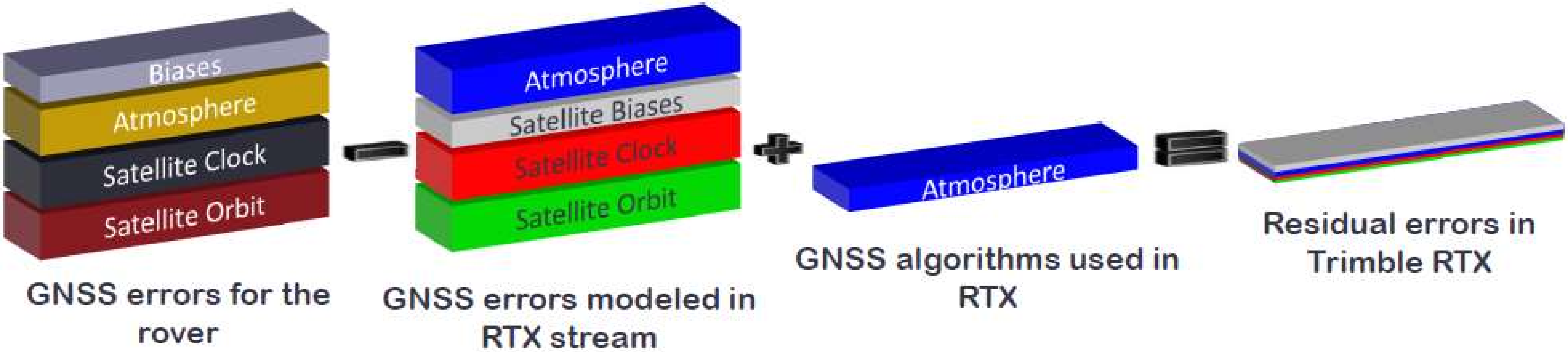
GNSS errors for the VRS

Residual errors in differential GNSS

Precise Point Positioning - RTX



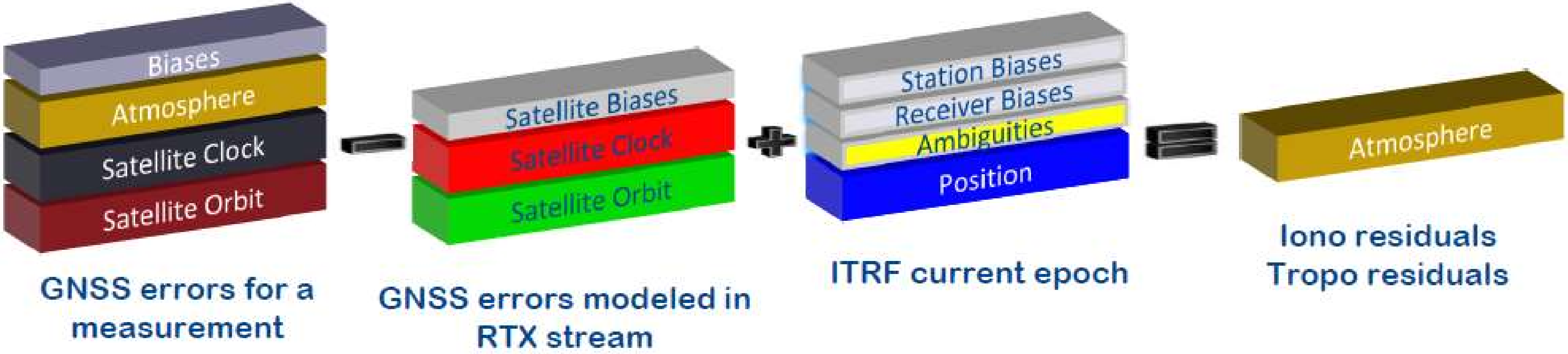
Precise Point Positioning – RTX-Fast



Network Processor - RTKNet

- Disadvantages
  - Relative processing
  - Errors distributed across the network
  - High demand on memory and processing power
  - ...

RTXNet



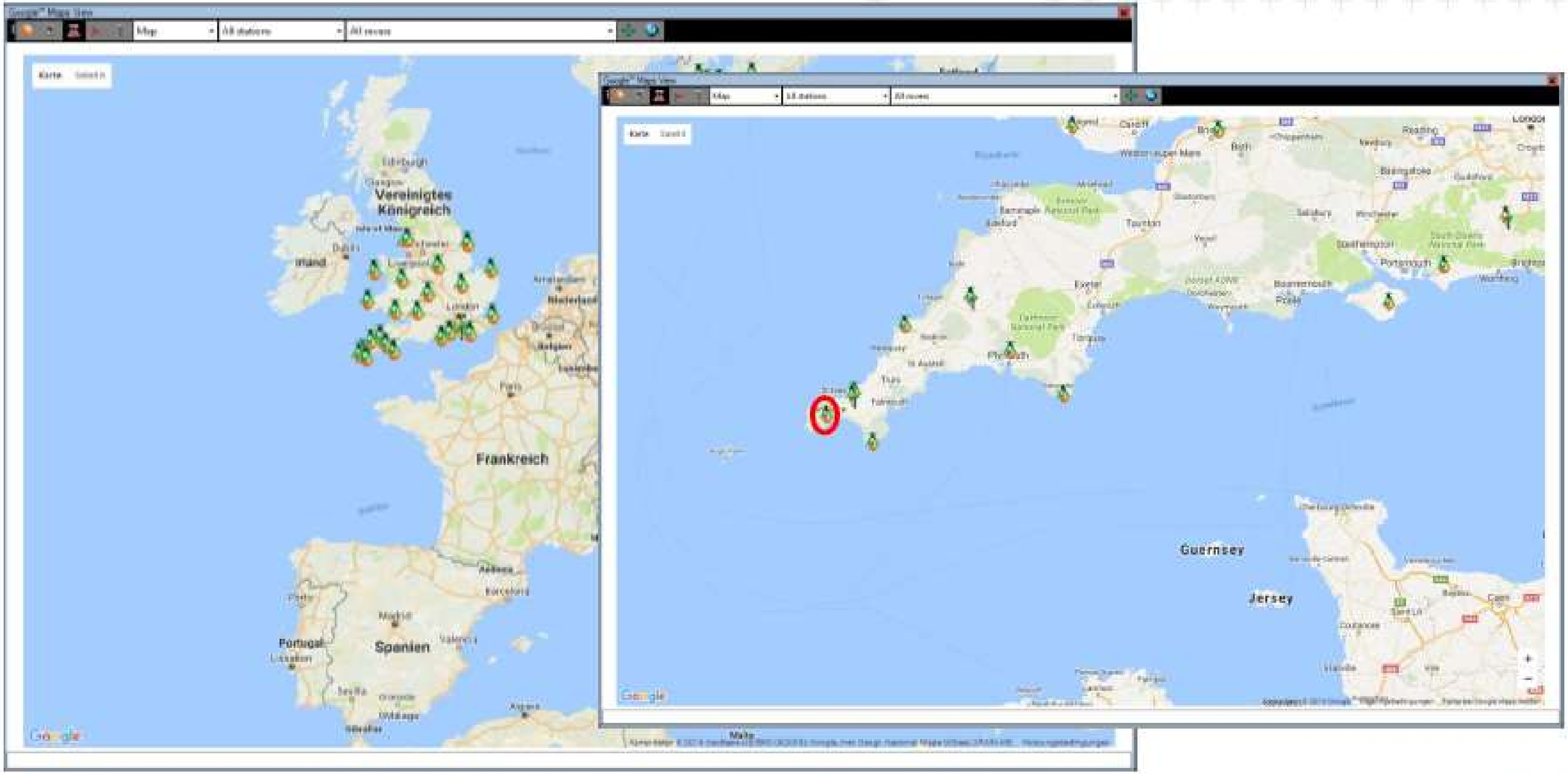
- PPP approach
- Computation on an absolute level
- Individual per station

