New developments in offshore precise GNSS positioning

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Contents

- Fugro
- GNSS services
- Precise Point Positioning and Integer Ambiguity Re
- BeiDou and Galileo
- Solar events and ionospheric scintillation

Profile

Mission is to be the **world's leading service-provider** in the collection and interpretation of data relating to the Earth's surface and sub-surface, and in the support of infrastructure developments on land, at the coast and on the seabed.

Survey services

Fugro provides the energy sector, commercial and engineering industries, governments and other agencies with **offshore survey** and **geospatial services** tailored to the specific needs of each client.

Geotechnical services

Fugro investigates the **engineering properties** and **geologic characteristics** of near-surface soils and rocks, advises on **foundation design** and provides construction **materials testing**, pavement management and installation support.

Subsea services

Fugro's subsea capabilities range from supporting **exploration drilling**, provision of support services for **field construction, inspections** and **interventions** on subsea infrastructure to **design** and **build** of complex remote systems and tools.

Seabed geosolutions joint venture

A Fugro/CGG joint venture, seabed geosolutions **acquires, processes, interprets and monitors geophysical data** from seabed-positioned technologies to help oil and gas clients optimise field development and production.

Client sectors

Oil and gas

Mining

Building and infrastructure

Sustainable energy

Public sector

Other sectors

Client sectors

We deliver critical knowledge and essential operational support to the upstream and downstream oil and gas industry, providing a true life-of-field solution from exploration and development through to production and decommissioning.

Our knowledge, expertise and resources play a vital role in the development of sustainable energy solutions, both onshore and offshore, furthering new ways of meeting future energy demands.

We help mining companies to recover raw materials efficiently and safely, using a range of survey, mapping, investigation and sampling technologies, together with geoconsulting services.

We contribute to the design, realisation, safety and integrity of construction and development projects through the collection, interpretation, application and management of data relating to natural and man-made environments.

Our mapping and data management services help local, regional and national government agencies manage urban planning, security, natural resources and environmental emergencies. Responsible strategies mean a safer future for all.

In sectors as diverse as agriculture, water supply and control, forestry and fishing, Fugro's technical expertise helps ensure the future of communities, as well as conserving our planet.

Resources

12,165 employees

50 vessels

75 CPT trucks

27 laboratories

29 jack-up platforms

27 aircraft

261 land-based drill rigs
17 offshore drill rigs

150 ROVs

9 AUVs

> 250 offices

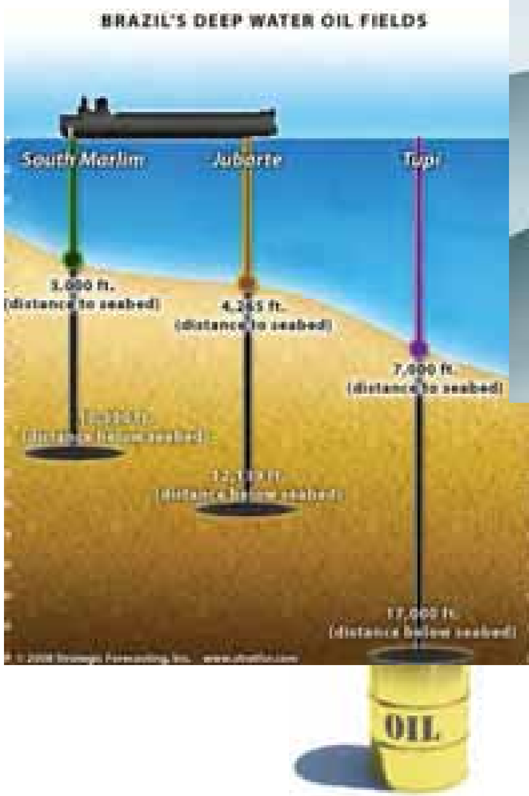
AUV – Autonomous Underwater Vehicle
CPT – Cone Penetration Testing
ROV – Remotely Operated Vehicle

Offshore positioning



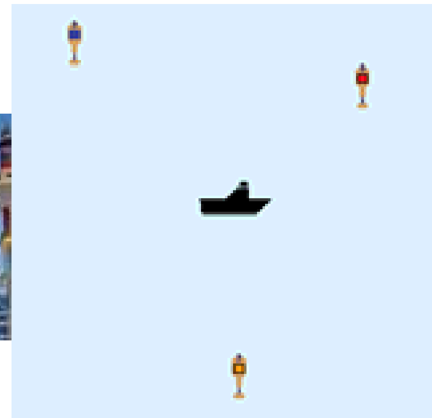


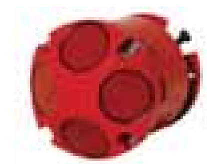

Subsea challenges



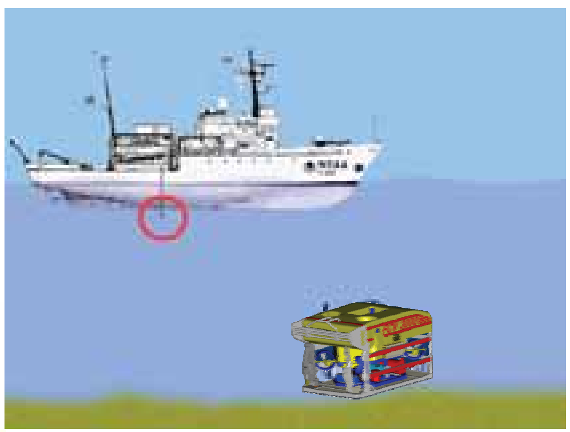
Subsea acoustic positioning and velocity systems

Long Baseline System (LBL)





Doppler Velocity Log (DVL)

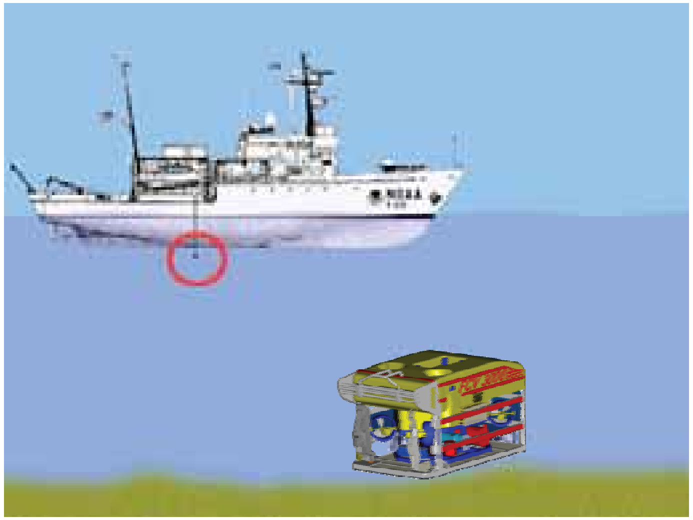


Ultrashort Baseline System (USBL)

Subsea acoustic positioning – USBL

Ultra Short Baseline (USBL) system

- Observations: distance and angles
- Precision: 0.1-0.5% of water depth
- Low update rate



Subsea acoustic positioning – USBL

An Ultra Short Baseline (USBL) system is portable and therefore popular for offshore use. It consists of a transponder on a subsea vehicle, such as an ROV (Remotely Operated Vehicle) and a transceiver on the surface vessel. Measurements are ranges (actually two-way travel times) and angles, which are used to determine the 3D position difference of the ROV with respect to the vessel. Adding the vessel's absolute position gives the ROV's absolute position.

The precision of a USBL depends on the water depth: for deep water, ranges are long and a small error in an angle propagates directly into the position difference. A USBL therefore needs to be properly calibrated, i.e., its attitude needs to be properly known.

Update rate is low, as speed of sound is low (1500 m/s). For example, for a water depth of 3000 m, it takes 4 seconds for an acoustic signal to travel from surface vessel to ROV and back. As a result, update rate in this case is once every four seconds (or less).

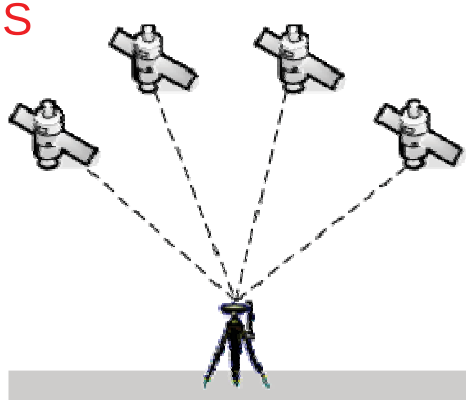
Subsea acoustic positioning – LBL

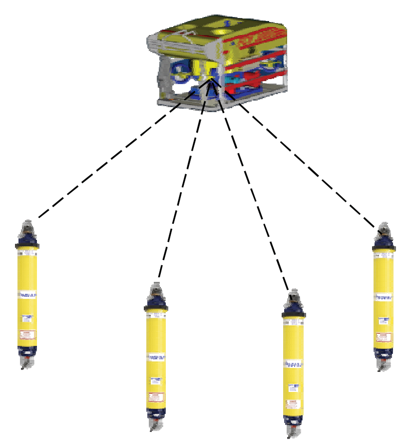
Long Baseline (LBL) system

- Observations: one- or two-way travel times
- Precision: 0.1-1 m
- Requires calibration of transponder array
- Low update rate

LBL ≈ GPS upside down

GPS





LBL

Subsea acoustic positioning – LBL

A Long Baseline (USBL) system can be considered as GPS upside down. It consists of transponders at known locations on the seabed and a transceiver on a subsea vehicle, such as an ROV (Remotely Operated Vehicle). Measurements consist of ranges (actually two way travel times) between vehicle and transponders. Positions are determined using trilateration.

Positions of the transponders are determined from a calibration procedure, where a surface vessel sails a pattern above the transponders and measures the ranges between transponder and vessel. Together with the known absolute position of the vessel, usually from GPS, the absolute positions of the transponders are determined. To further strengthen the network, it is often also possible to measure distances between transponders.

Subsea acoustic positioning – DVL

Doppler Velocity Log (DVL)

- Observations: 3D velocity relative to seabed
- Precision: 0.003-0.01 m/s
- Distance to seabed: 1-100 m

Subsea acoustic positioning – DVL

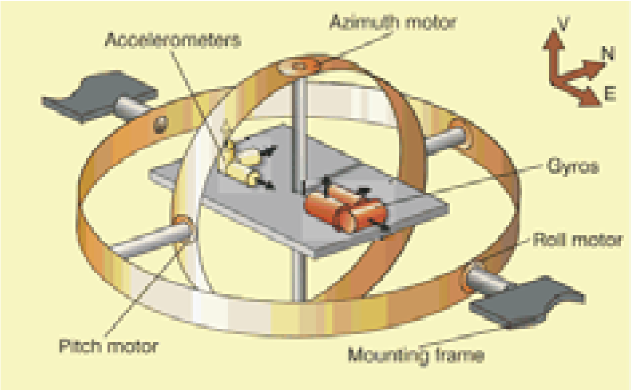
A Doppler Velocity Log (DVL) uses four acoustic beams to measure velocity relative to the seabed. These four velocities are derived from the Doppler shift between DVL and seabed.

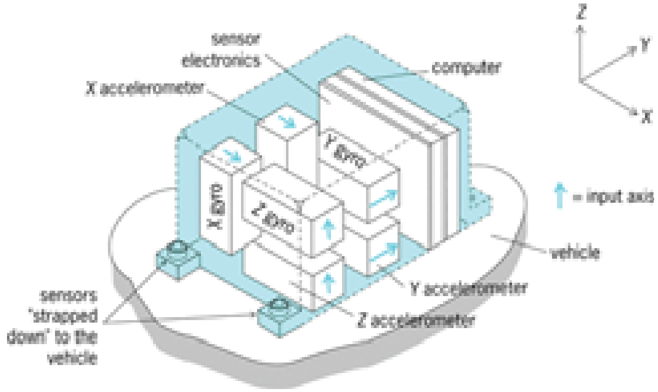
The four beam velocities are transformed to three velocity components in the DVL's body frame. Using the attitude of the DVL or the vehicle on which it is mounted, it is possible to transform these velocities into an Earth fixed navigation frame, such as north, east and up.

Inertial navigation – INS

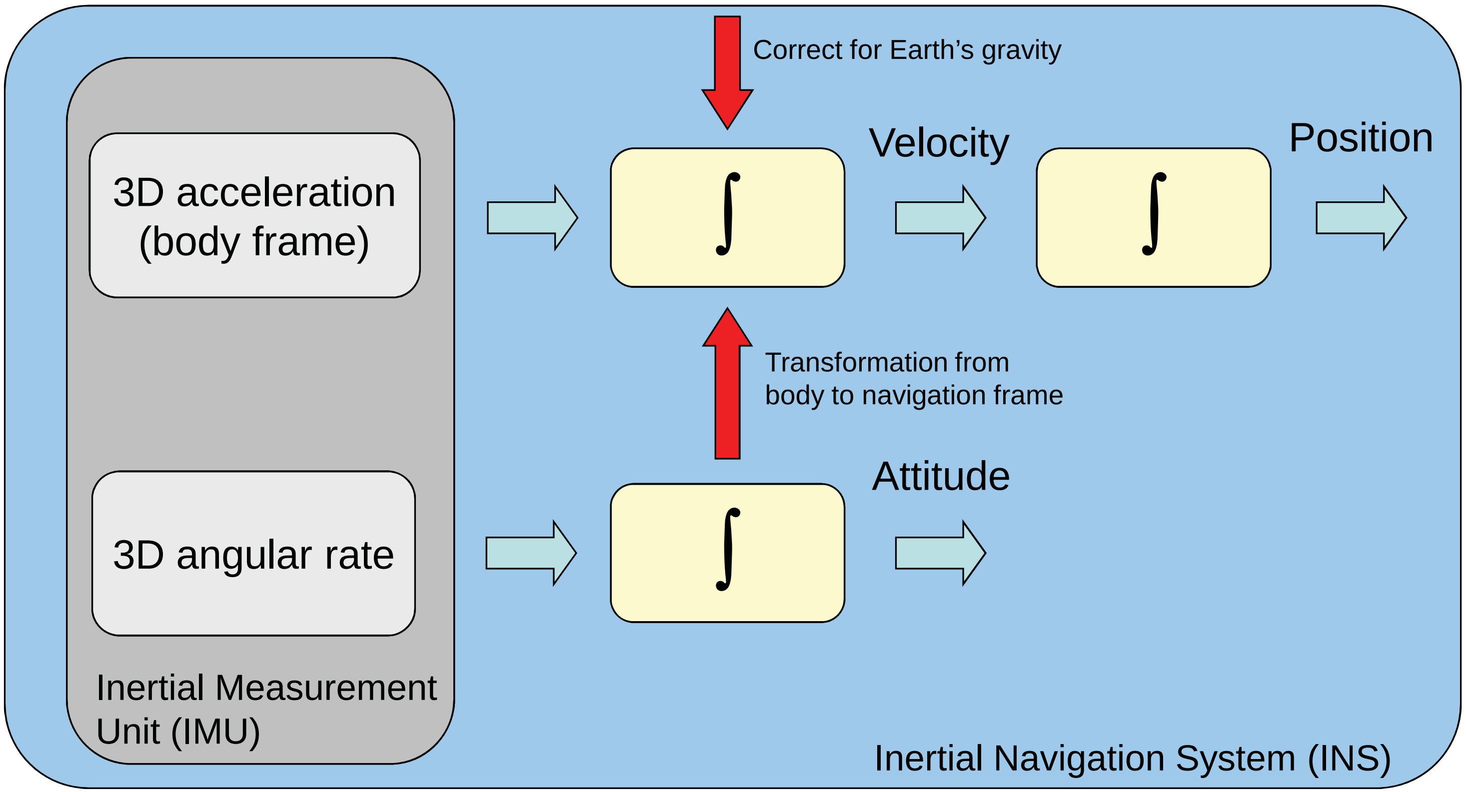
Inertial Navigation System (INS)

- Observations: accelerations and angular rates
- Self-contained
- High update rate
- Good short term accuracy
- Poor long term accuracy





Inertial navigation – INS



Body frame : Fixed to sensor
Navigation frame : Usually North, East, Up

Inertial navigation – INS

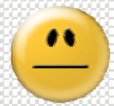
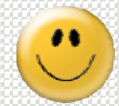
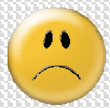
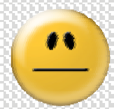
An Inertial Navigation System (INS) consists of an Inertial Measurement Unit (IMU) and a computer to estimate position, velocity, attitude and a number of (hardware) biases.

An IMU consists of three accelerometers and three gyroscopes to measure accelerations and angular rates. Integrating these quantities gives velocity and angular differences, integrating the velocity differences gives position differences. The accelerations are given in the IMU's body frame. The integrated angular data is used to compute attitude in a global navigation frame, such as north, east, up and to transform the body-fixed velocities and positions to this frame as well.

An IMU is self-contained and does not need any external sensors. However, it is a dead reckoning system, which means that only position, velocity and attitude differences can be determined. Using a special calibration is it possible to determine the initial attitude, whereas absolute initial position and velocity can be obtained from e.g. GPS.

Also, although an IMU is very stable for short periods, it drifts considerably after longer periods (km/hour). Aiding an IMU with other sensors, like GPS, will eliminate the drift or at least keep it within bounds.

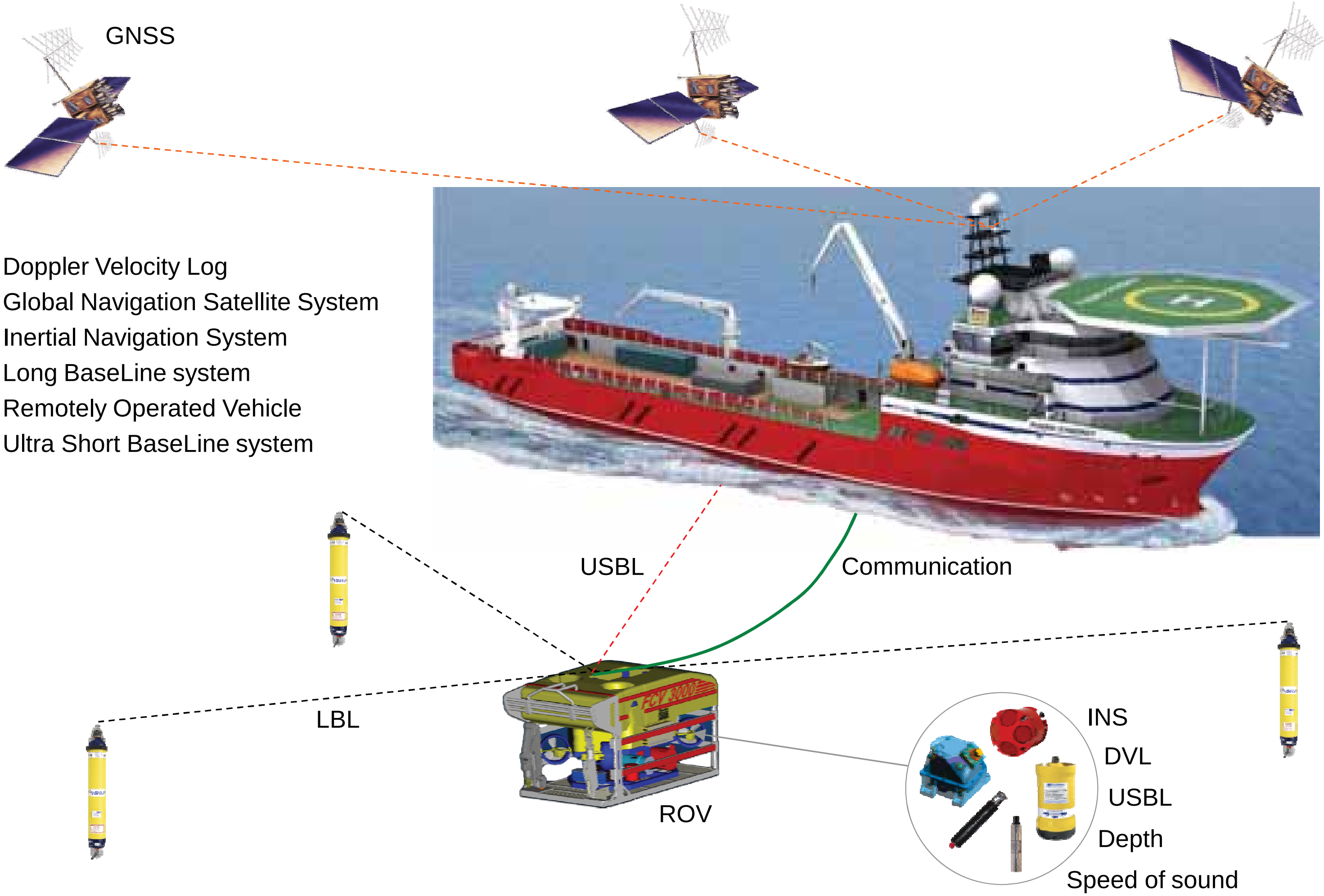
Integrated positioning – benefits

	INS	Conventional (GNSS/LBL/USBL/DVL)	Integrated
Precision			
Short term			
Long term			
Availability			

DVL – Doppler Velocity Log
GNSS – Global Navigation Satellite System
INS – Inertial Navigation System
LBL – Long BaseLine system
USBL – Ultra Short BaseLine system

Integrated surface and subsea positioning

DVL – Doppler Velocity Log
GNSS – Global Navigation Satellite System
INS – Inertial Navigation System
LBL – Long BaseLine system
ROV – Remotely Operated Vehicle
USBL – Ultra Short BaseLine system



Integrated positioning

In integrated positioning systems data from different sensors are combined to provide a single solution. Sensors are chosen in such a way that if one fails, the others can still provide a reliable solution. Precision is important, but perhaps even more important is availability.

Data from different sensors is in general used in a Kalman filter. Such a filter estimates (corrections to) position, velocity, attitude, gyro and accelerometer biases and scale factors, speed of sound, misalignment errors, etc.

Integrated positioning filter can become very complex. Care should be taken that all parameters are in fact estimable, that proper dynamical and stochastic models are used. If this is not the case, the filter may diverge.

ROV – Positioning equipment

Inertial Navigation System (INS)

Doppler Velocity Log (DVL)

ROV – Remotely Operated Vehicle

Contents

- Fugro
- GNSS services
- Precise Point Positioning and Integer Ambiguity Resolution
- BeiDou and Galileo
- Solar events and ionospheric scintillation

Current GNSS services

Service	Accuracy	Correction source	Navigation satellites	Signal frequencies	Positioning mode
L1	Meter	Reference stations	GPS	Single	Differential
HP	Decimeter	Reference stations	GPS	Dual	Differential
EPlus	Sub-meter	Orbit & clock	GPS & GLONASS	Single	PPP
XP	Decimeter	Orbit & clock	GPS	Dual	PPP
G2	Decimeter	Orbit & clock	GPS & GLONASS	Dual	PPP

GNSS – Global Navigation Satellite System
PPP – Precise Point Positioning

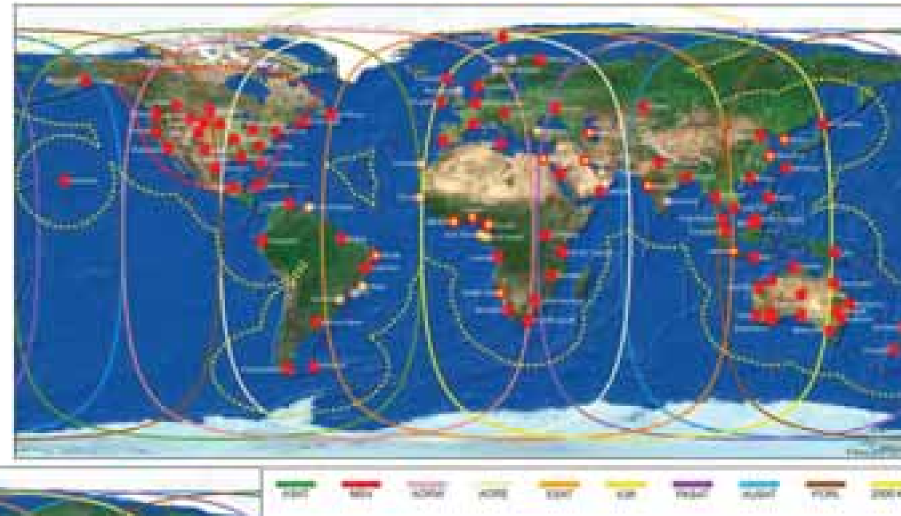
Current GNSS services

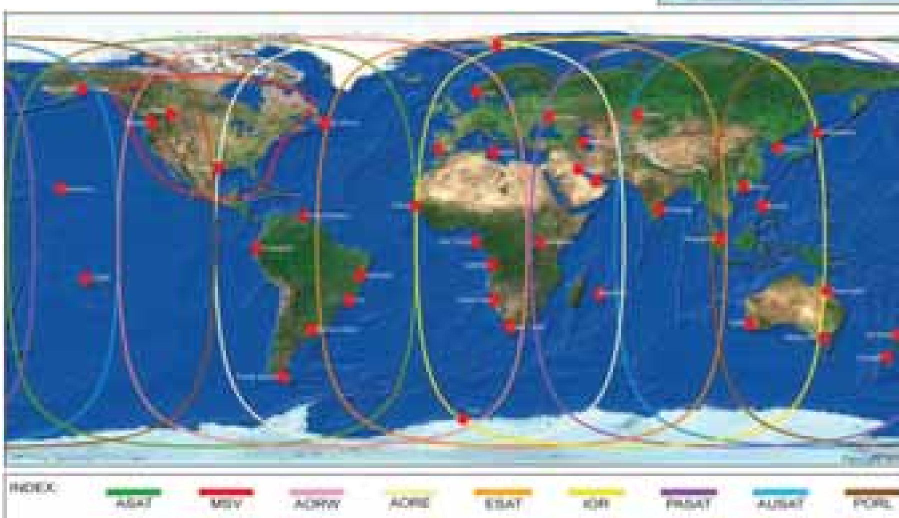
L1 and HP are examples of DGNSS (Differential GNSS (Global Navigation Satellite System, such as GPS, Glonass, Galileo and BeiDou)) service. Differential positioning uses reference stations at known locations to compute the distance between these stations and the GNSS satellites. The difference between observed and computed distance is considered to be a bias and used as a correction for mobile stations in an area up to several hundred kilometers around the reference stations. Biases can be due to errors in the satellite position and clock and the atmsophere (troposphere and ionosphere).

XP, G2 and EPlus are PPP (Precise Point Position) services. For PPP no differential corrections are used. Instead, a sparse global network of reference stations is used to compute precise satellite orbits and clocks in real-time. These precise orbits and clocks are valid worldwide and used at a mobile, which besides position, also needs to estimate atmospheric parameters (it can also eliminate ionospheric parameters by using a linear combination of data from different frequencies).

Infrastructure

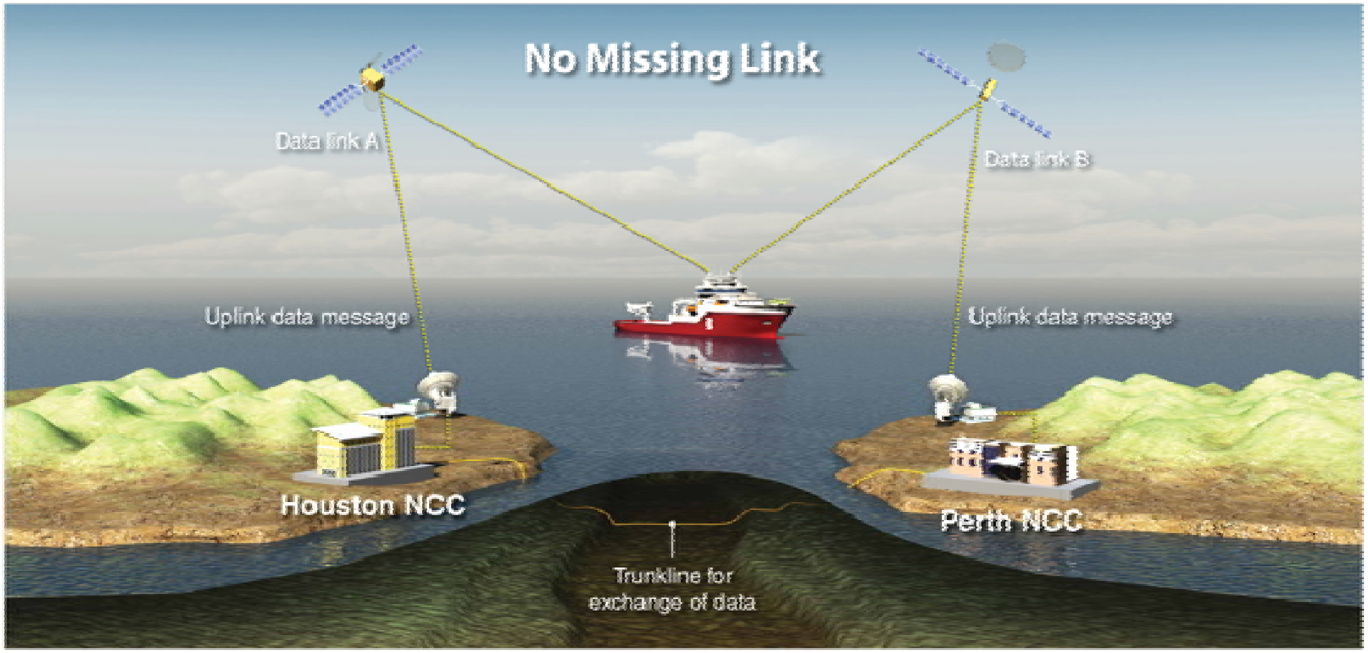
L1 and HP





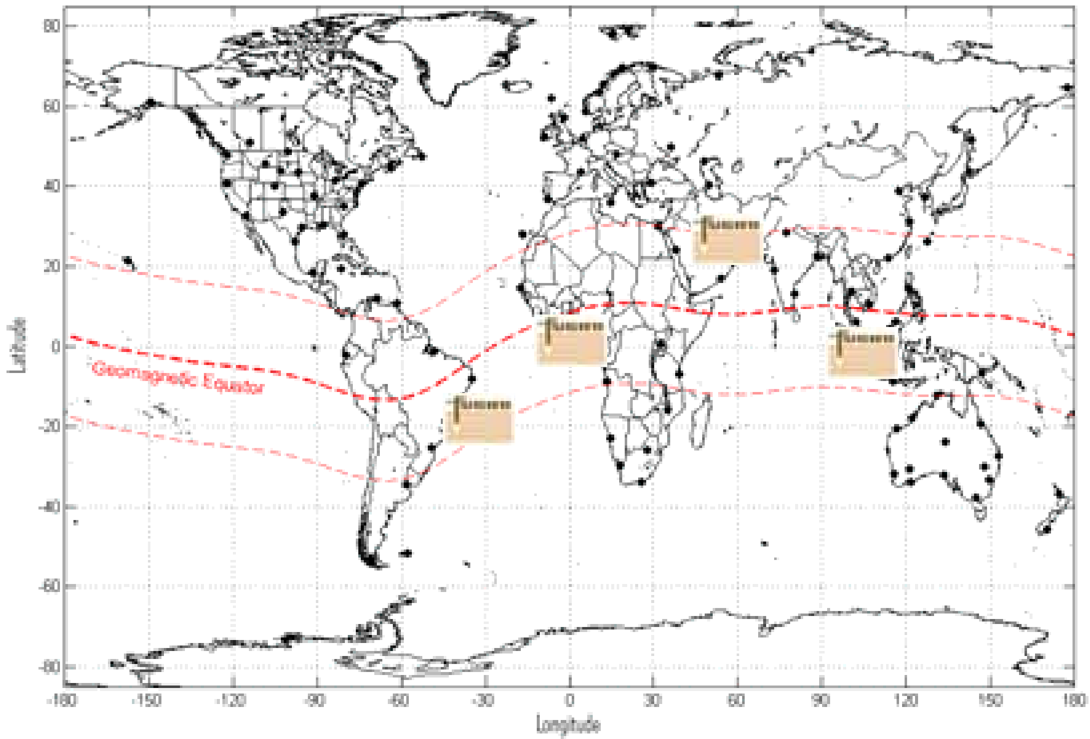
G2

Independence and redundancy



NCC – Network Control Center

Active equatorial ionospheric regions

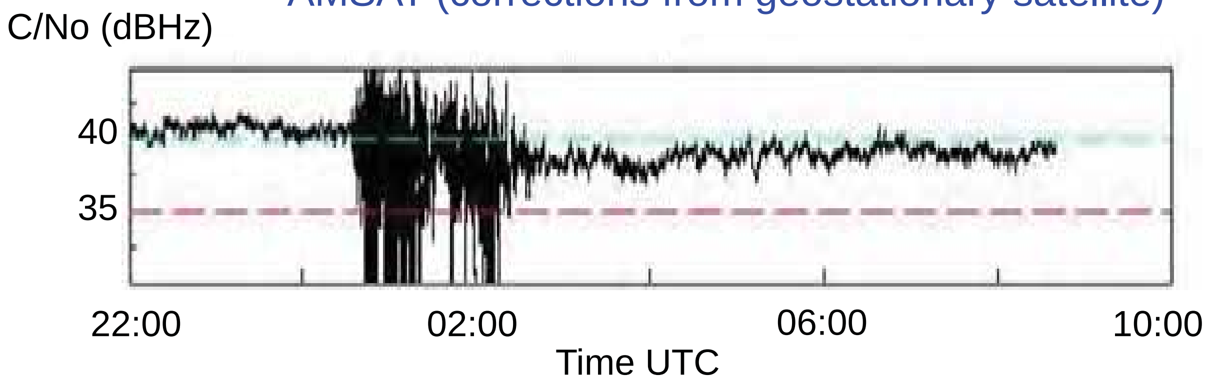


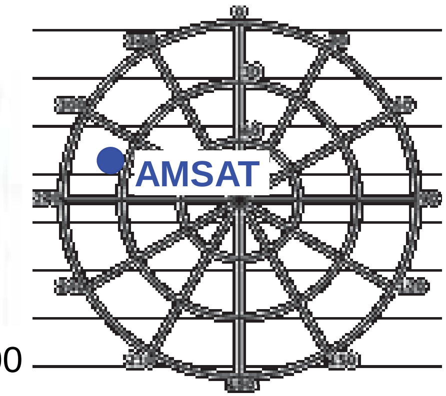
● – Reference station (L1 and HP services)

– Fugro activities

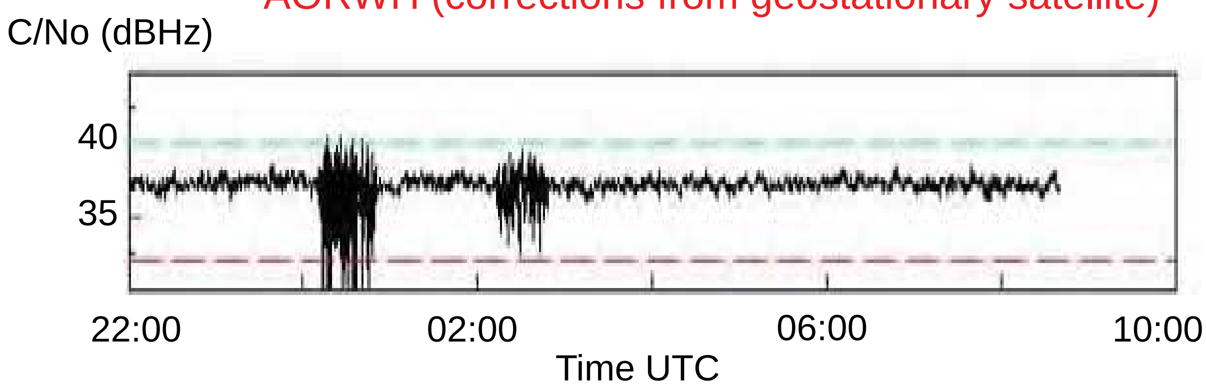
Importance of redundancy – scintillations

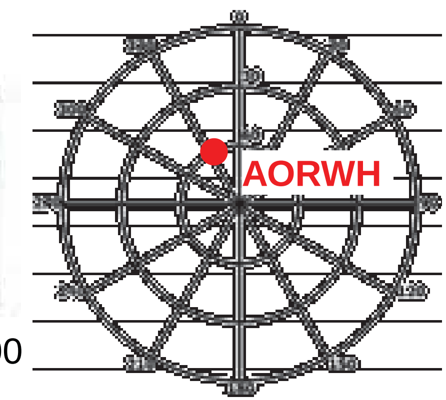
AMSAT (corrections from geostationary satellite)





AORWH (corrections from geostationary satellite)



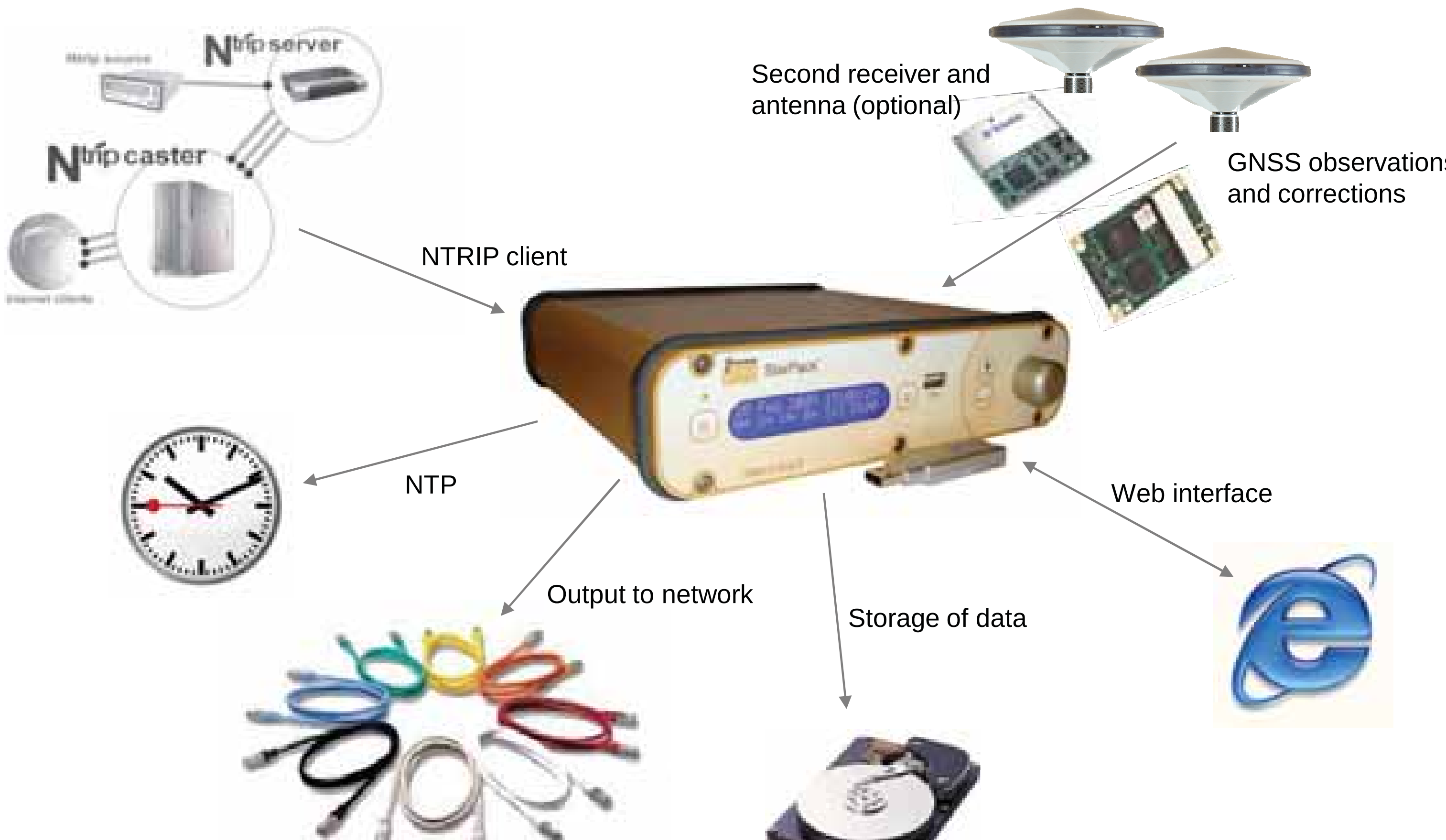


Importance of redundancy – scintillations

Fugro broadcasts GNSS corrections from geostationary satellites using L-band frequencies. The figure on the previous slide shows tracking of the GNSS corrections in Rio for two different geostationary satellites on 20 October 2011. Rio is located in the center of the two polar plots on the right.