Its not that simple

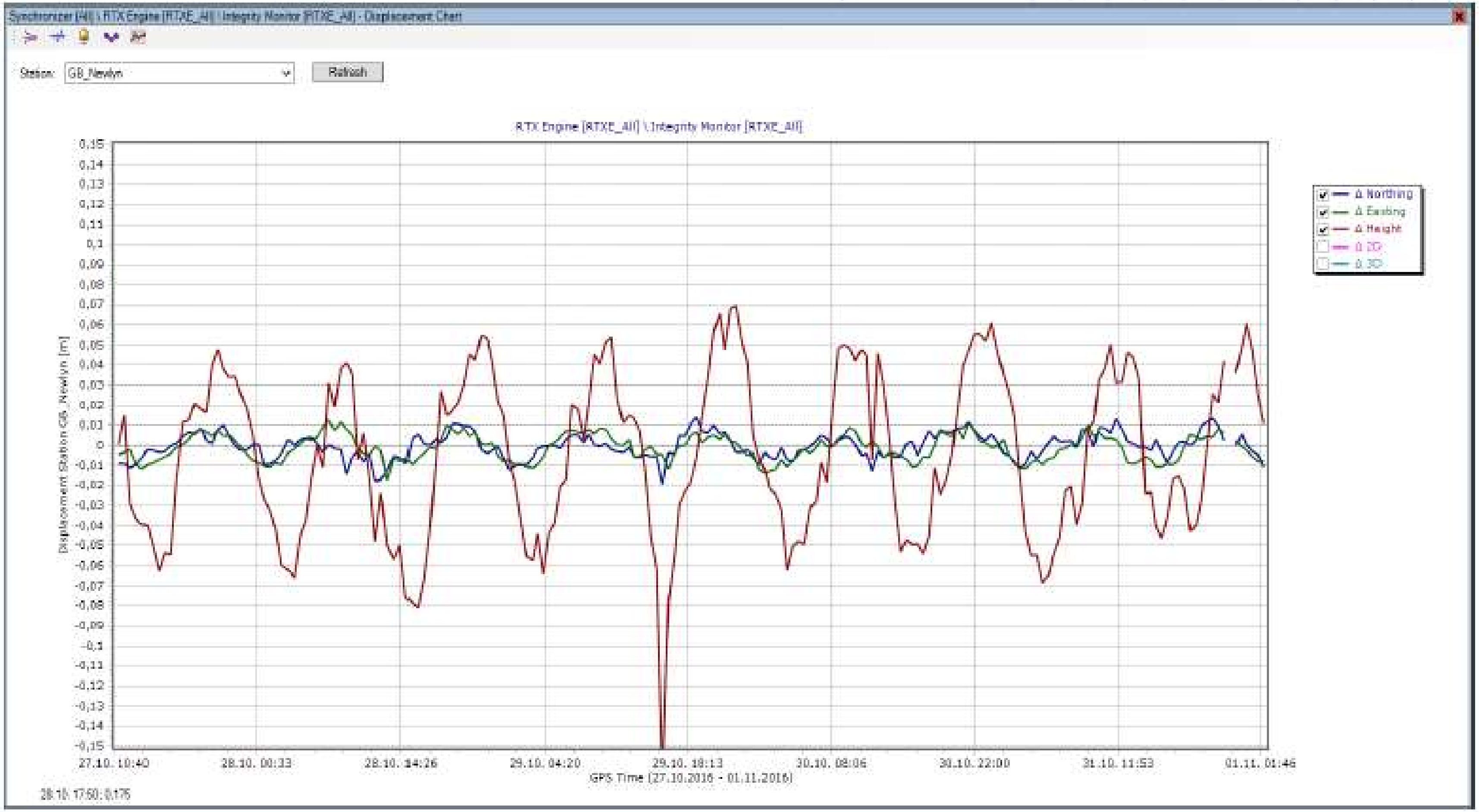
RTXNet – PPP Approach

Error	Magnitude up to	Correction
Satellite bias	1m	RTX Stream / DCB Files
Satellite antenna phase center	< 2 m	From calibration files
Receiver antenna phase center	< 20 cm	From calibration files
Earth tides	< 50 cm	Computed from files
Ocean tide loading	20 cm	Computed from files
Pole tide effect on earth crust	few cm	Computed from files
Carrier phase wind-up	< 10 cm	Computed
Receiver code bias	cm – m	Receiver type calibration
Station code bias	cm – m	Station type calibration
Position	few cm	Dynamic station coordinates