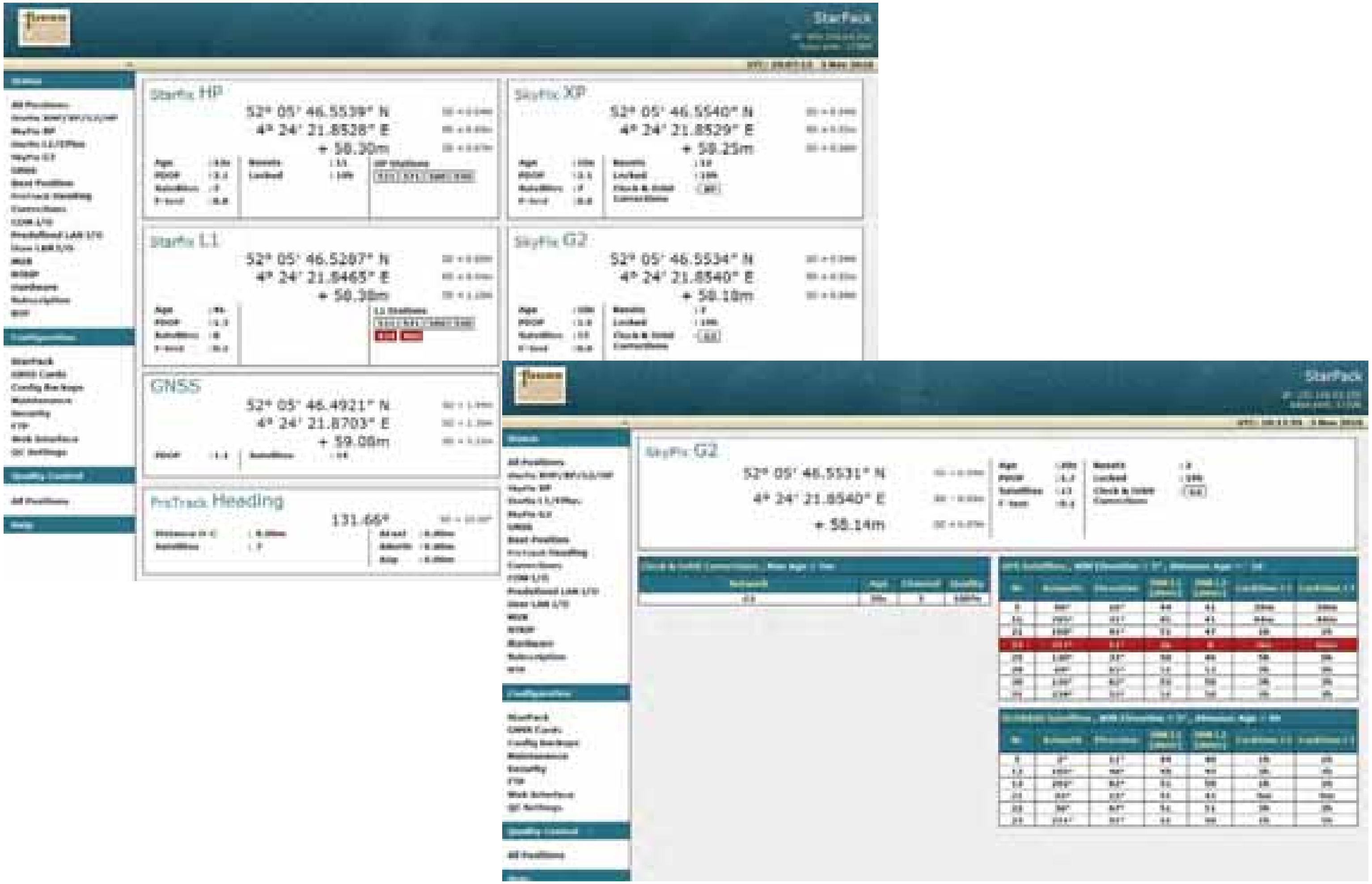
The receiver repeatedly looses lock and then re-acquires the signals, probably due to scintillations. This goes on for about two hours. One of the satellites, AMSAT (AMerican SATellite), at an elevation of 25 degrees and an azimuth of 285 degrees is affected more frequent then the other satellite, AORWH (Atlantic Ocean Region West, High), which is at 61 degrees elevation and 333 degrees azimuth. What is also typical is that they are not affected at the same time, because they are at different places in the sky. This shows the importance of redundancy.

StarPack

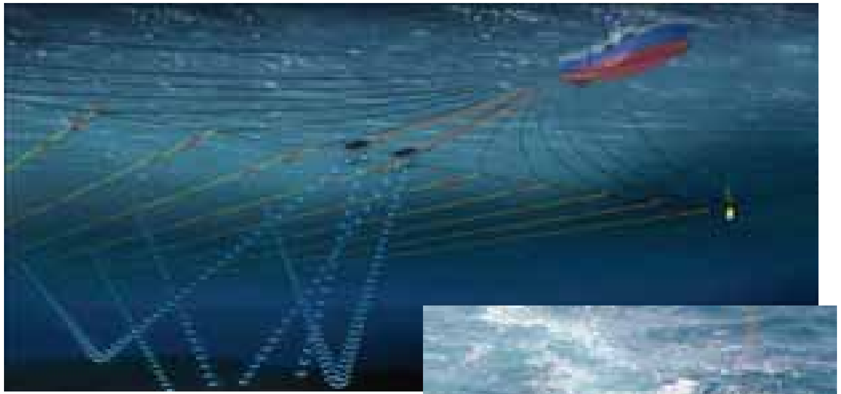


GNSS – Global Navigation Satellite System
NTP – Network Time Protocol
NTRIP – Network Transport of RTCM via Internet Protocol

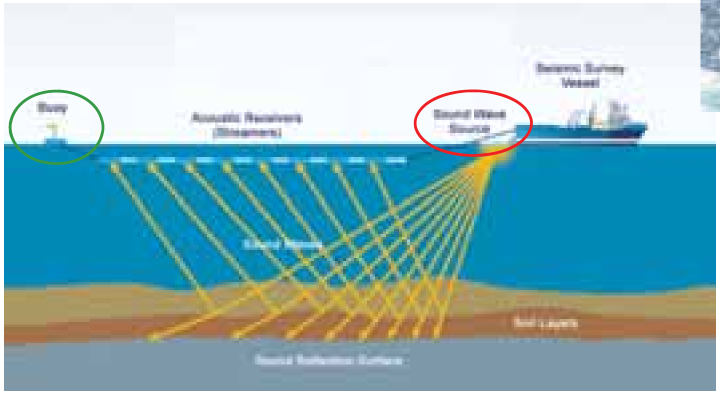
StarPack – web interface



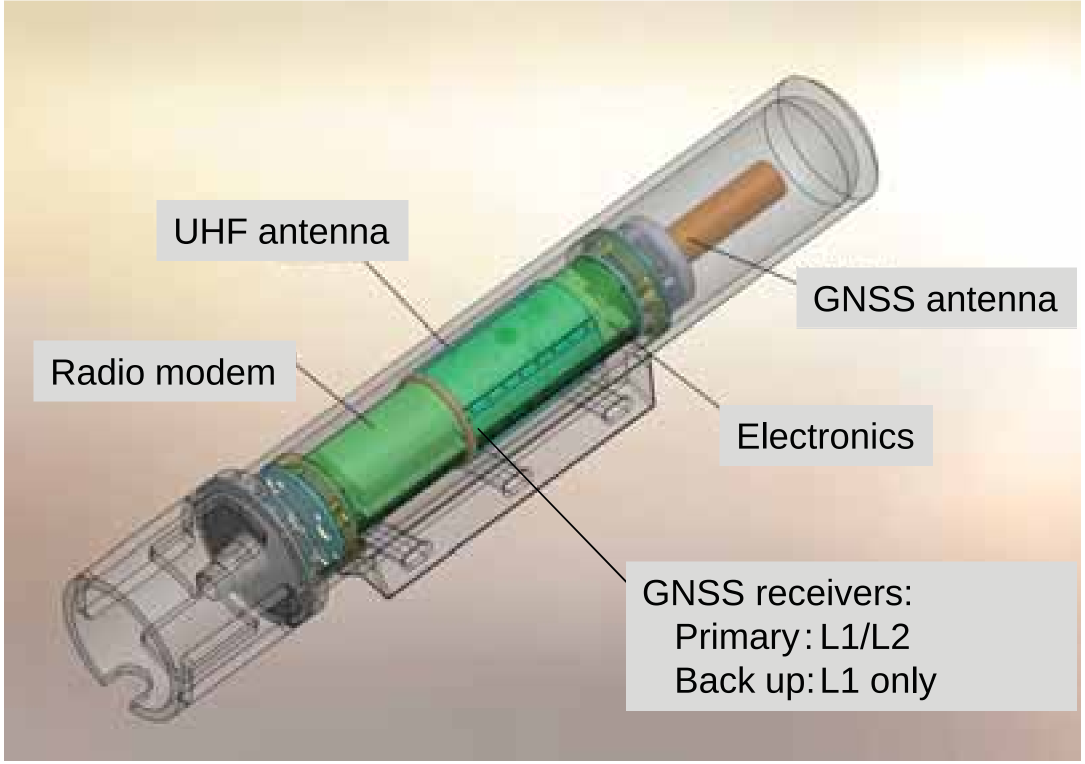
StarTrack – Seismic streamer positioning



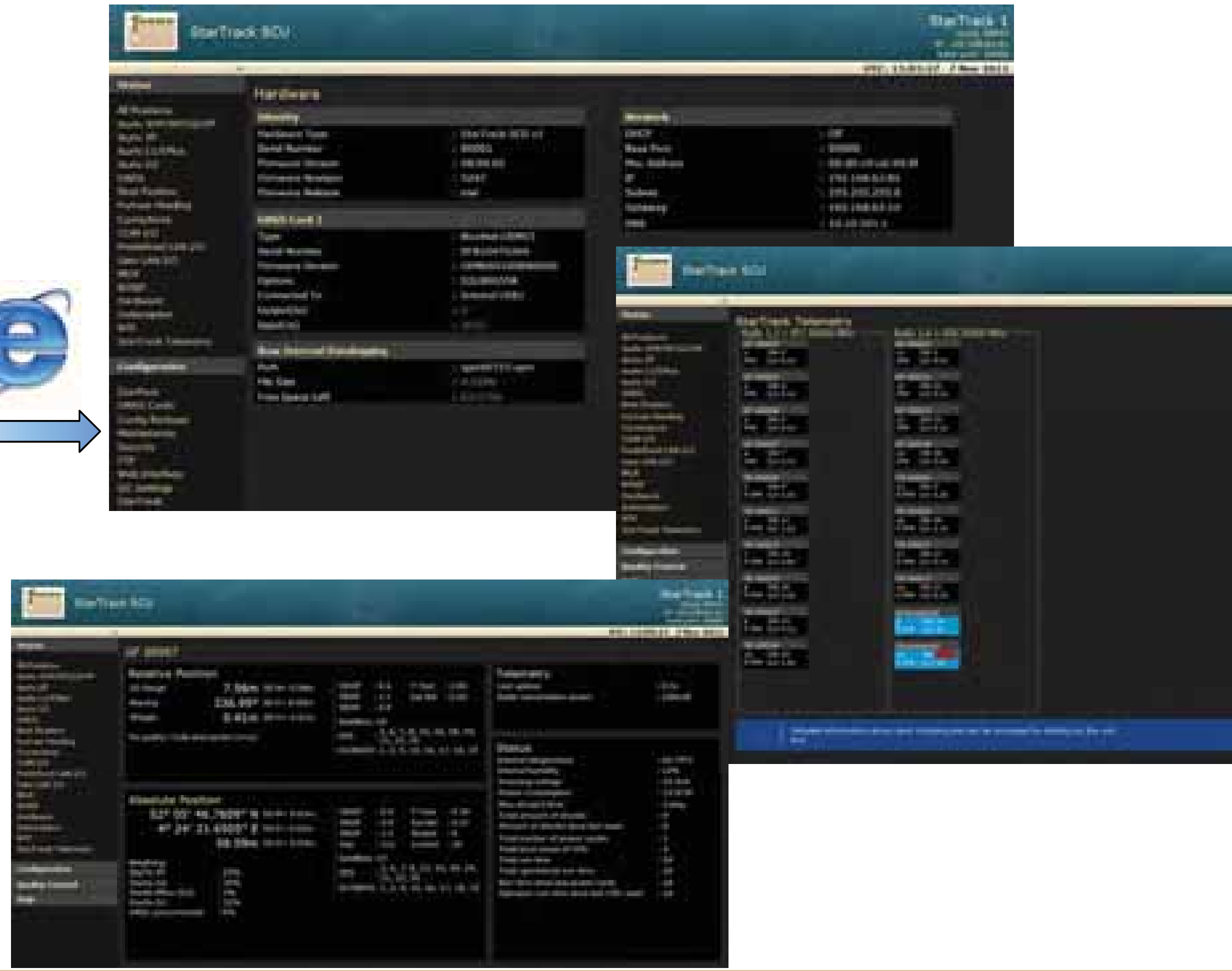
Positioning of gun float and tail buoy



StarTrack Remote Unit (SRU)



Web interface

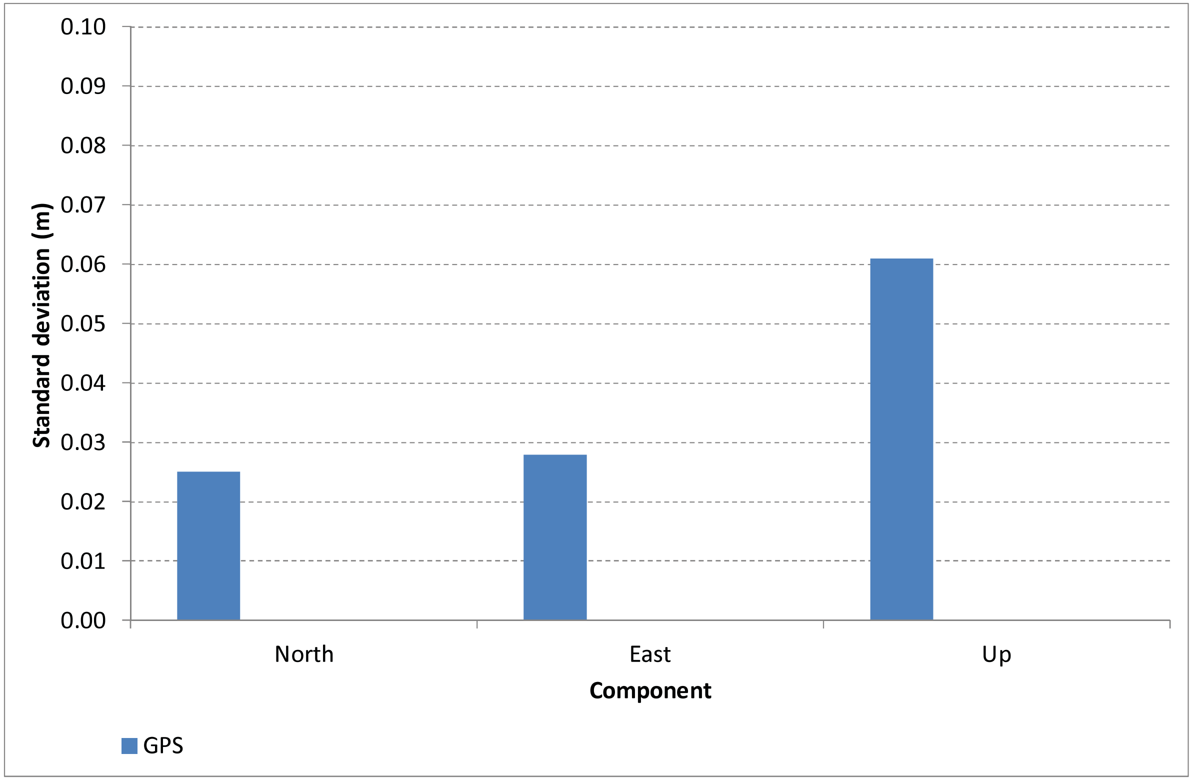


Precise Point Positioning (PPP) services

Service	Accuracy	Correction source	Navigation satellites	Satellite frequencies
EPlus	Sub-meter	Orbit & clock	GPS & GLONASS	Single
XP	Decimeter	Orbit & clock	GPS	Dual
G2	Decimeter	Orbit & clock	GPS & GLONASS	Dual