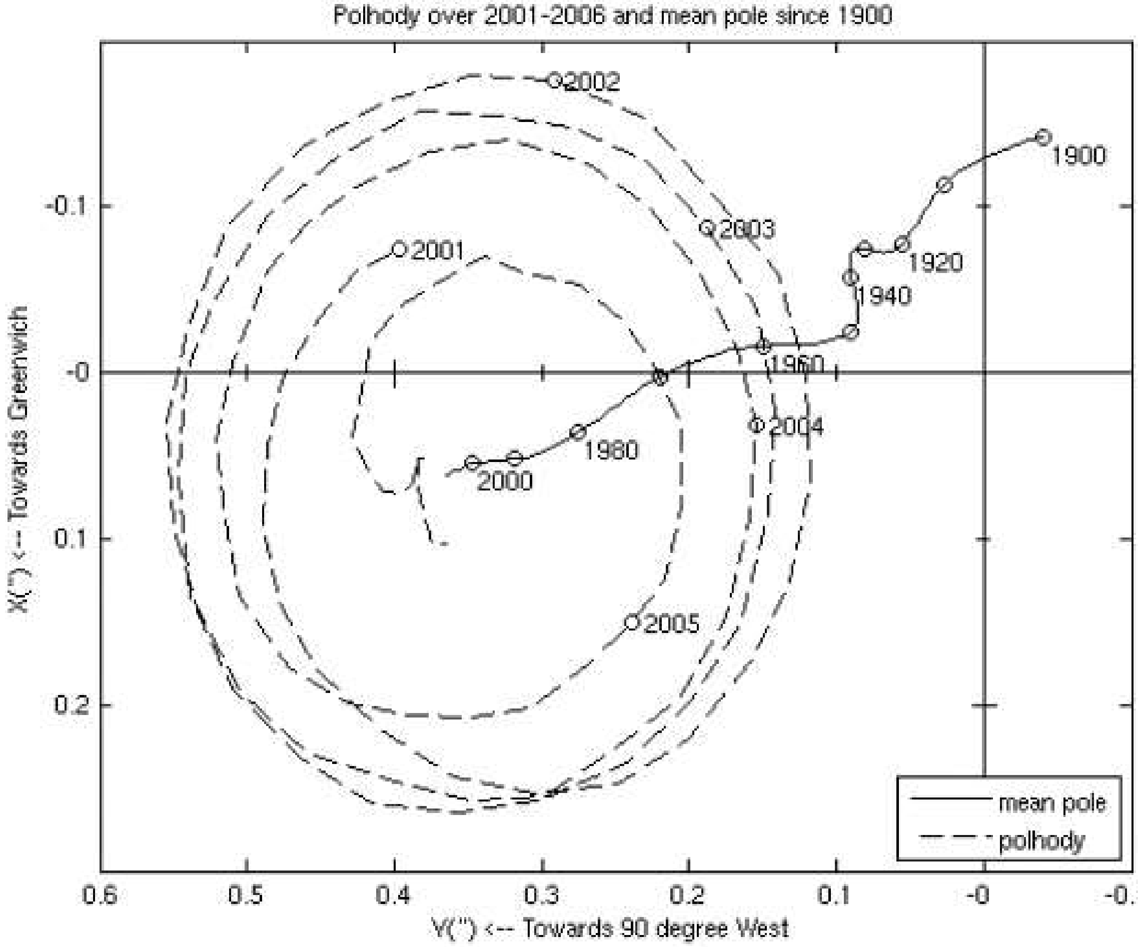
Ocean Tide Loading



Ocean Tide Loading

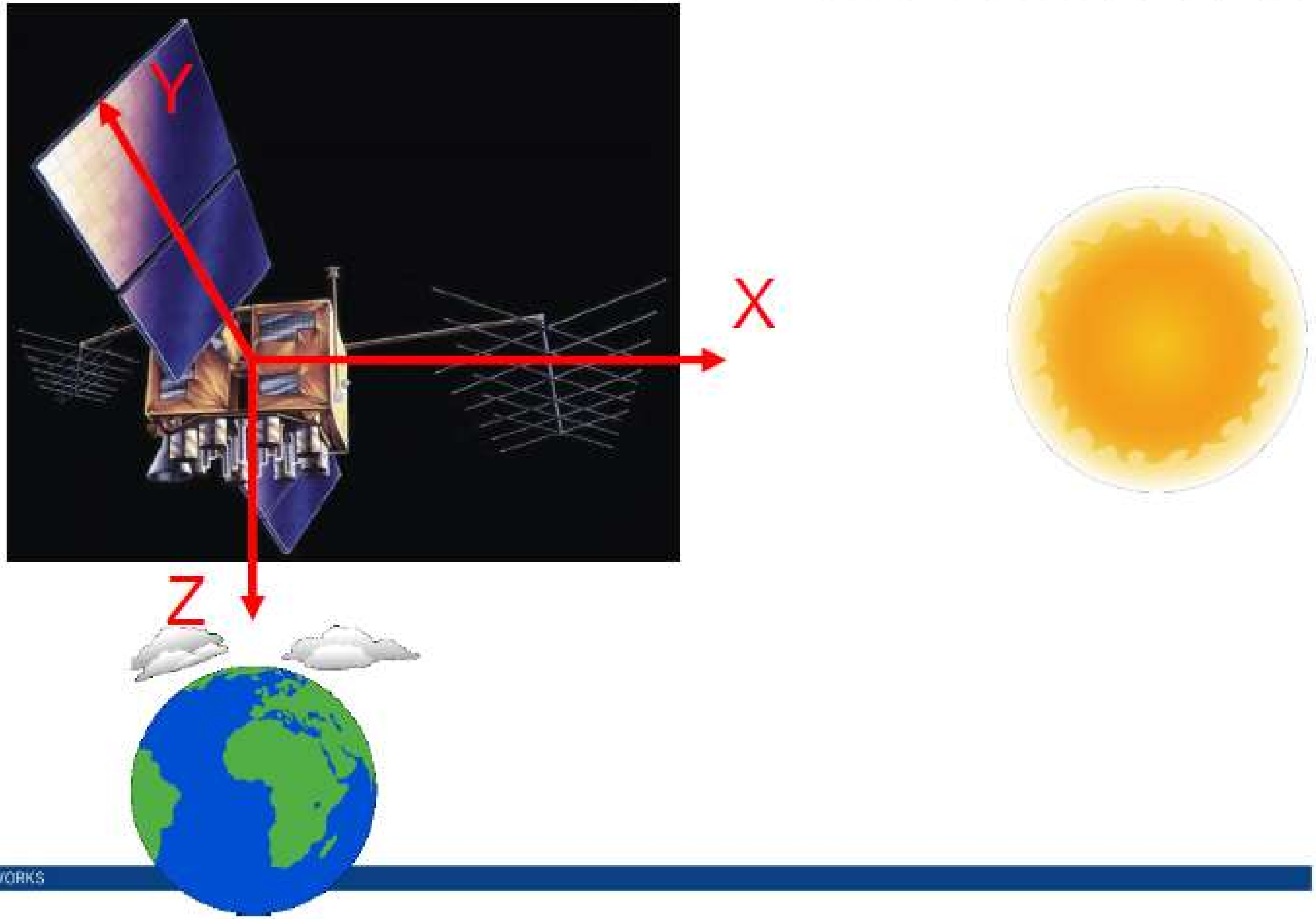


Pole tide effect

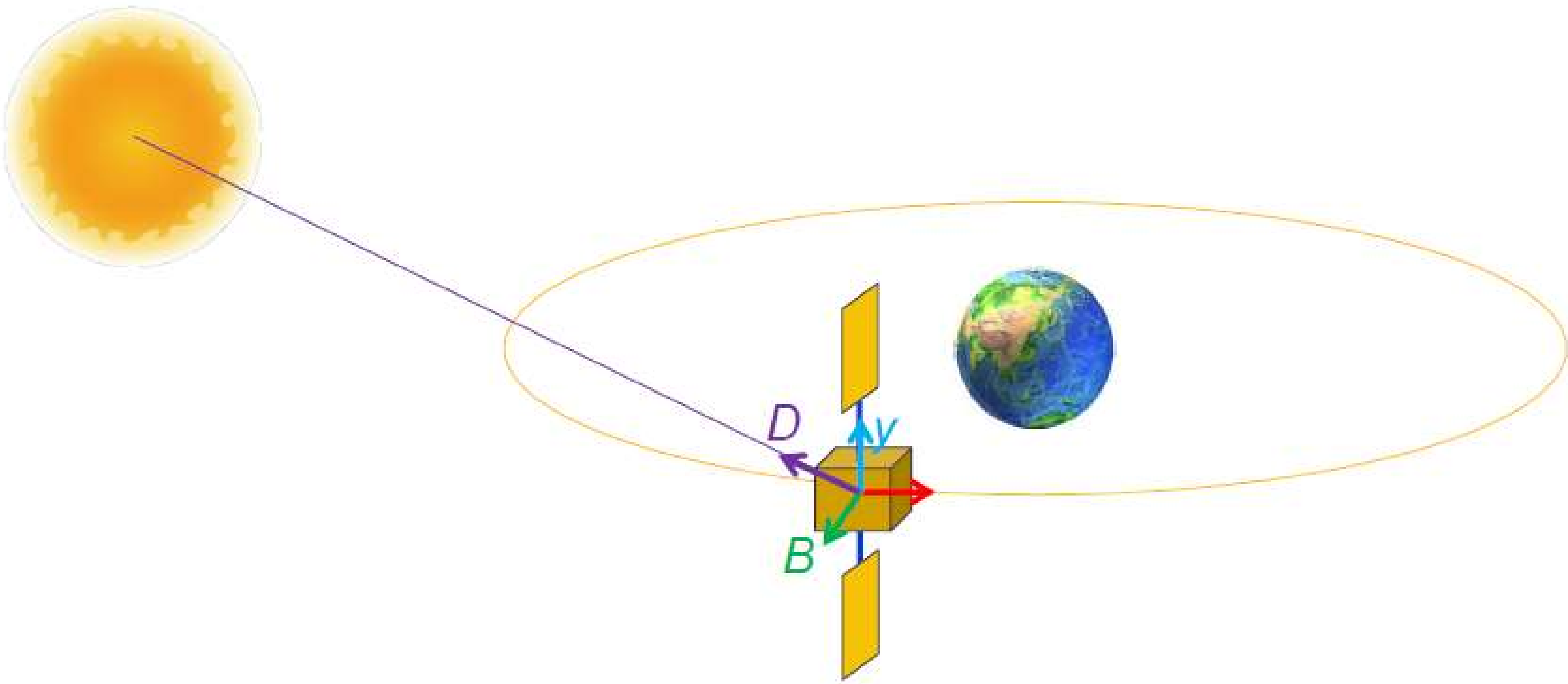


https://www.iers.org/IERS/EN/Science/EarthRotation/PolarMotionPlot.html?nn=12932

Phase Wind-Up

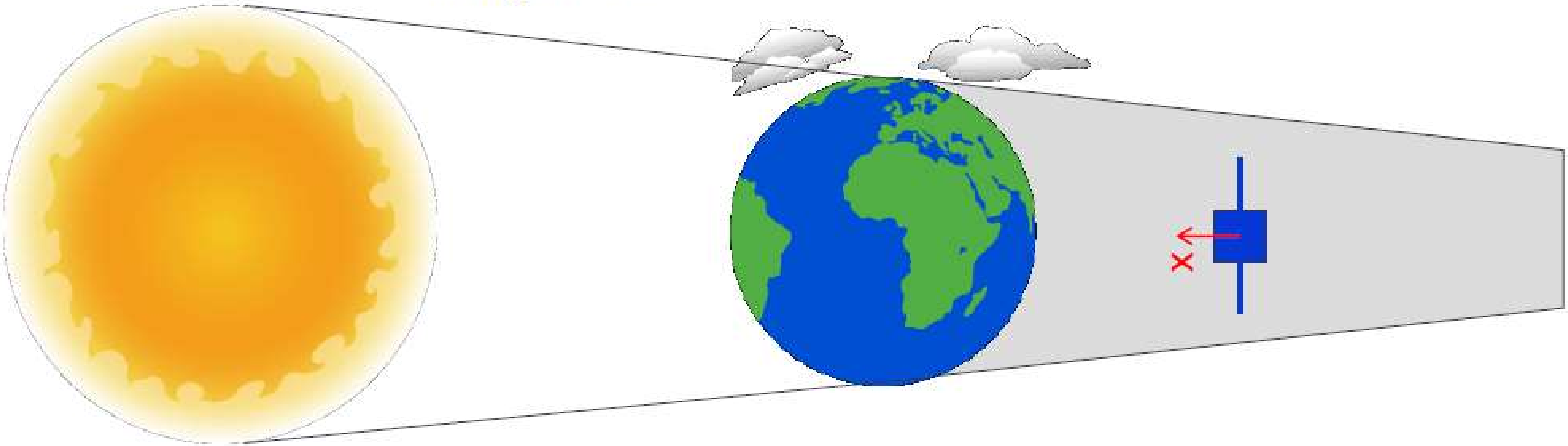


Phase Wind-Up



Phase Wind-Up

Midnight turn



Code Bias Calibration

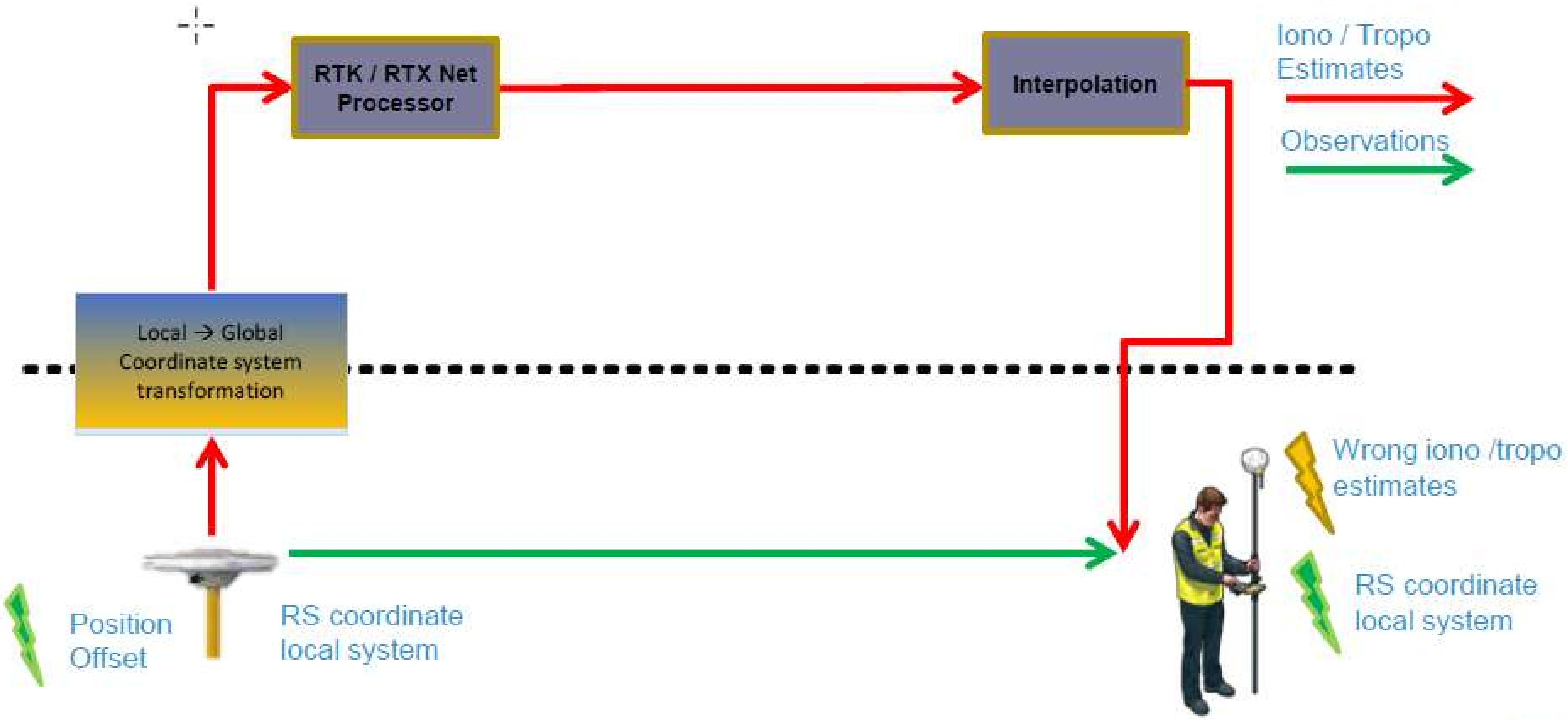
Dependent on:

- Satellite, frequency and observation type
- Receiver type and firmware version
- Antenna type and cable length