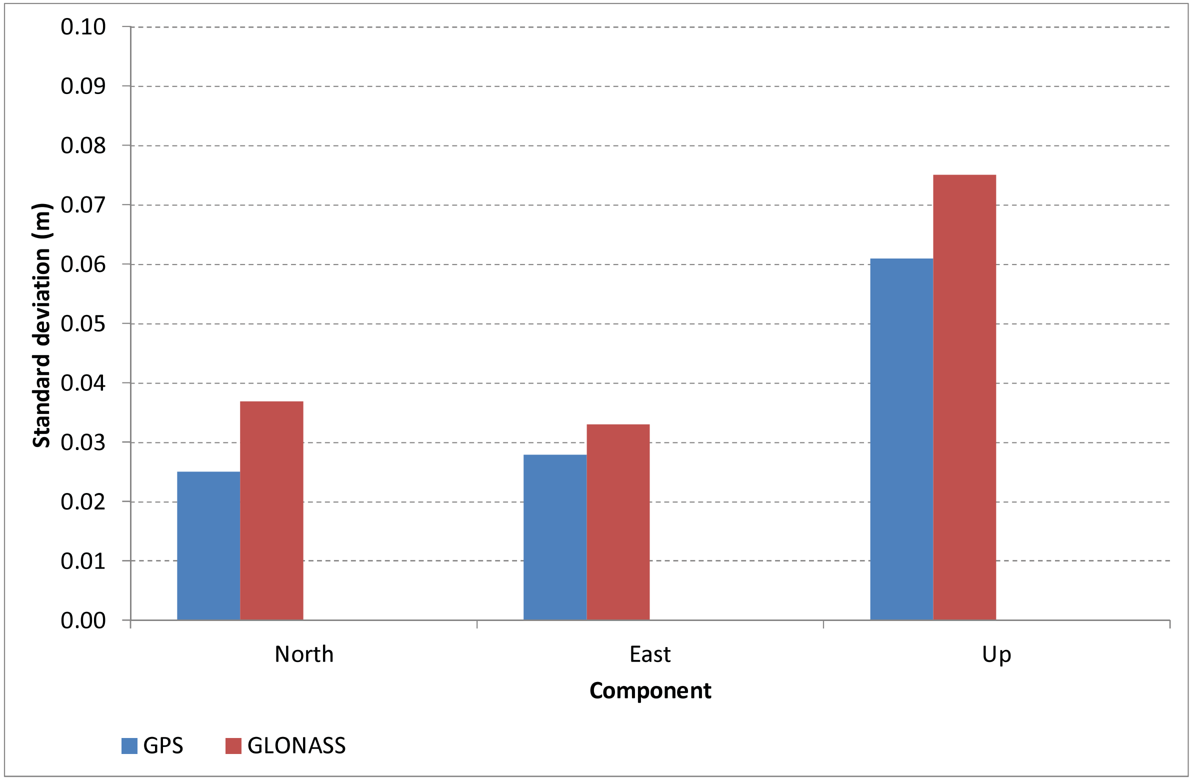
G2 performance

Kinematic positioning, real-time orbits and clocks, Oslo



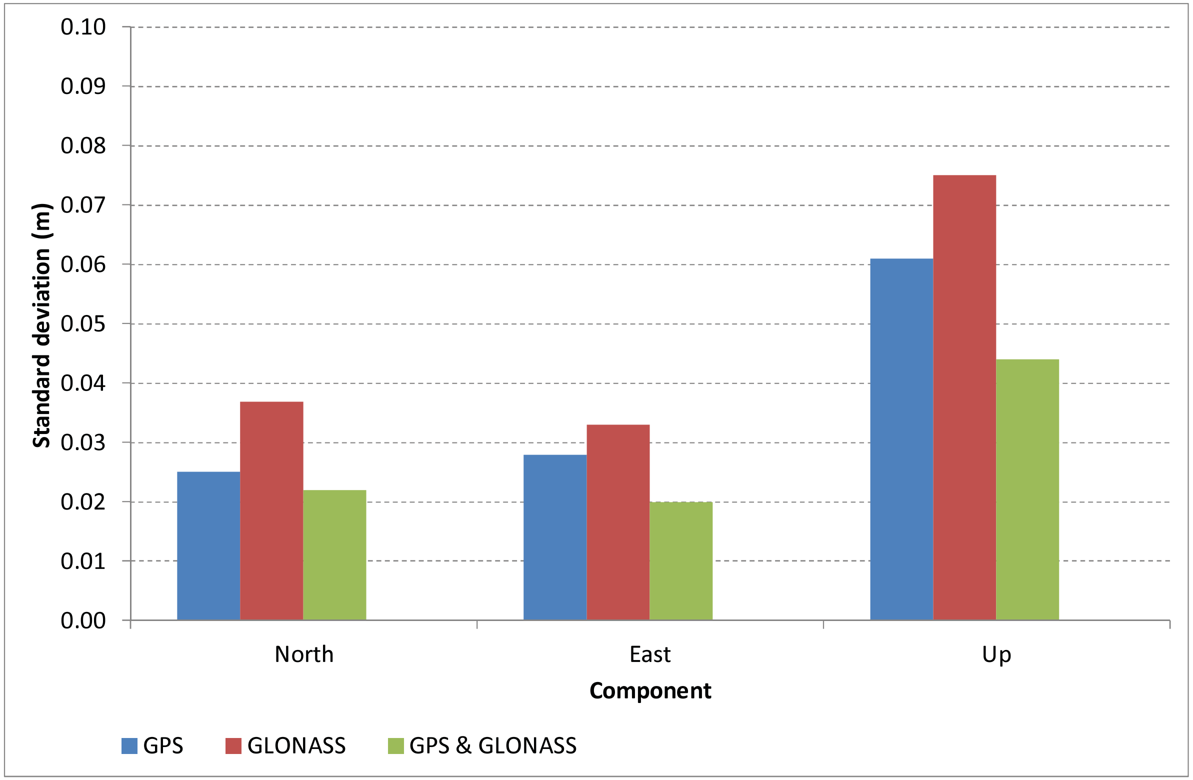
G2 performance

Kinematic positioning, real-time orbits and clocks, Oslo



G2 performance

Kinematic positioning, real-time orbits and clocks, Oslo



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Future developments – PPP IAR

Implementation

- EHP PPP

Test beds

- North Sea
- Gulf of Mexico

Data

- GPS and GLONASS
- Dual-frequency code and carrier
- Real-time orbits and clocks
- Corrections: carrier delays (Uncalibrated Phase Delays – UPDs)

PPP IAR – Test bed North Sea

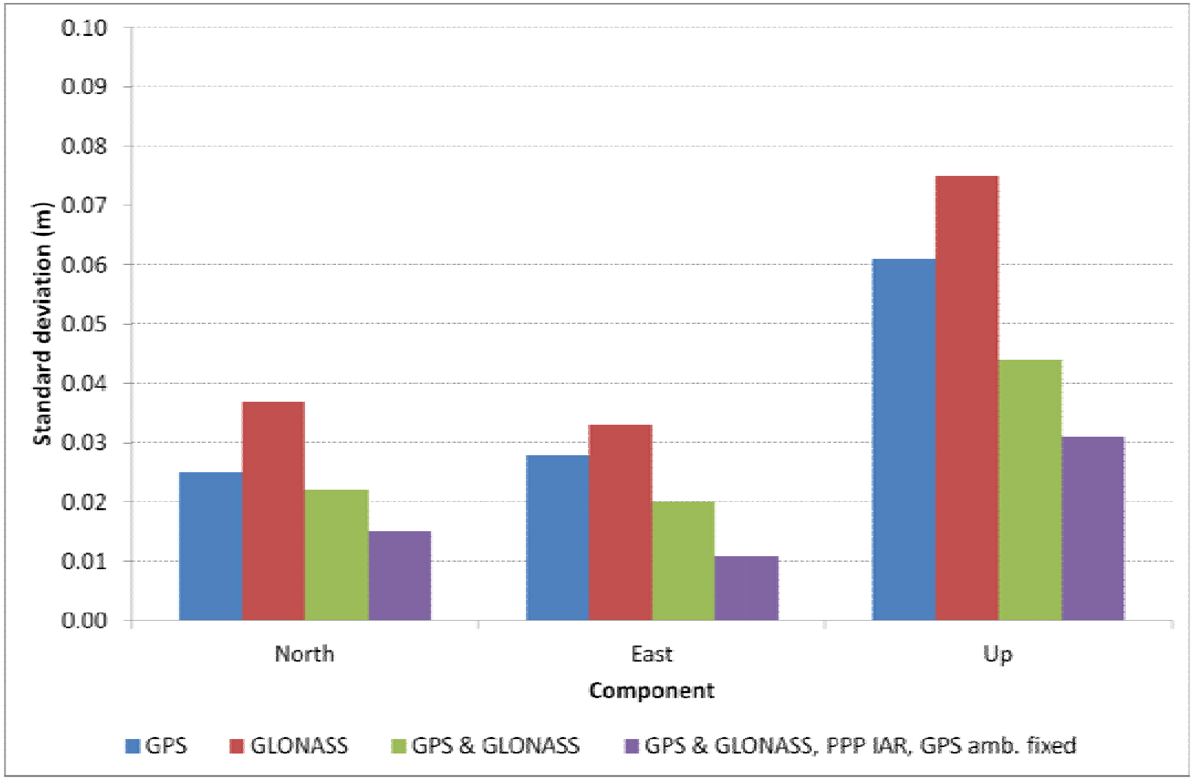
Distance from Leidschendam

Great Yarmouth	190 km
Aberdeen	700 km
Bergen	925 km
Oslo	960 km

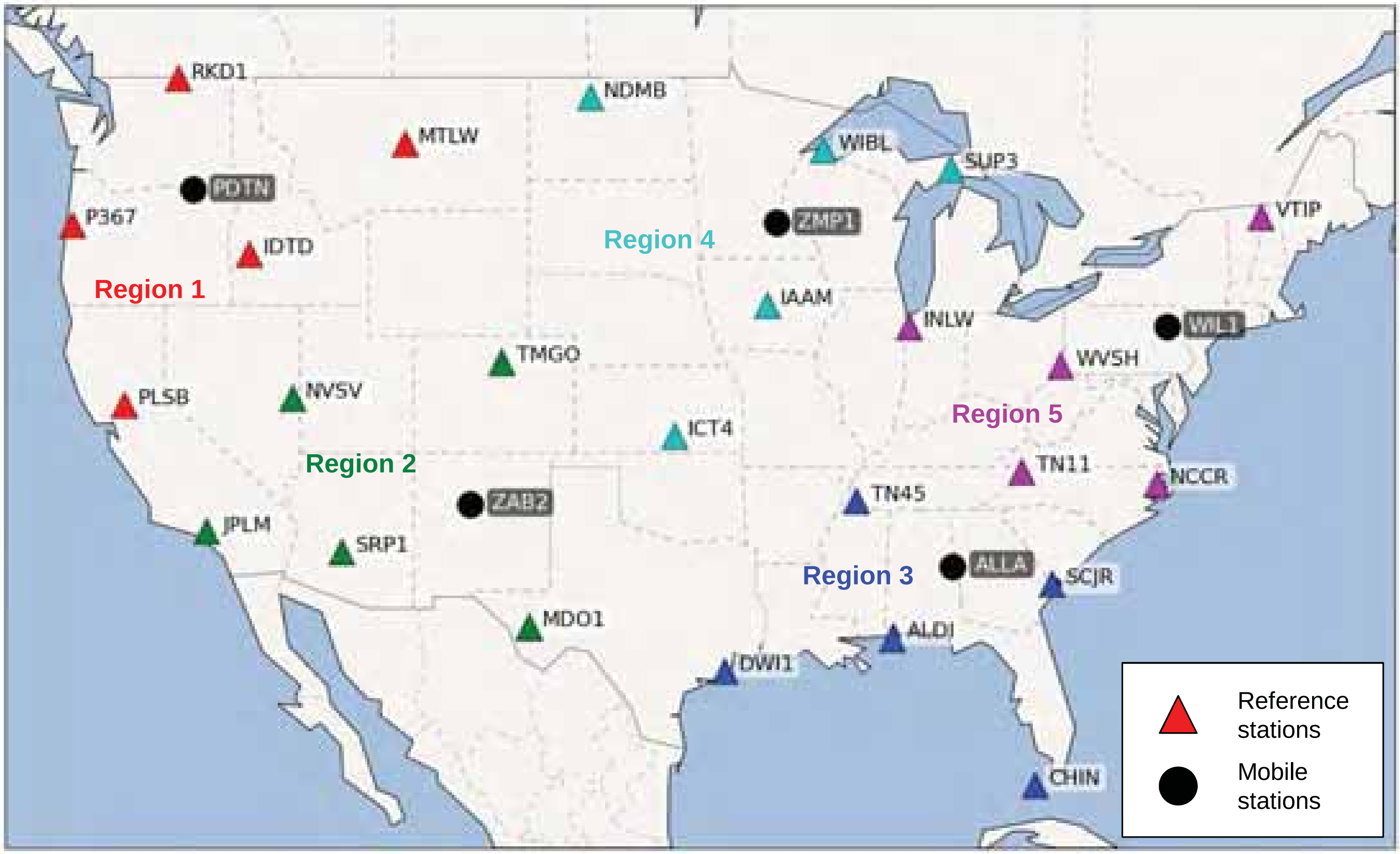
IAR – Integer Ambiguity Resolution
PPP – Precise Point Positioning

PPP and PPP IAR results

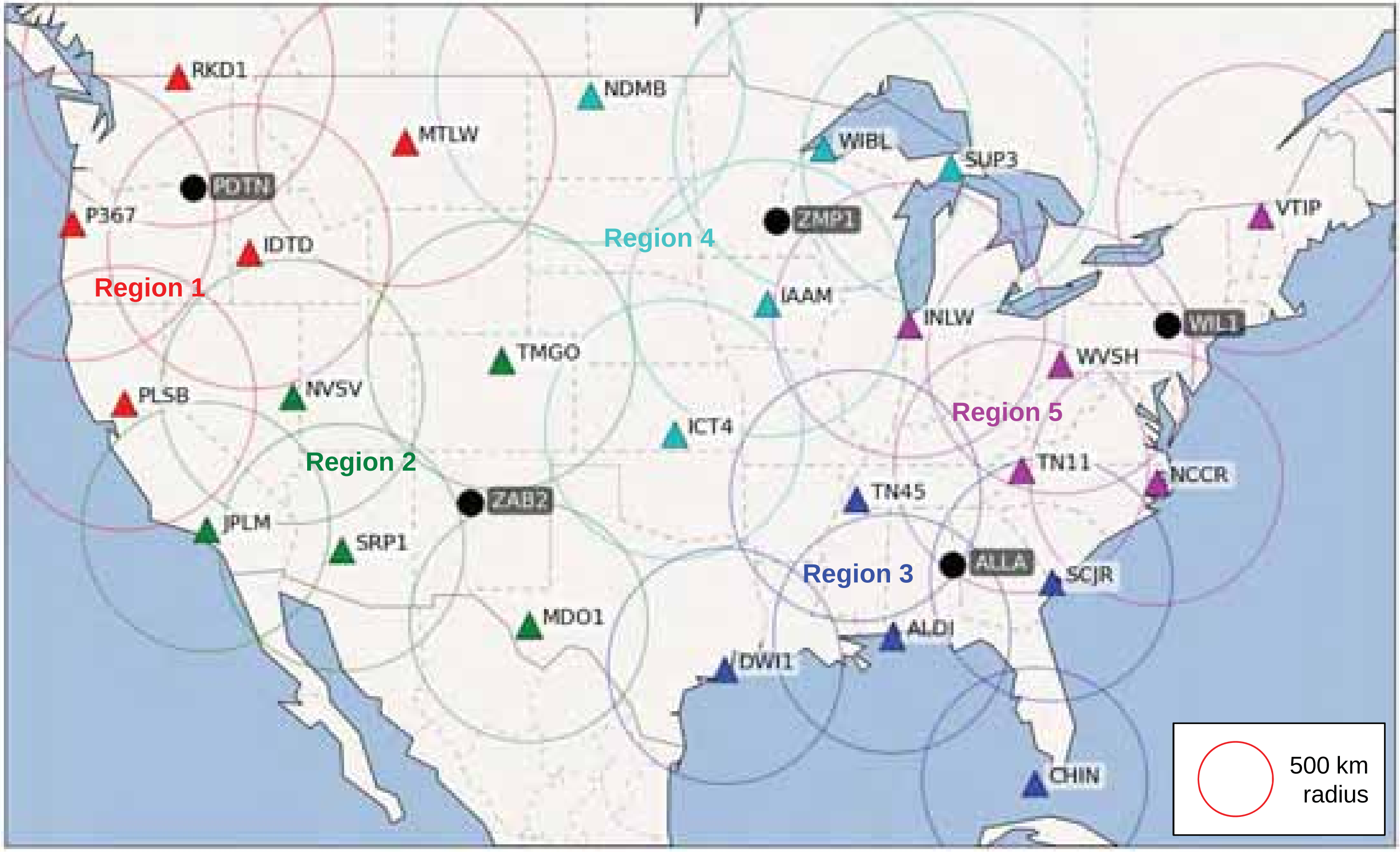
Kinematic positioning, real-time orbits and clocks, Oslo