- Station specific environment

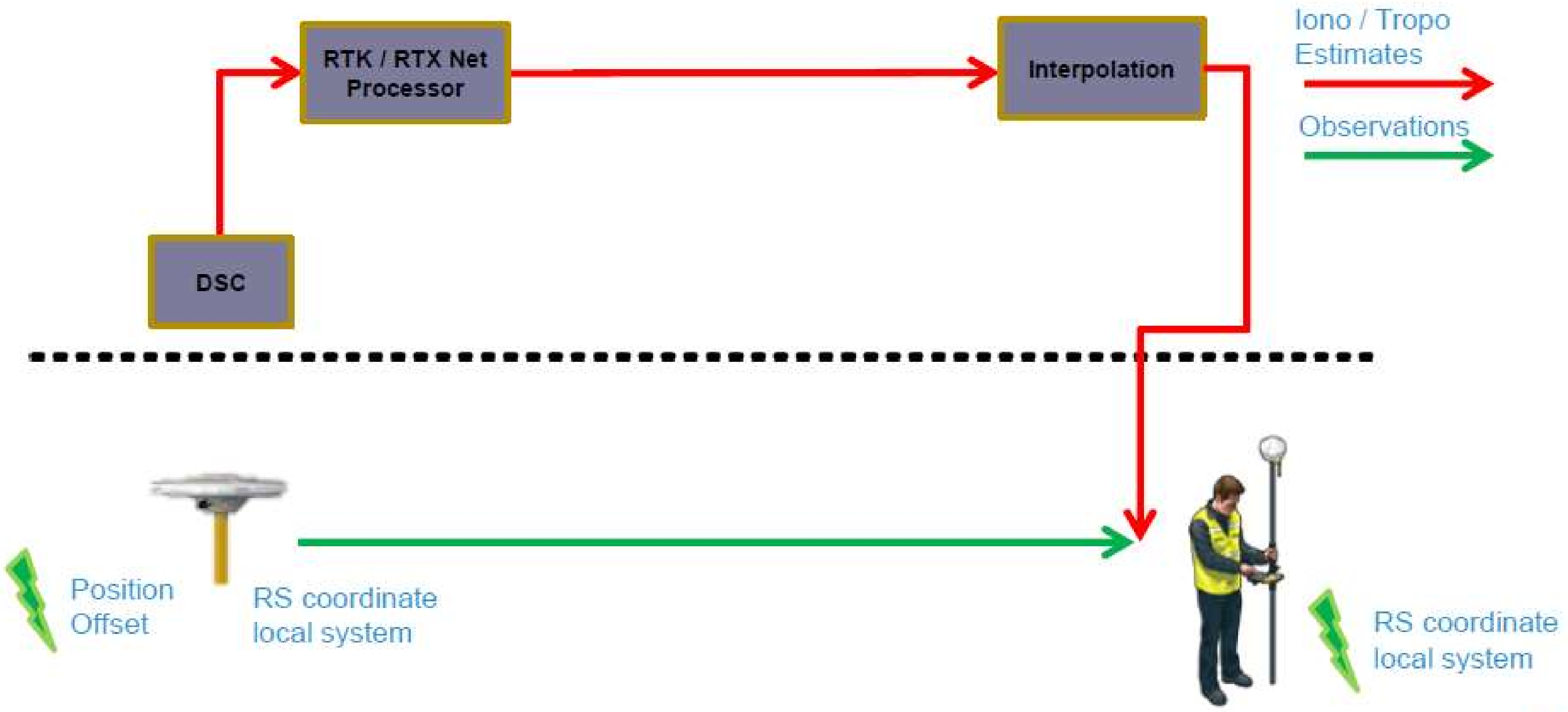
Calibration

- Zero Baseline
  - Identical antenna
  - At least two weeks of data
- Absolute calibration
  - Based on PPP with known position
  - Post processing and static
  - At least two weeks of data