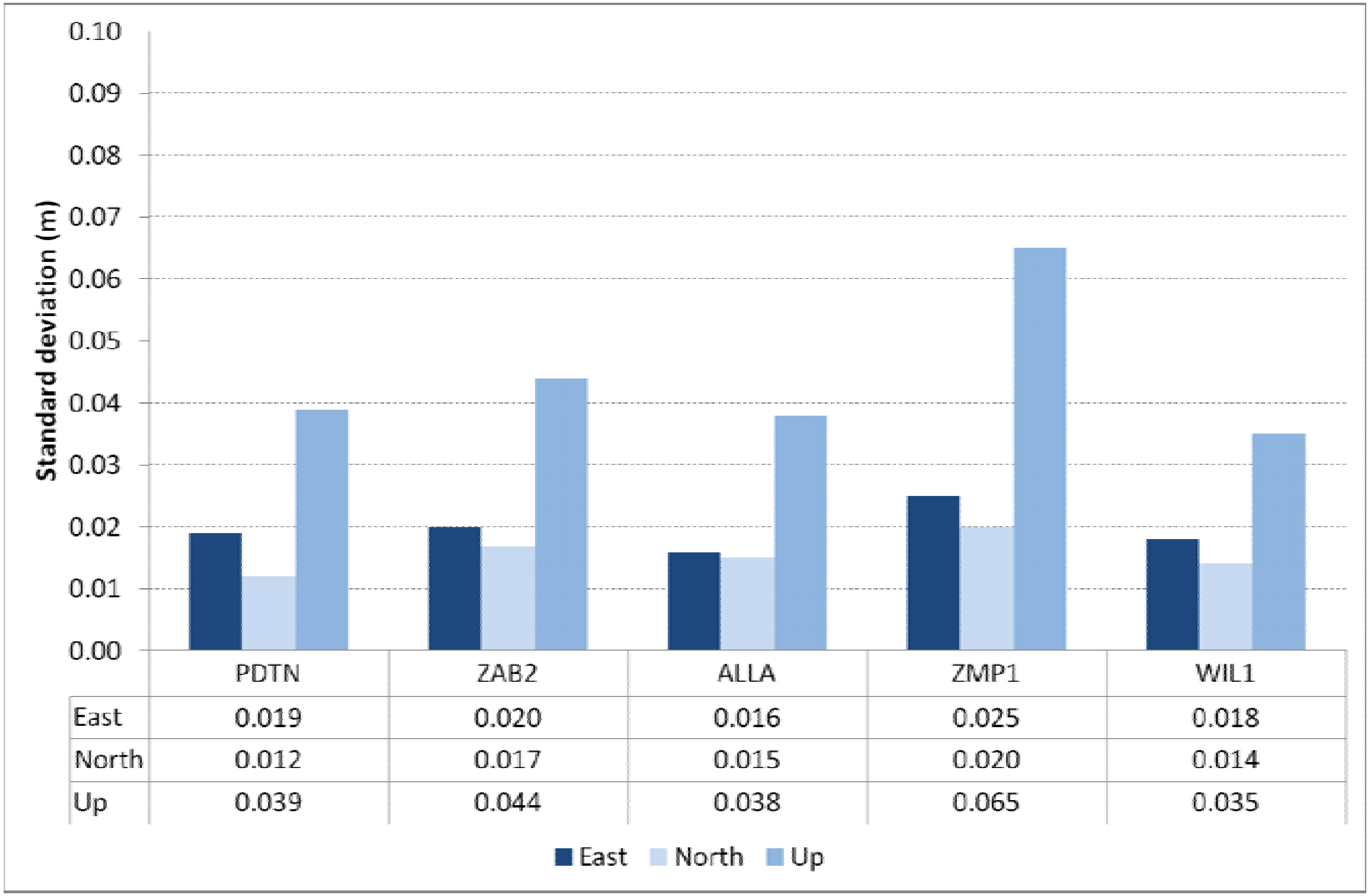
Continental USA network



Continental USA network

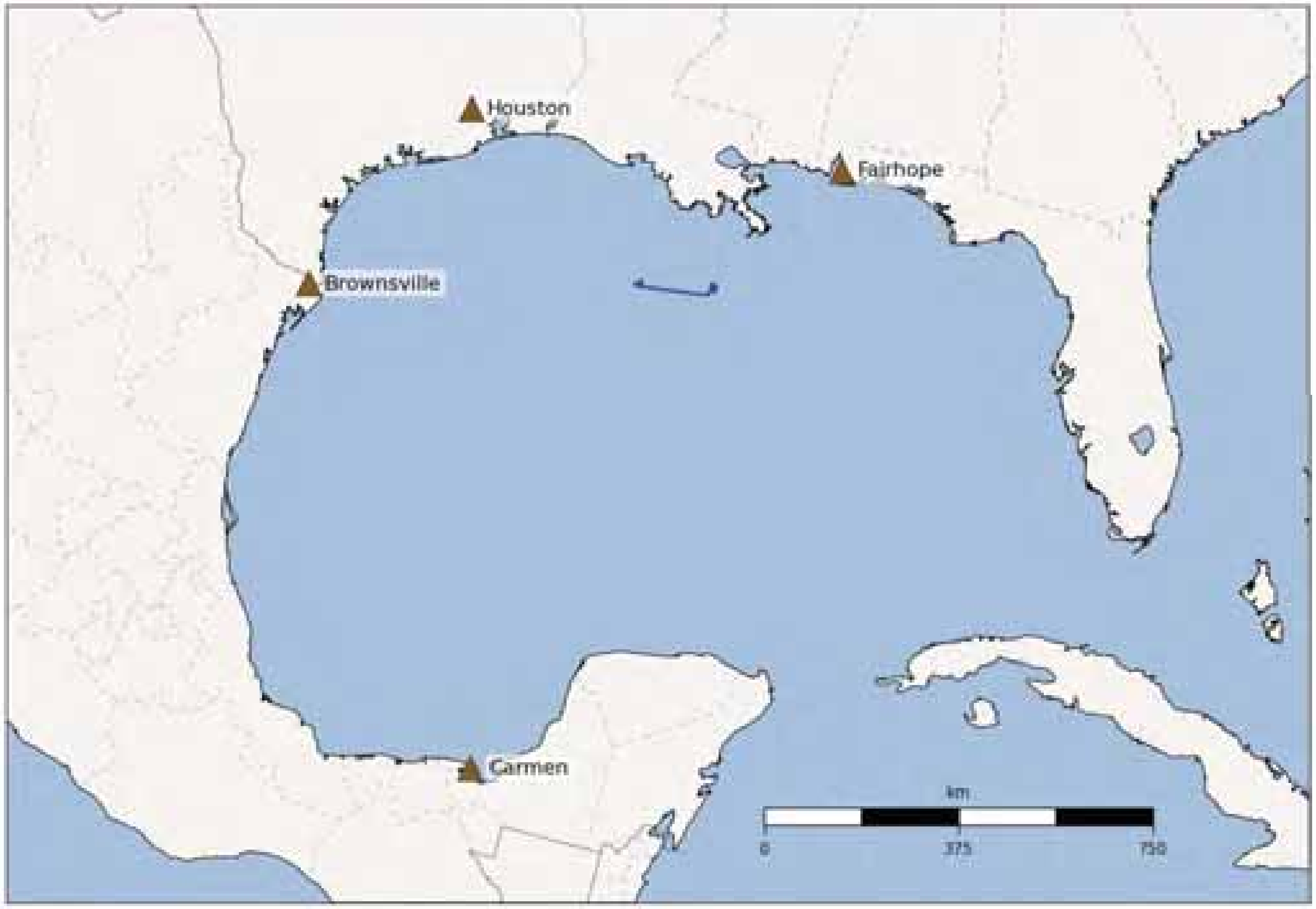


PPP IAR results

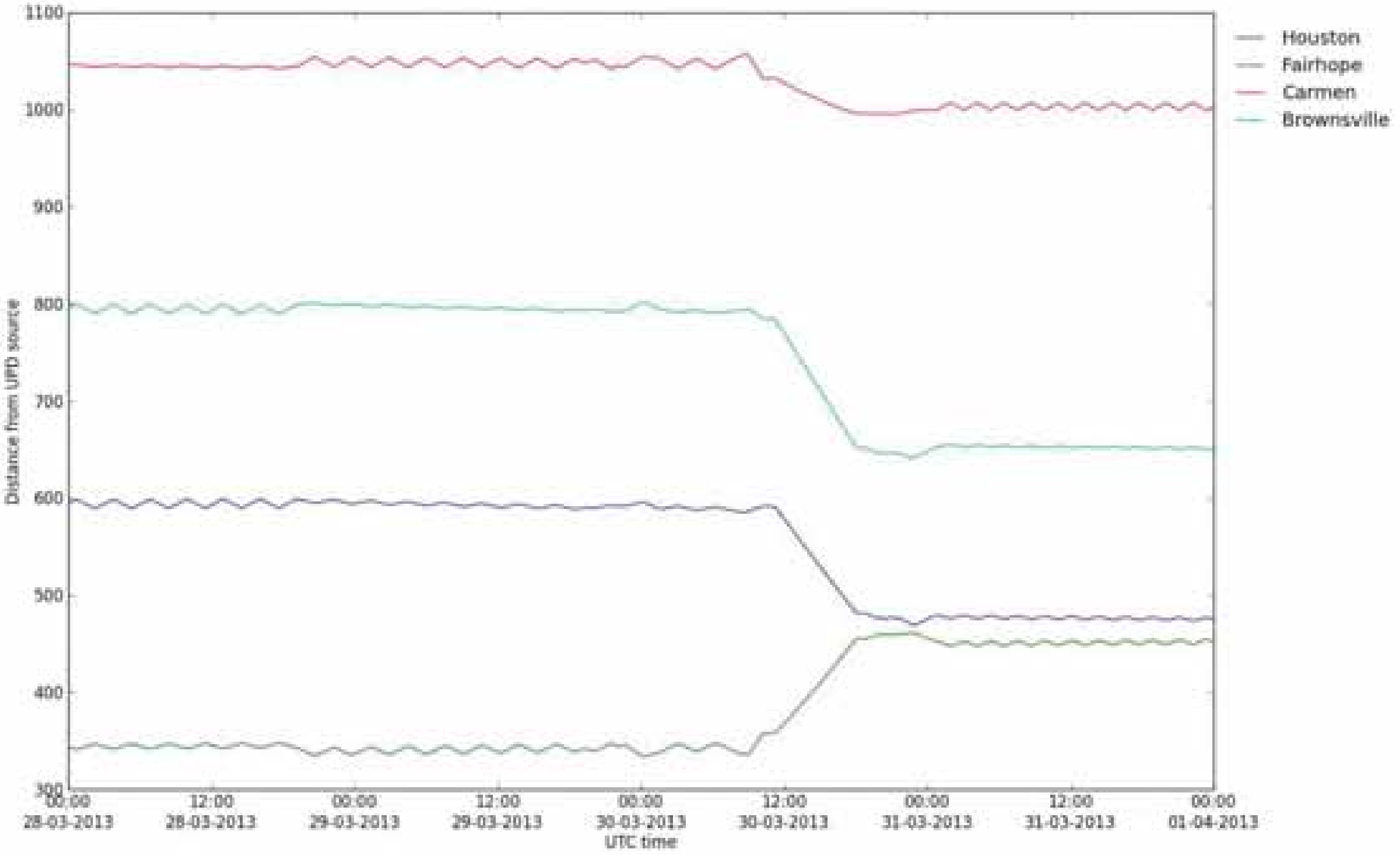


	PDTN	ZAB2	ALLA	ZMP1	WIL1
East	0.019	0.020	0.016	0.025	0.018
North	0.012	0.017	0.015	0.020	0.014
Up	0.039	0.044	0.038	0.065	0.035

Test bed Gulf of Mexico

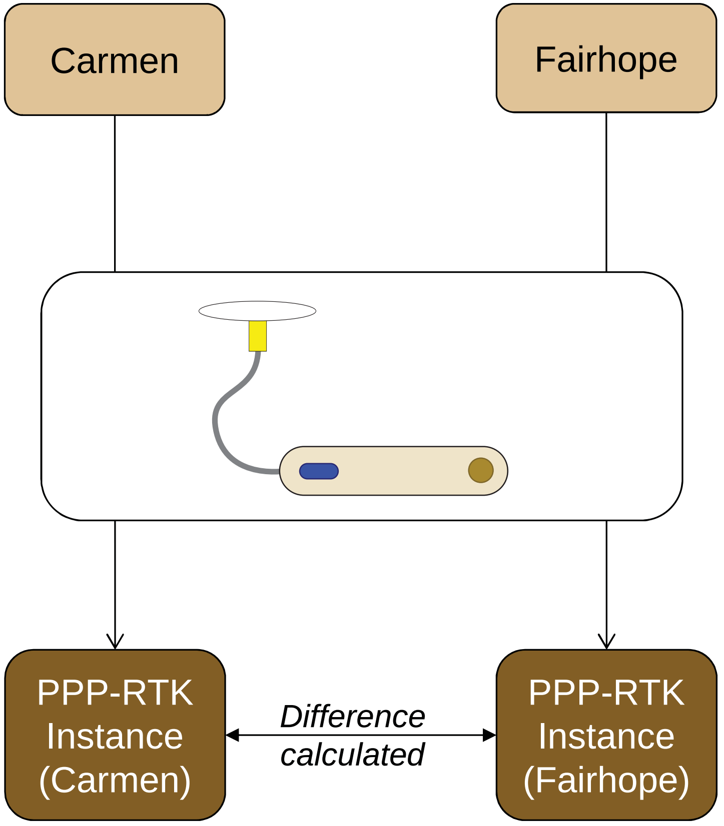


Comparing different sources of UPDs

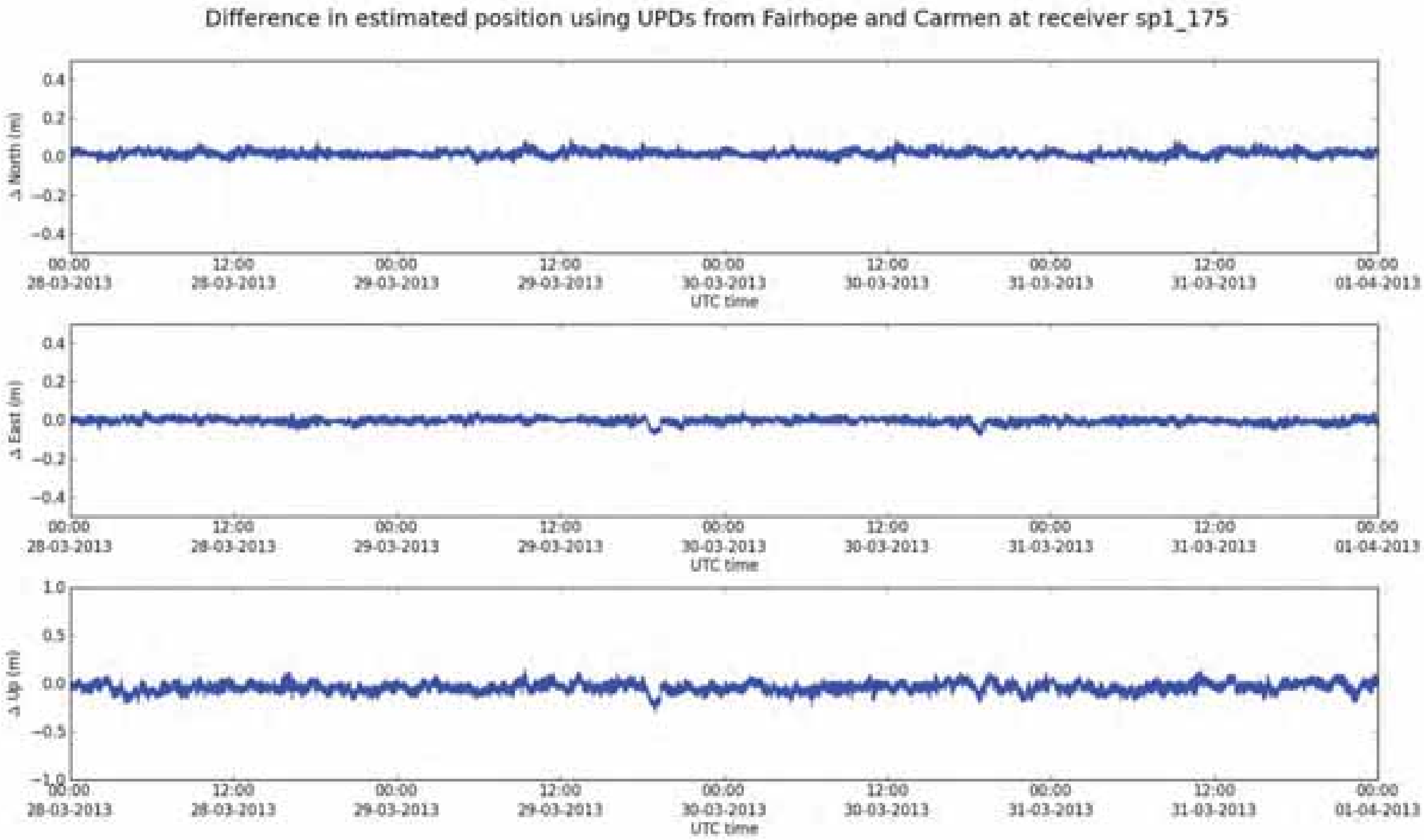


Comparing different sources of UPDs

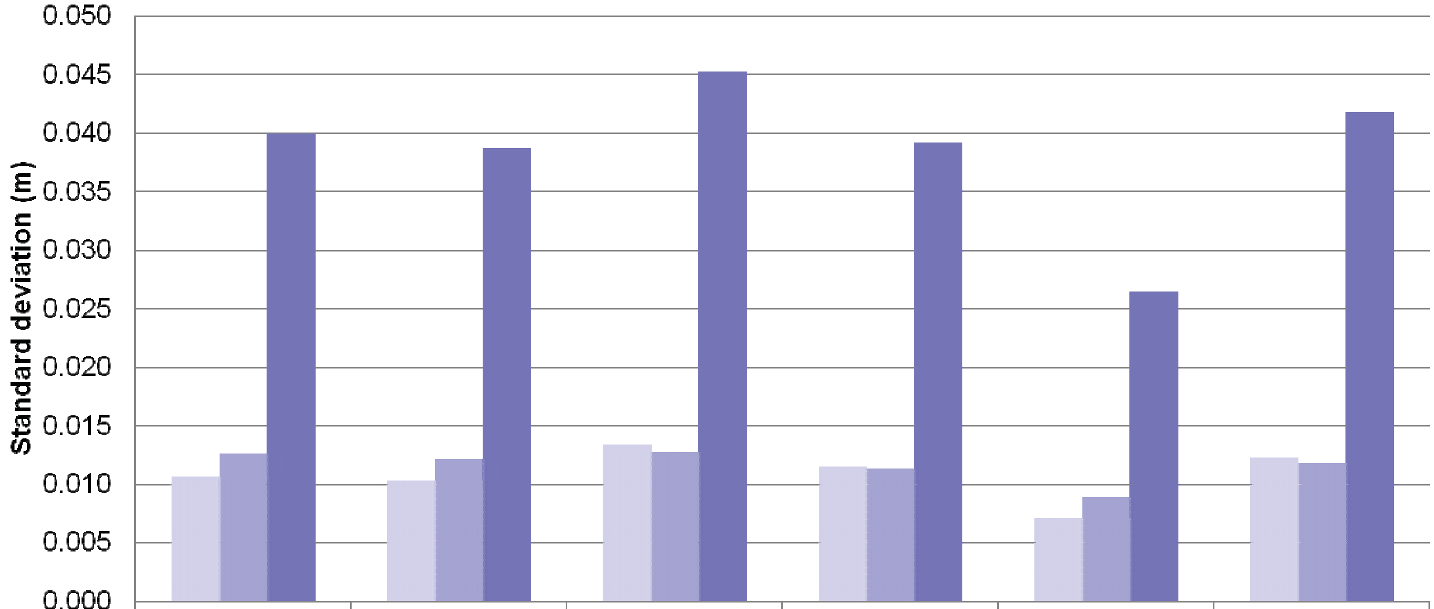
- Dynamic environment with real-time solution.
- One antenna mounted
- Two instances of a PPP IAR solution with different sources of UPDs.
  - e.g. Carmen and Fairhope
- Difference in east, north and height components calculated



Comparing different sources of UPDs



Comparing different sources of UPDs



	Houston and Fairhope	Houston and Carmen	Fairhope and Carmen	Houston and Brownsville	Fairhope and Brownsville	Carmen and Brownsville
N	0.011	0.010	0.013	0.011	0.007	0.012
E	0.013	0.012	0.013	0.011	0.009	0.012
U	0.040	0.039	0.045	0.039	0.026	0.042

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BeiDou and Galileo – satellites

	BeiDou			Galileo	GPS
Orbit type	MEO	GEO	IGSO	MEO	MEO
Satellites	4 (27)	5 (5)	5 (3)	4 (30)	31
Semi-major axis	27878 km	42164 km	42164 km	29600 km	26600 km
Inclination	55°	0°	55°	56°	55°
Orbital planes	3	1	3	3	6

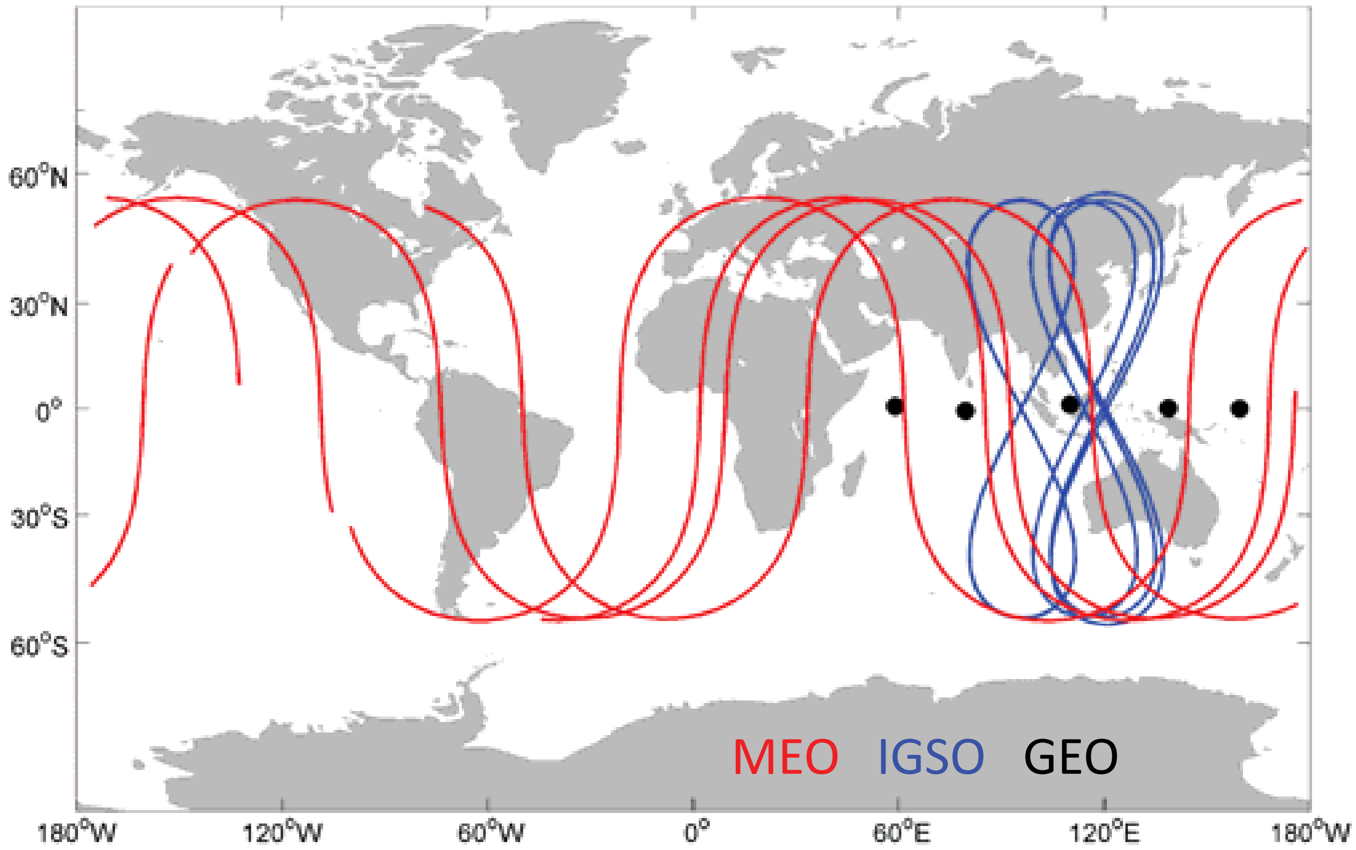
(.) – Number of satellites when fully operational