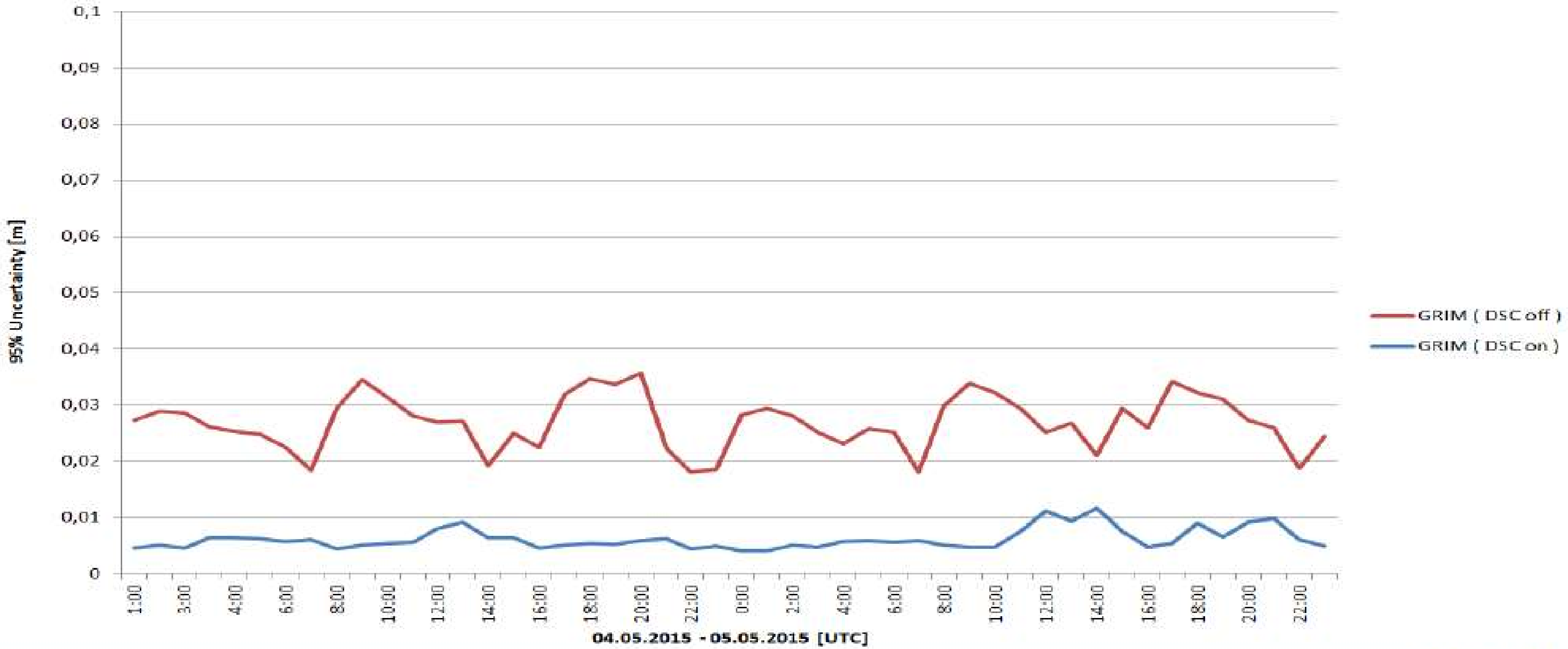
Traditional Approach for VRS



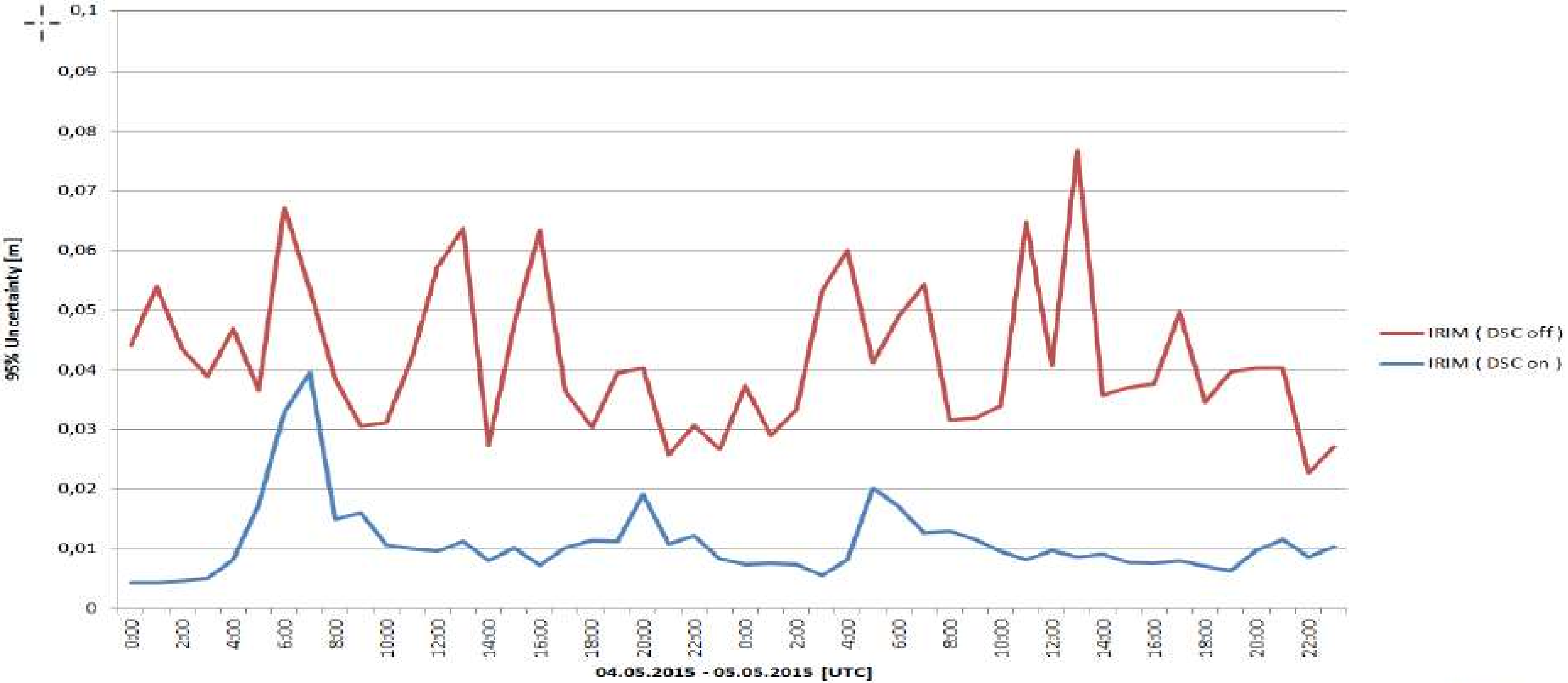
DSC Approach for VRS



Test Setup And Results
Tropospheric Residuals (GRIM)



Test Setup And Results
Ionospheric Residuals (IRIM)

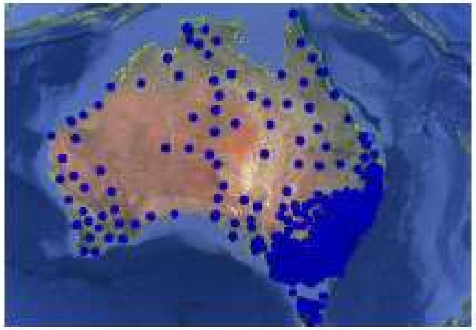


Intro – Network Operations Overview

- We build, operate, and maintain infrastructure that delivers TAP services to customers
- Software applications – responsible for all Trimble VRS Now & RTX services
- Deploy/Maintain GNSS reference station networks with approx. 2400 stations globally
- Implement/Operate/Monitor servers and network devices with high redundancy
- Service quality monitoring
- Second-level "Tier 2" technical support