BeiDou and Galileo – signal frequencies

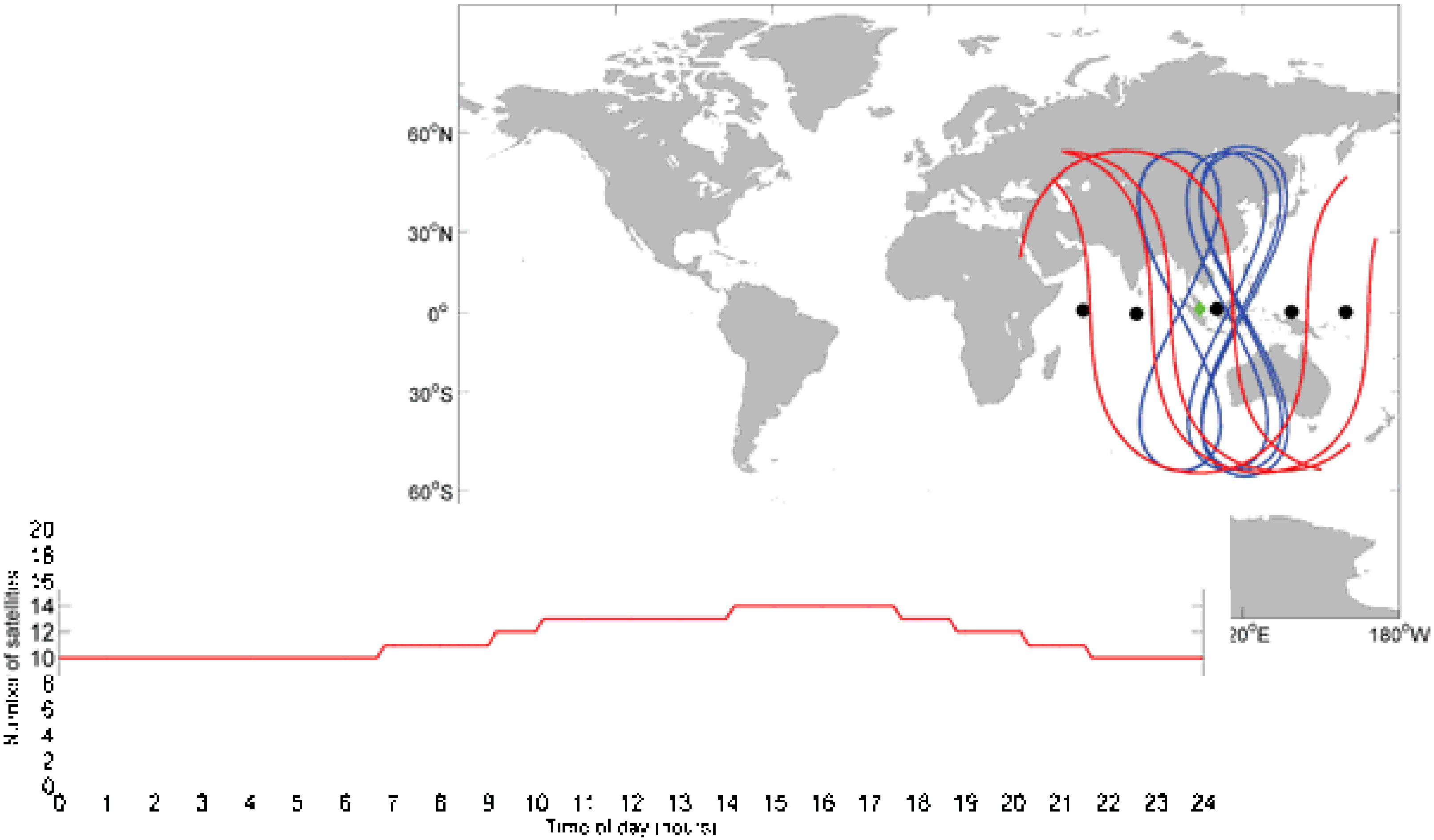
BeiDou		Galileo		GPS	
B1	1561.098	E1	1575.42	L1	1575.42
B2	1207.14	E5a	1176.45	L2	1227.60
B3	1268.52	E5b	1207.14	L5	1176.45
		E5	1191.795		

All frequencies in MHz

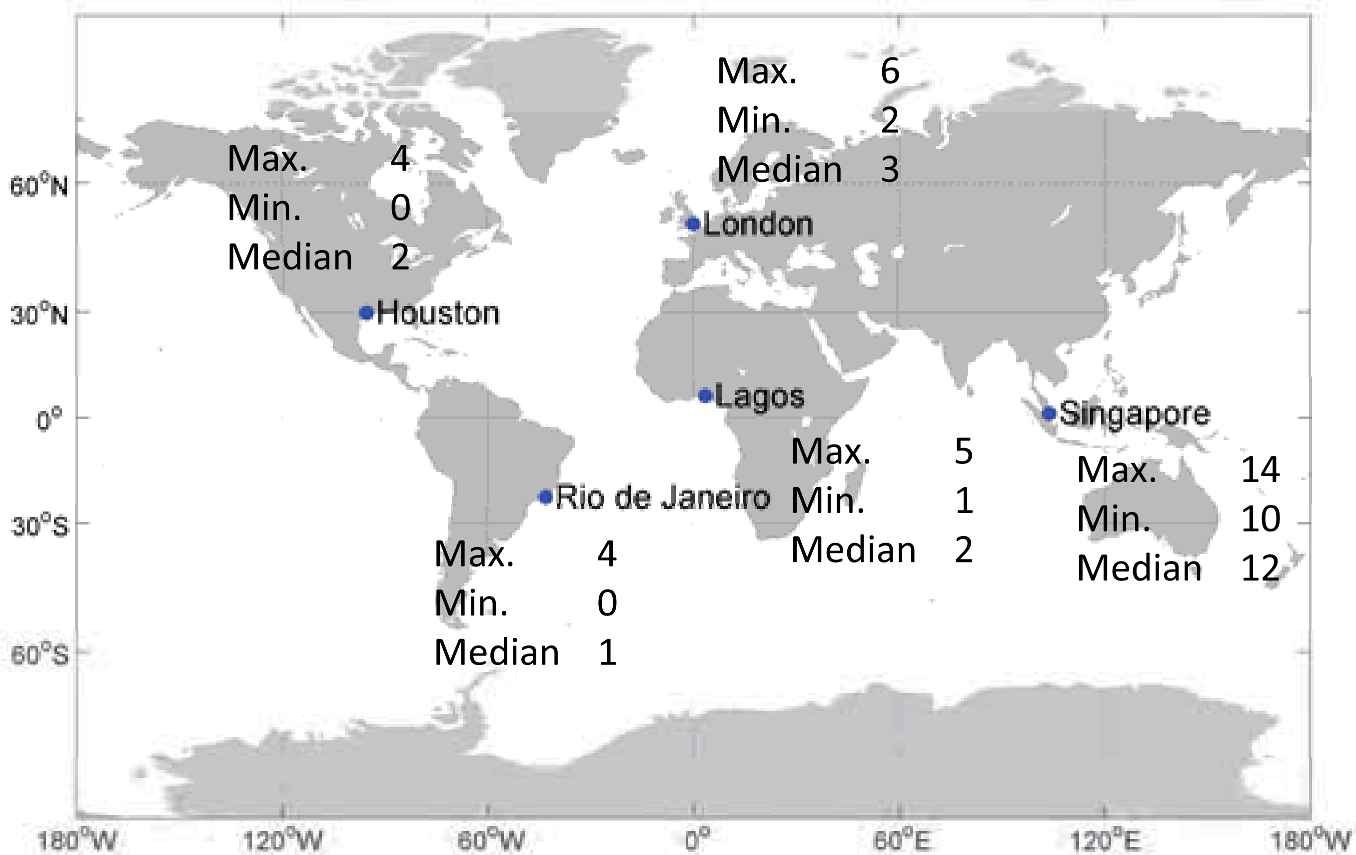
BeiDou ground tracks – 6 November 2013



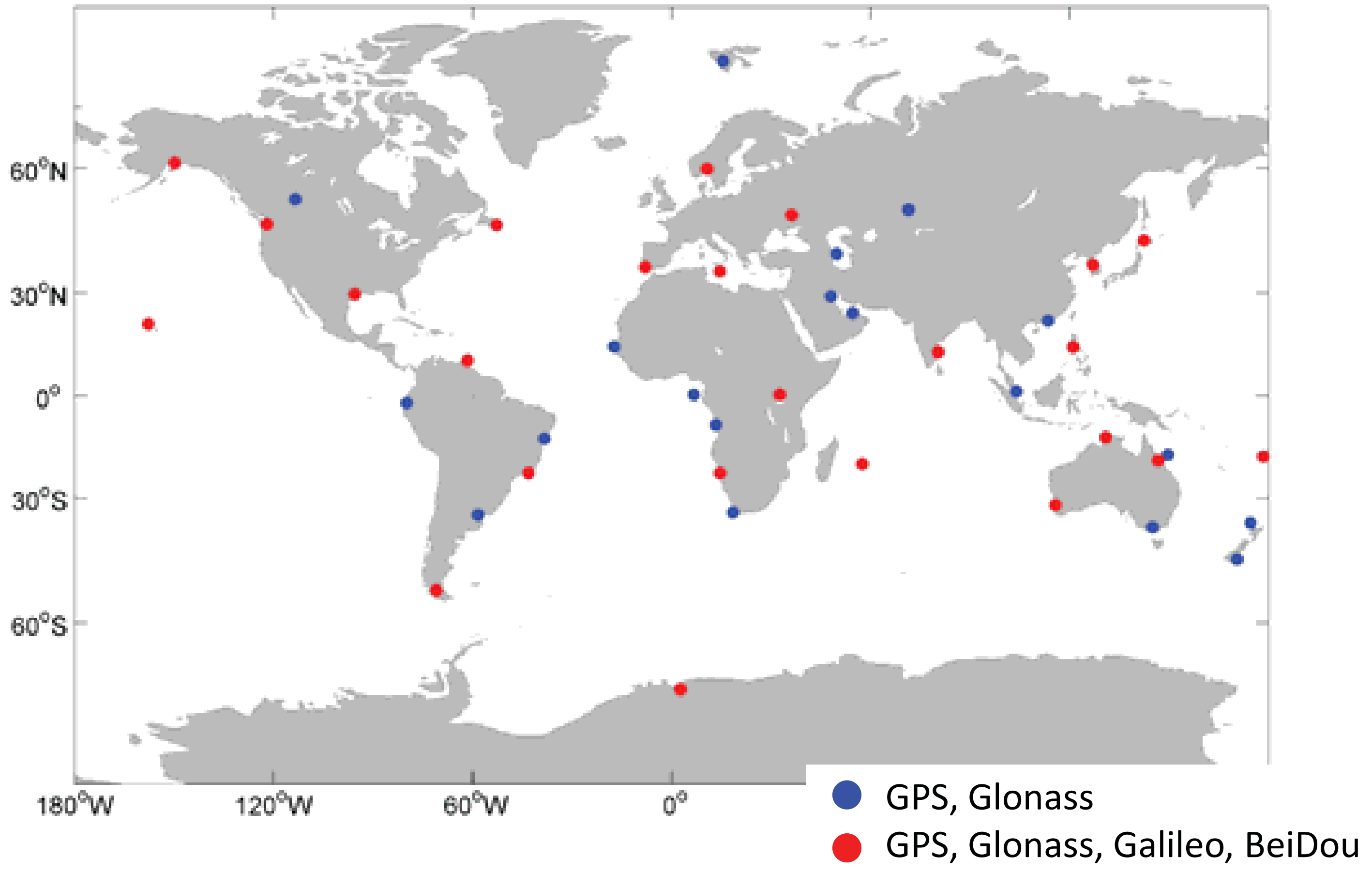
Singapore – ground tracks and visible satellites



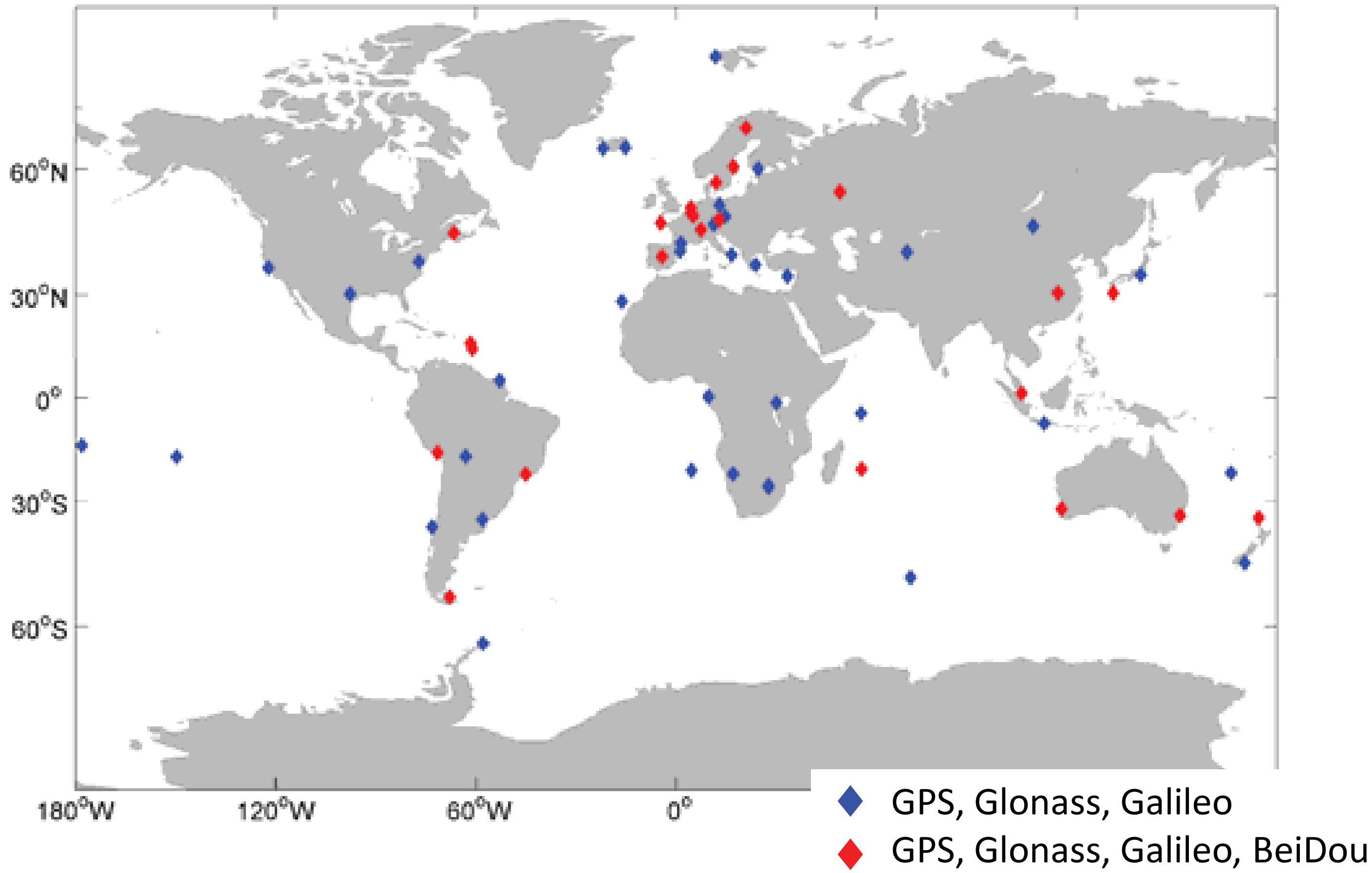
BeiDou satellite visibility – 6 November 2013