Trimble RTX

VRS Now US



VRS Now AU

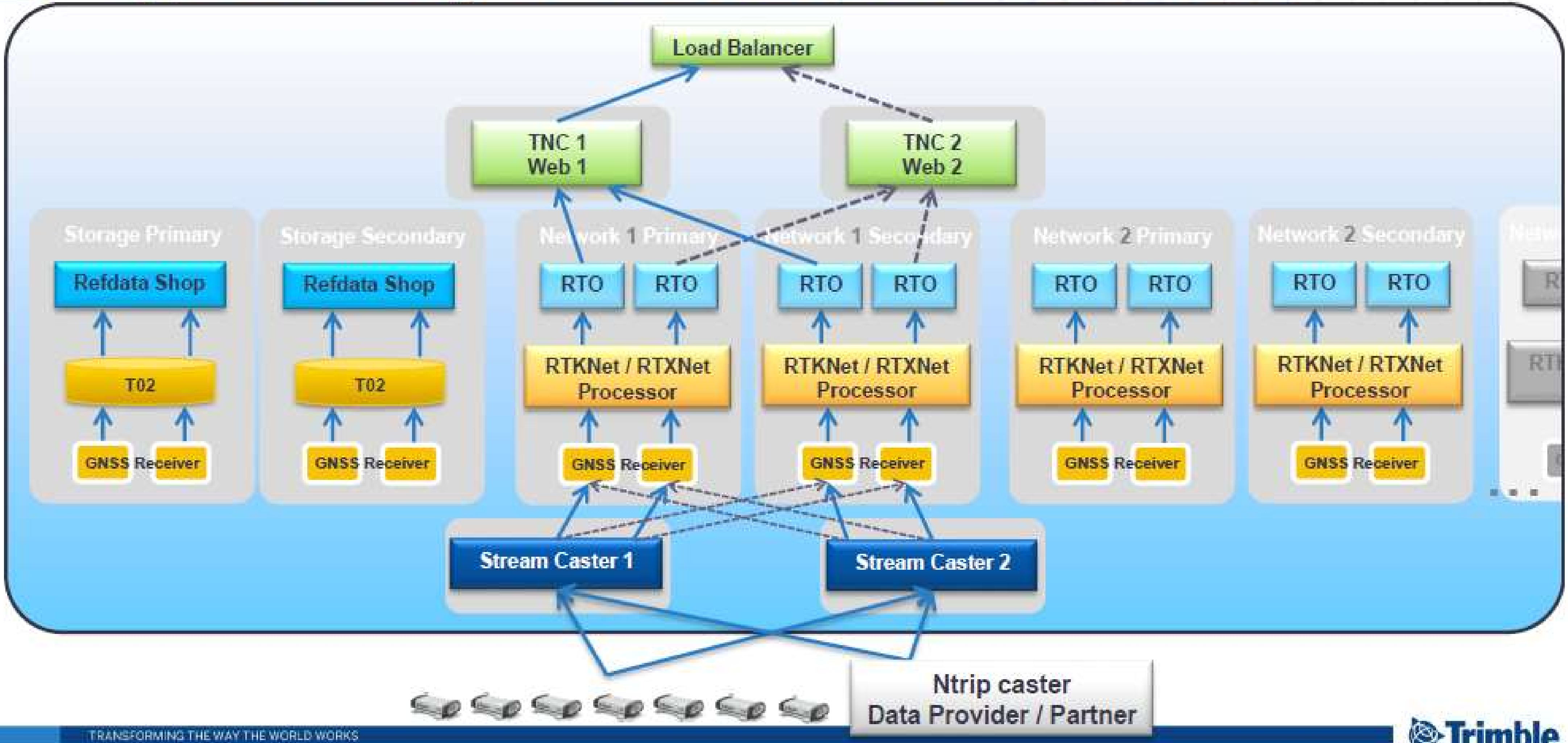
VRS Now EU

Trimble RTX

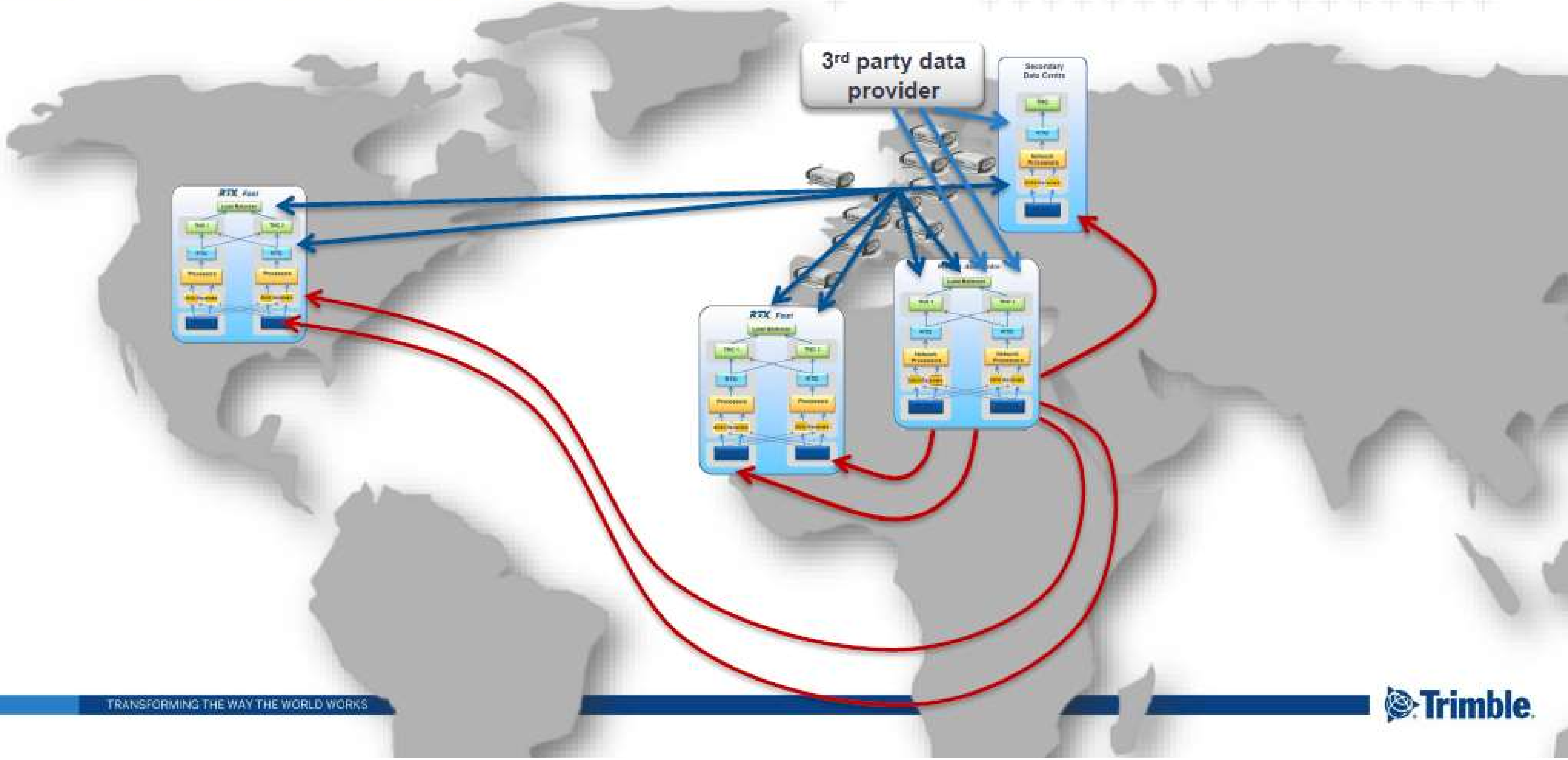
Redundancy

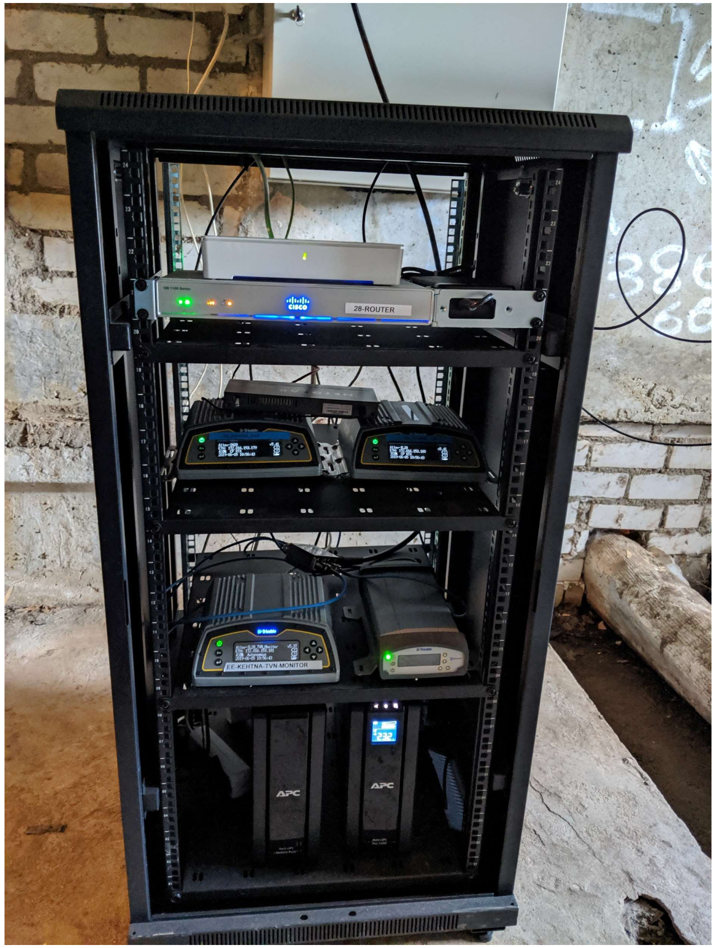
- Automatic failover for every single component, hardware and software
- Redundancy for
  - Customer Interfaces (Ntrip casters, webservers,...)
  - Data feeds
  - Servers
  - Hard disks
  - Power and internet
  - Network components (ISP, firewall, switches, ...)
  - Data bases
  - Data centers

Typical setup of VRS correction services



Data streaming




28-ROUTER
EE-KEHTNA-TVN-MONITOR
APC
APC


ALILEO USER ASSEMBLY
28-29 NOVEMBER 20
MADRID
NAVIGATION
SOLUTIONS
POWERED BY
EUROPE
European
Global Naviga
Satellite Syste
Agency
CE TO USER NE

Thank you
☺