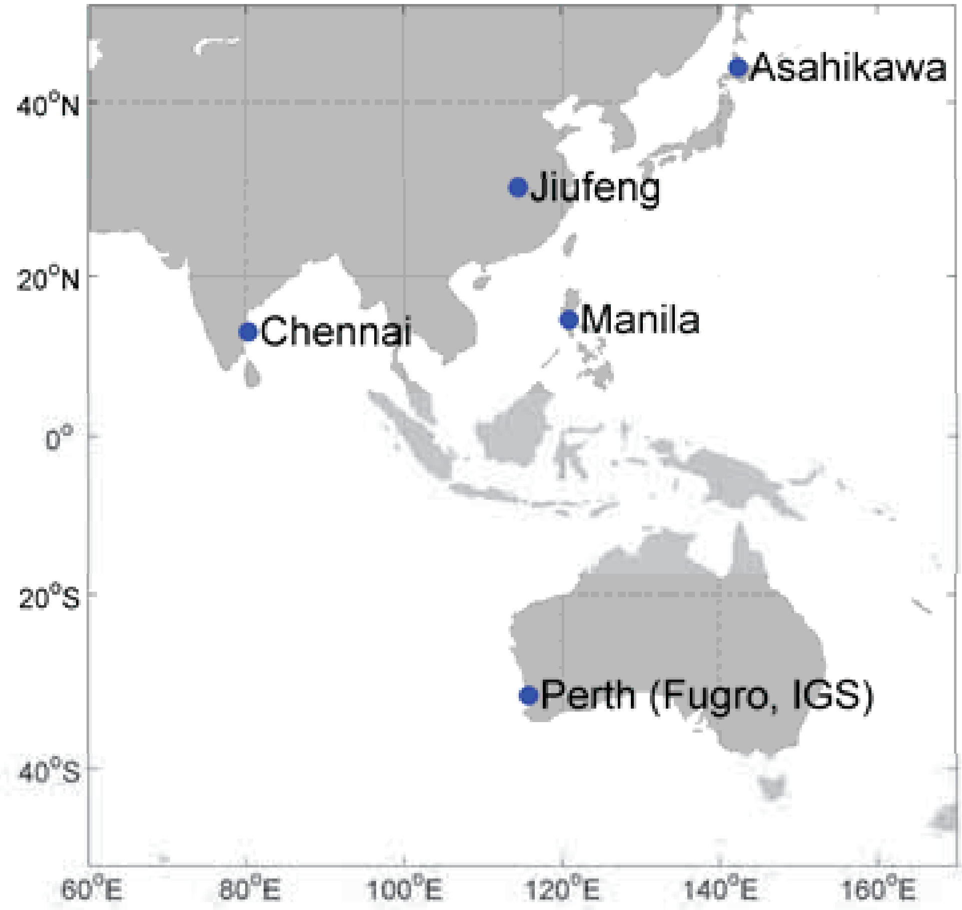
Fugro G2 tracking network



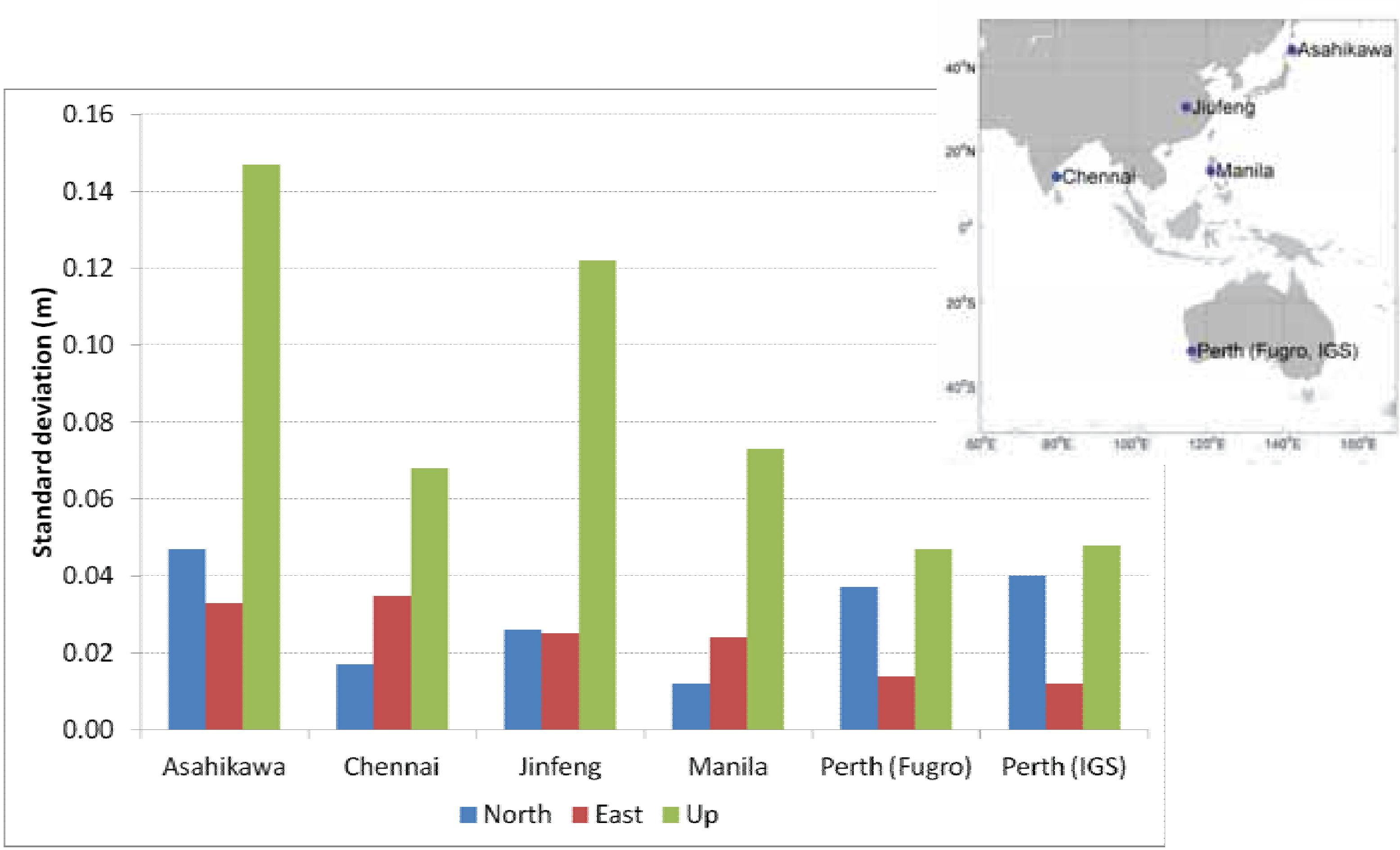
IGS MGEX tracking network



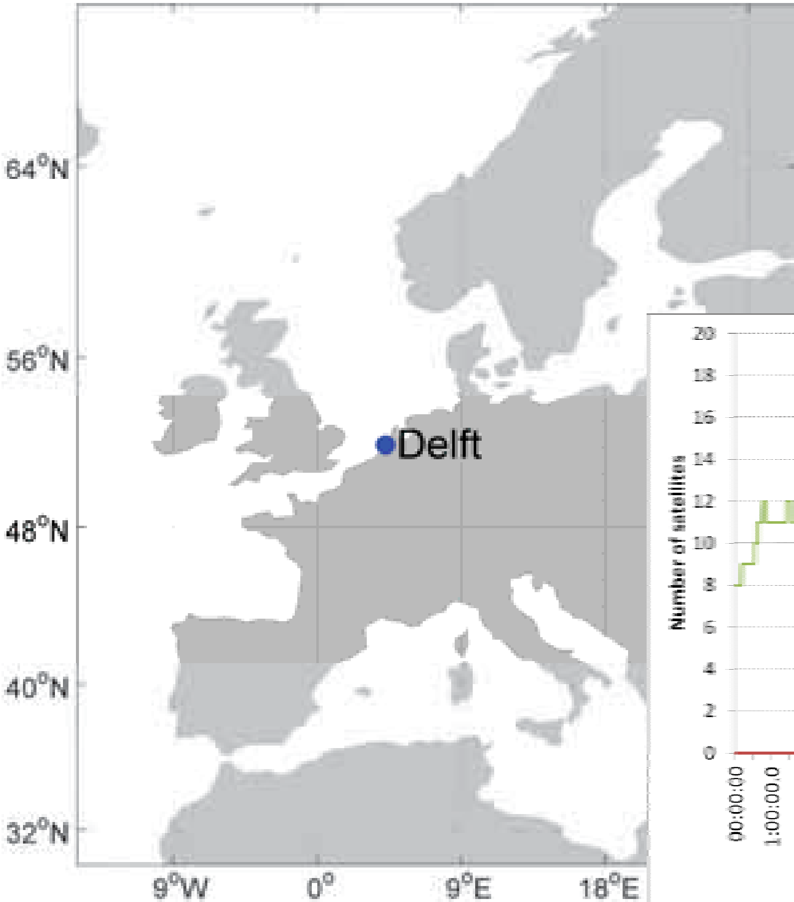
BeiDou-only PPP stations

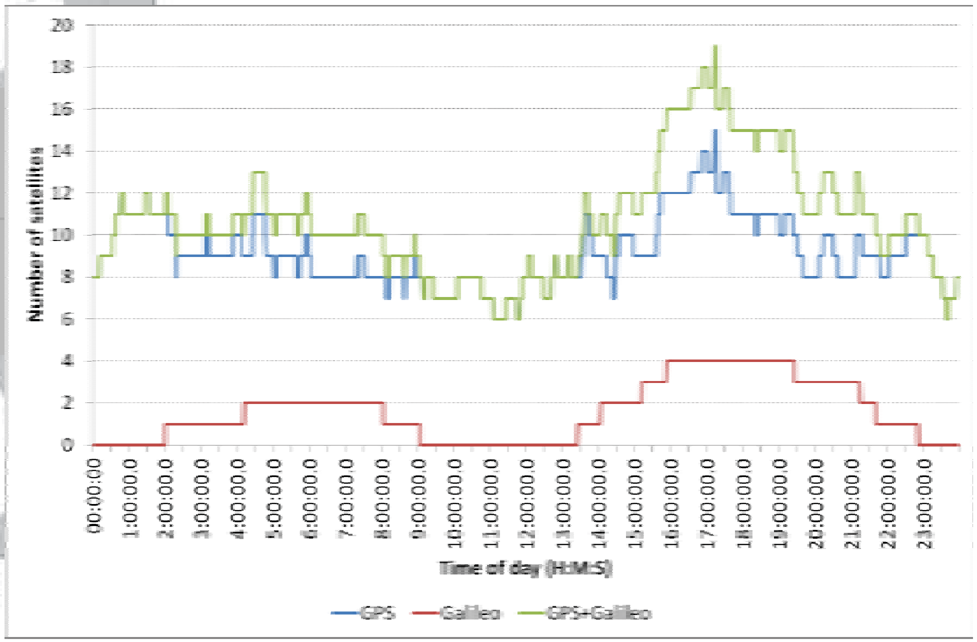


BeiDou-only kinematic PPP results

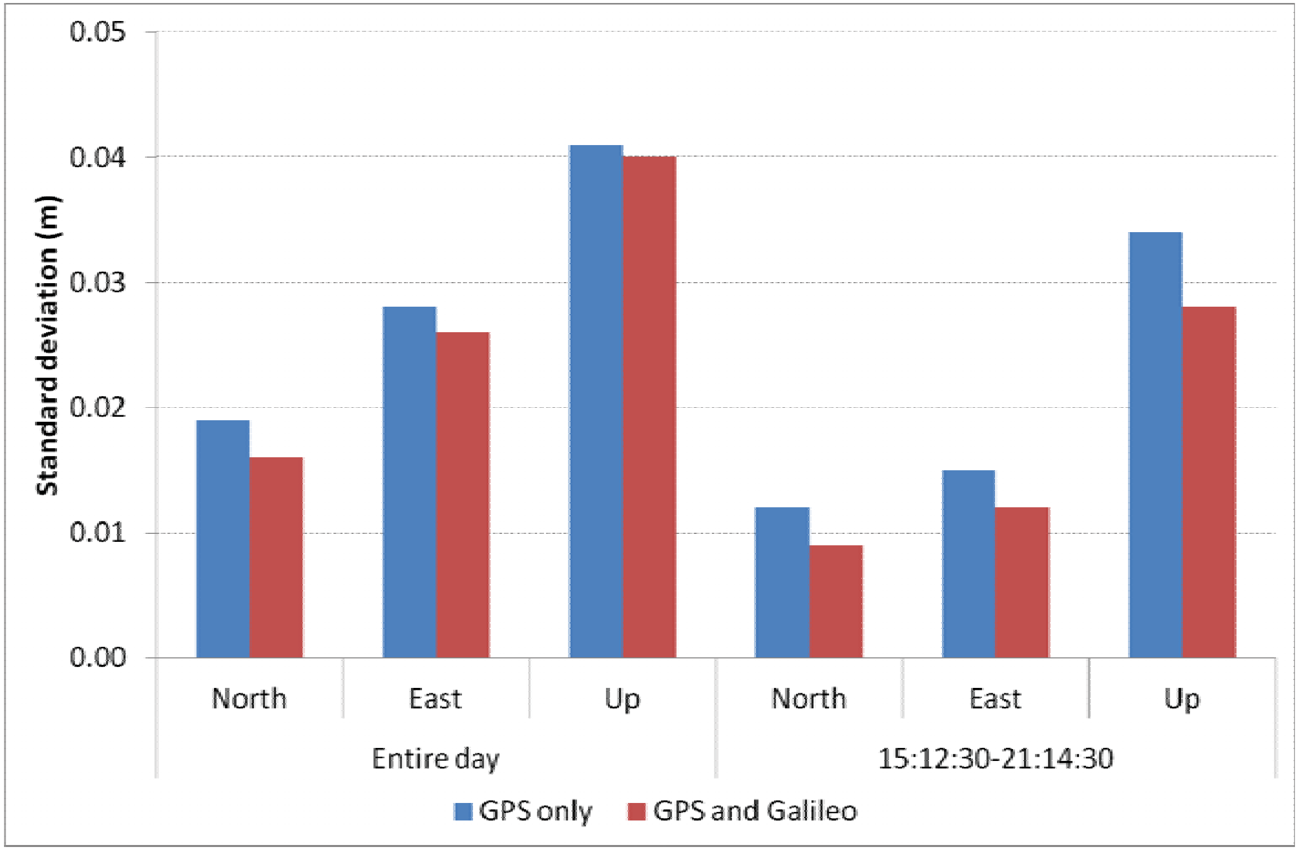


GPS+Galileo PPP station

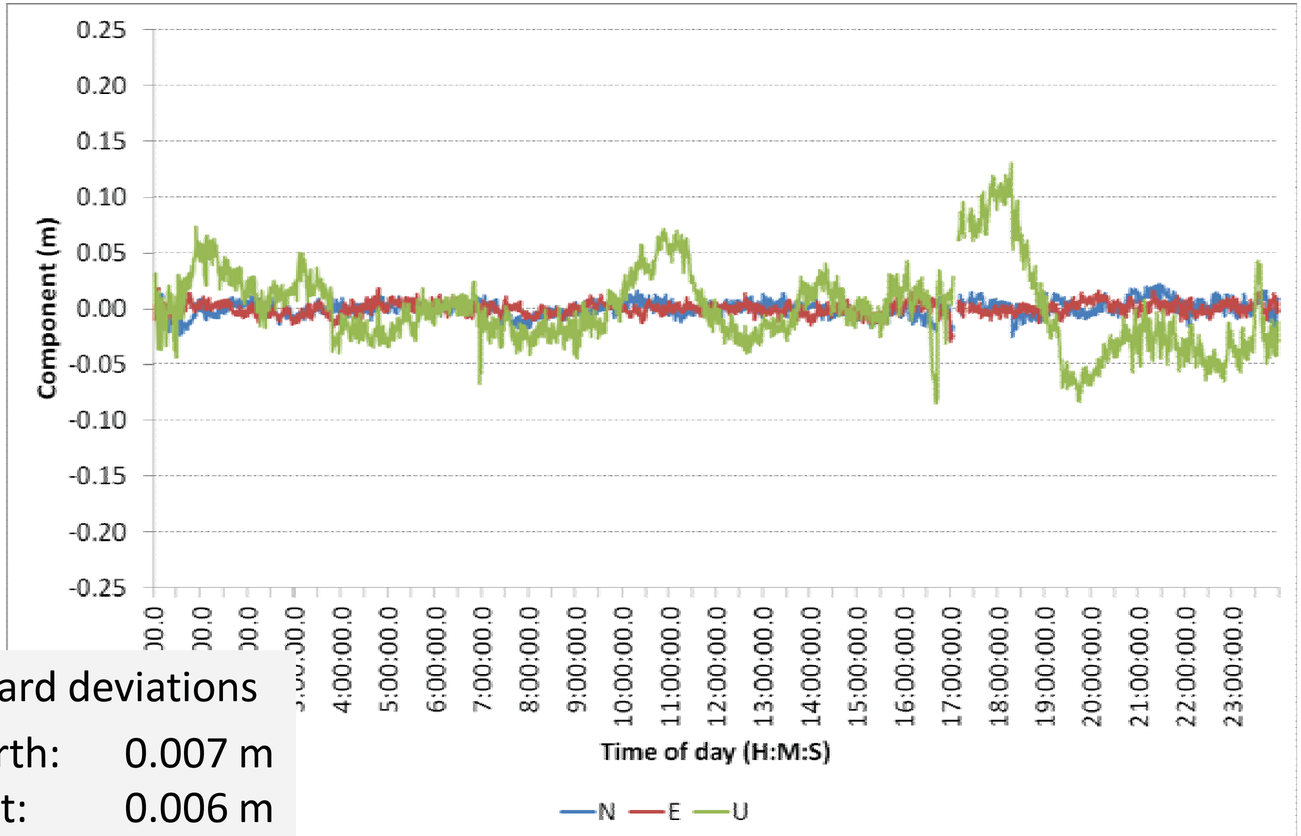




GPS-only and GPS+Galileo kinematic PPP results



PPP IAR – GPS/Glonass/BeiDou/Galileo

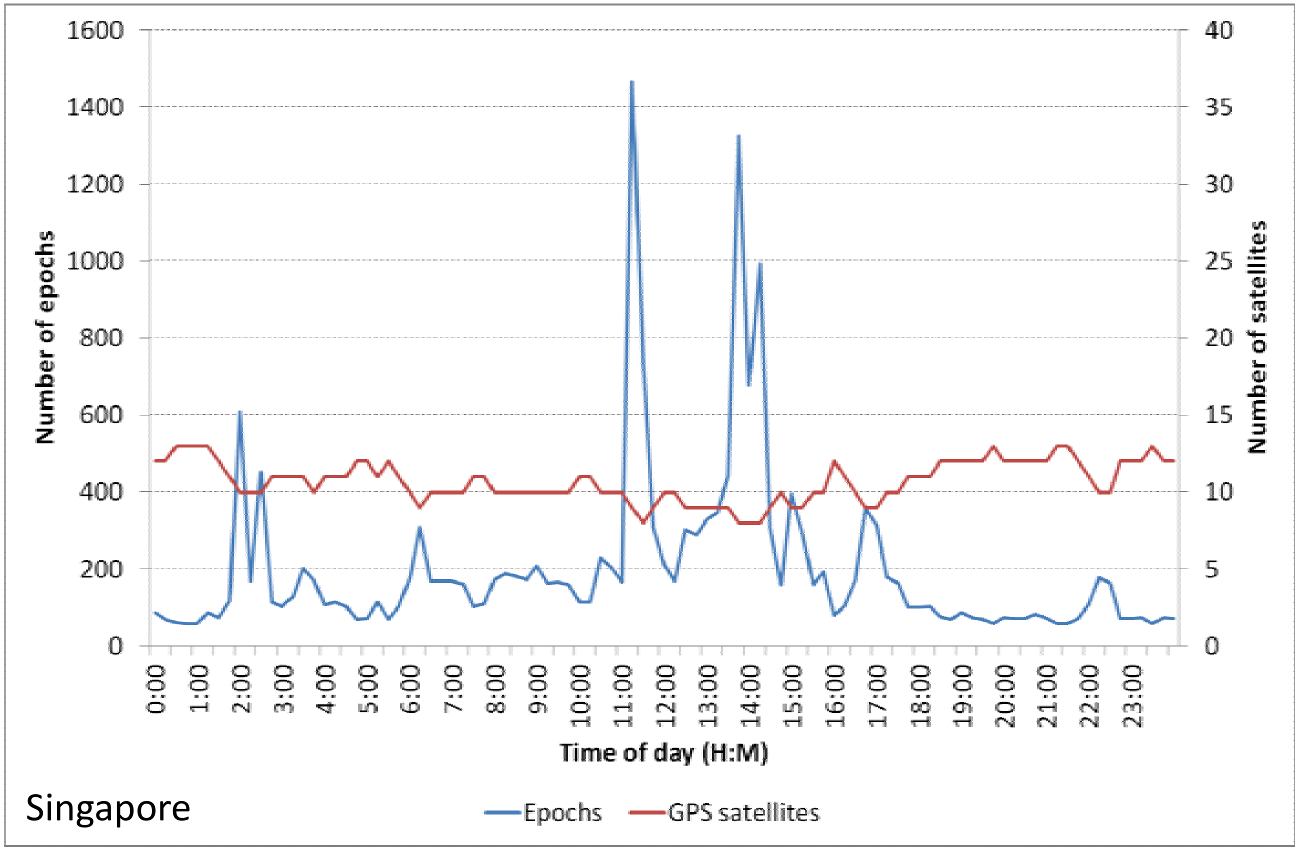


Standard deviations

North:	0.007 m
East:	0.006 m
Up:	0.035 m

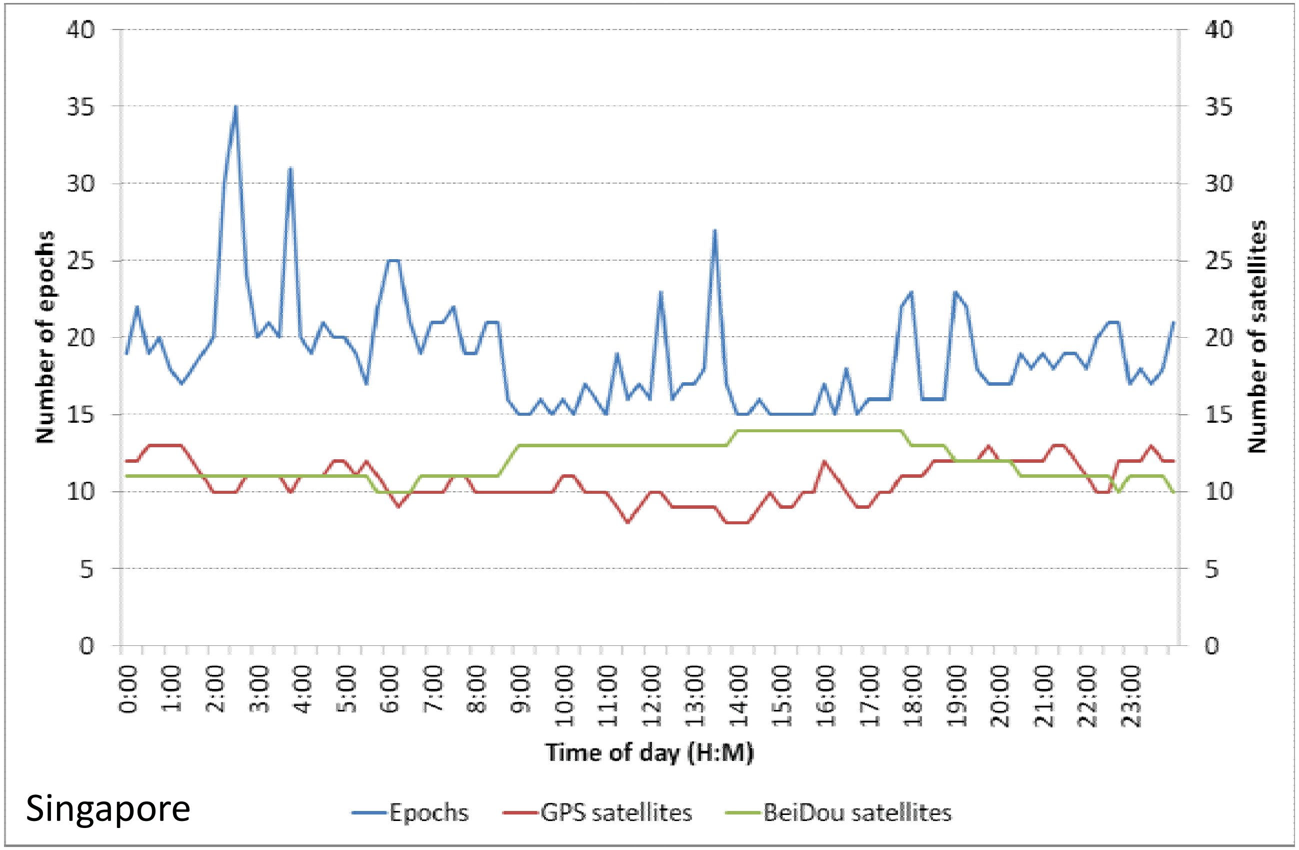
PPP IAR convergence times – GPS only

Dual frequency GPS, current constellation, 99.9% success rate



PPP IAR convergence times – GPS and BeiDou

Dual frequency GPS, triple frequency BeiDou, current constellation, 99.9% success rate



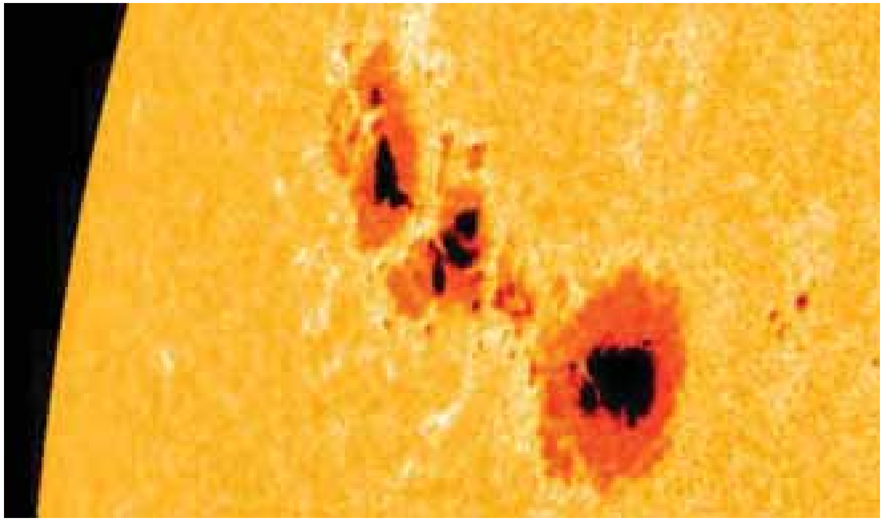
Contents

- Fugro
- GNSS services
- Precise Point Positioning and Integer Ambiguity Resolution
- BeiDou and Galileo
- Solar events and ionospheric scintillation

Sunspot 1302, Sep 2011

Sunspot region 1302, Sep 24, 2011

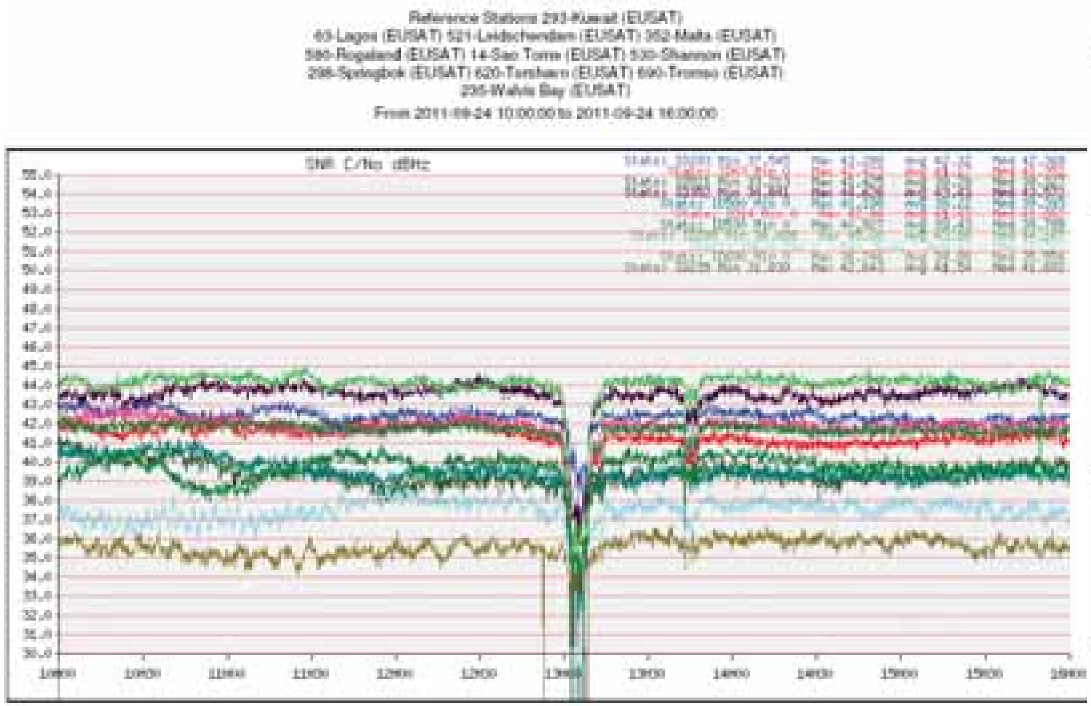
Sunspot 1302 poses a threat for X-class solar flares. Credit: SDO/HMI

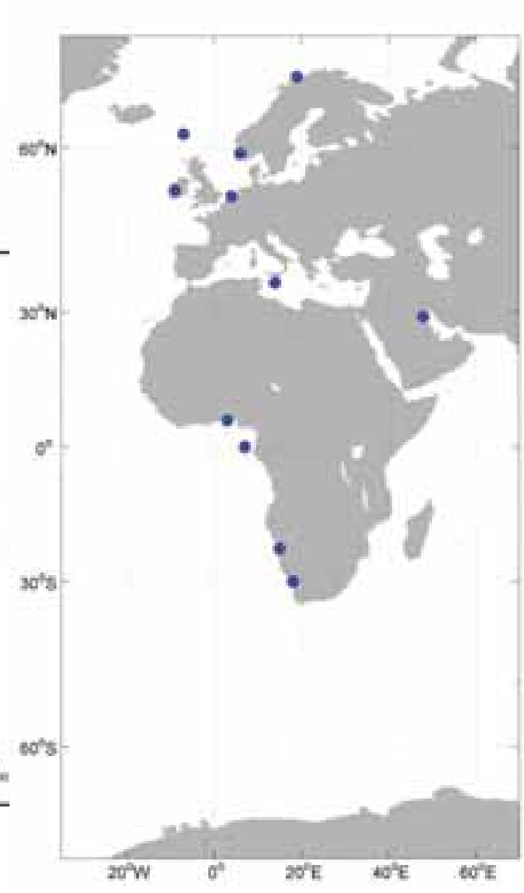


Affected Fugro reference stations

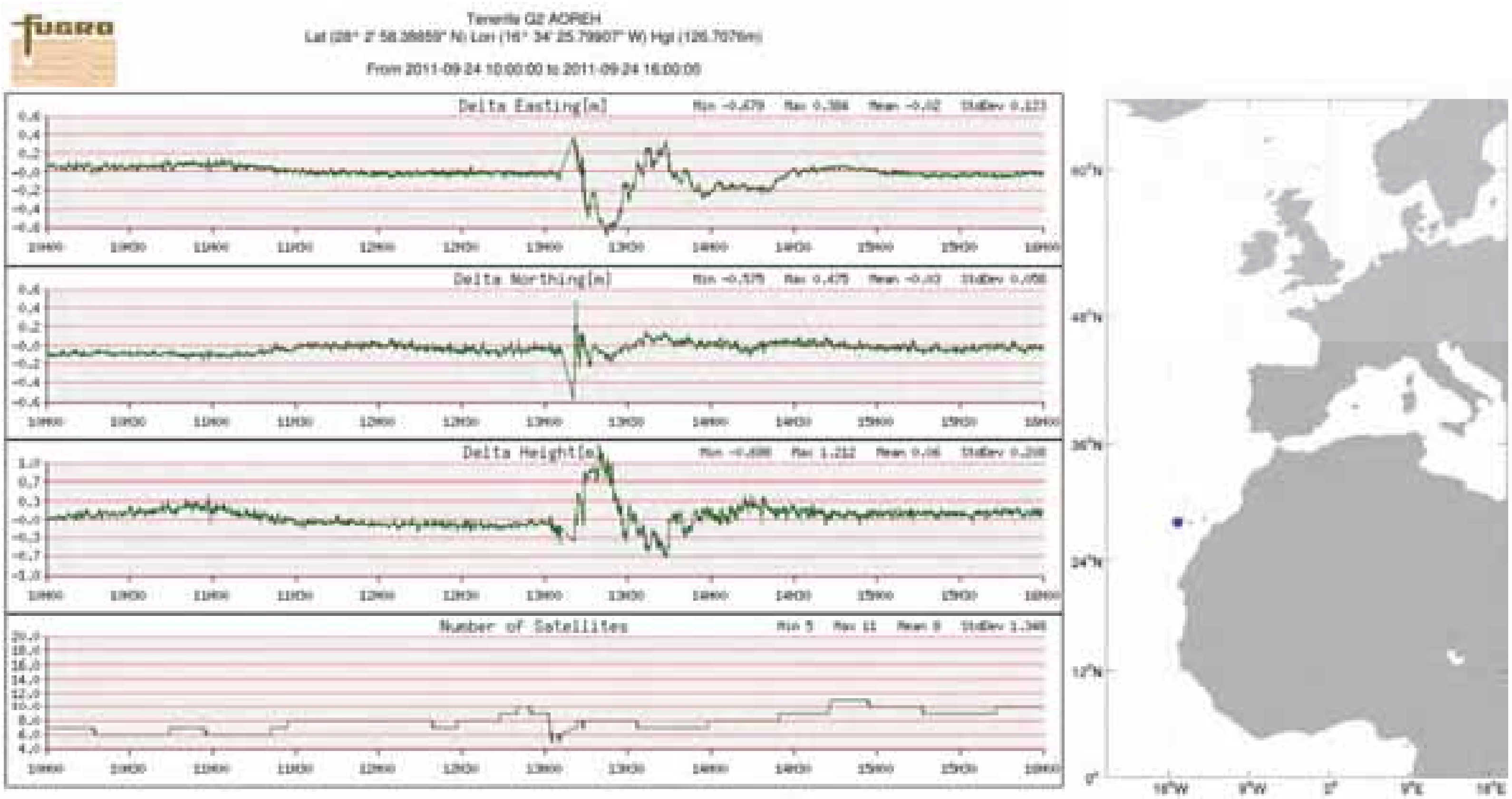
All receivers on sunlit part of the Earth were affected

L-band tracking EUSAT, Sep 24

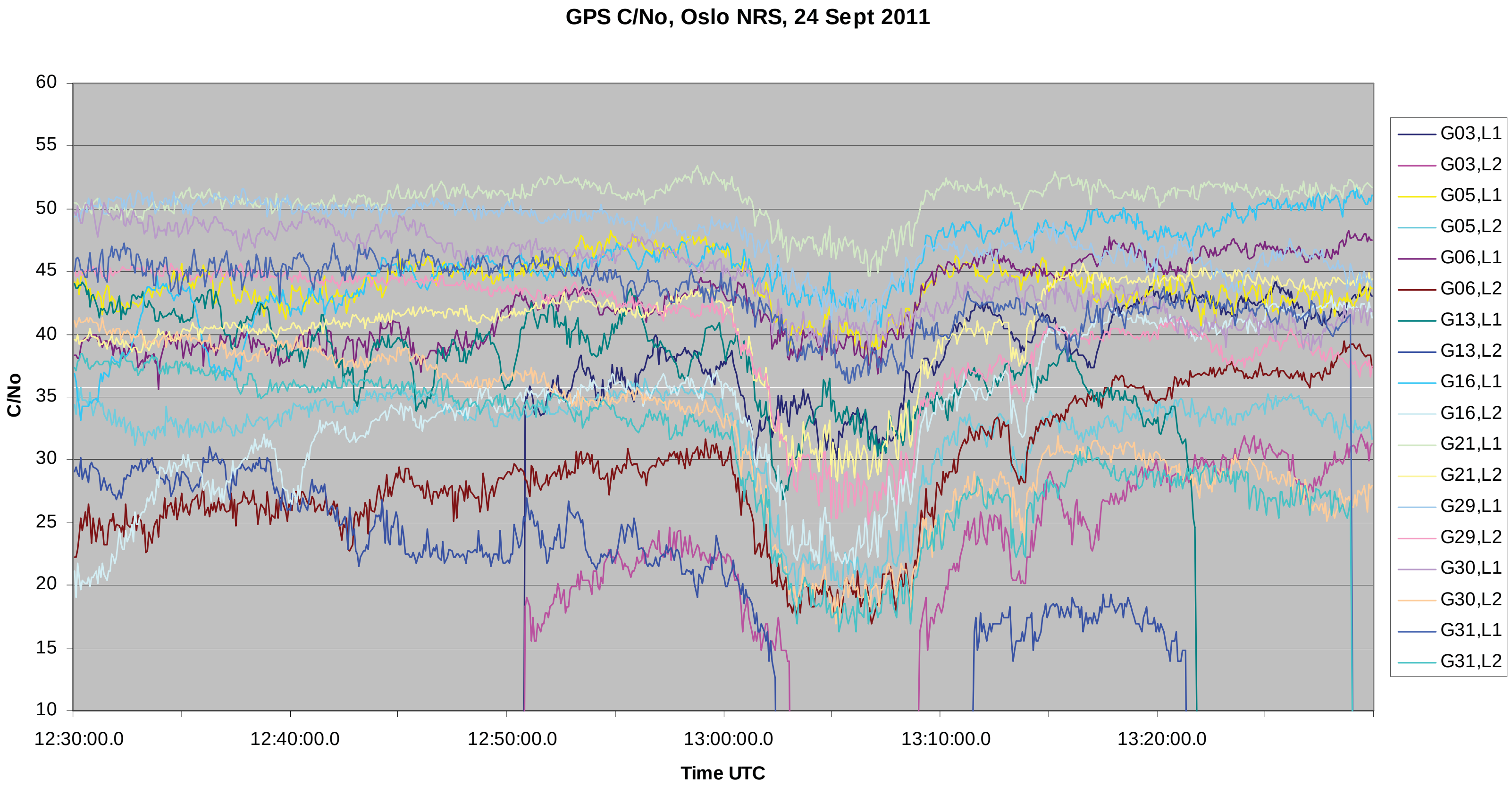




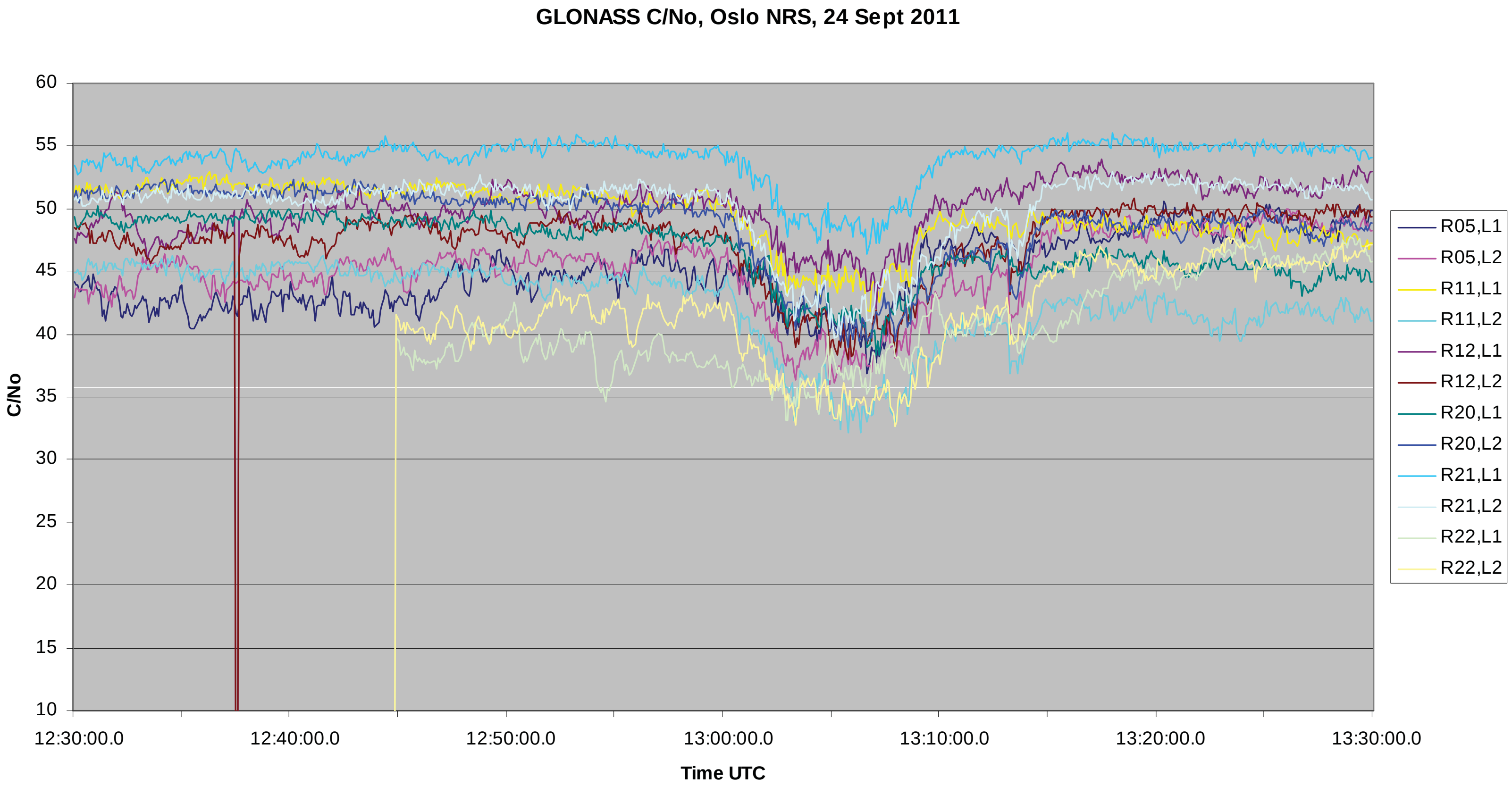
Tenerife G2 performance, Sep 24



GPS tracking Oslo, Sep 24



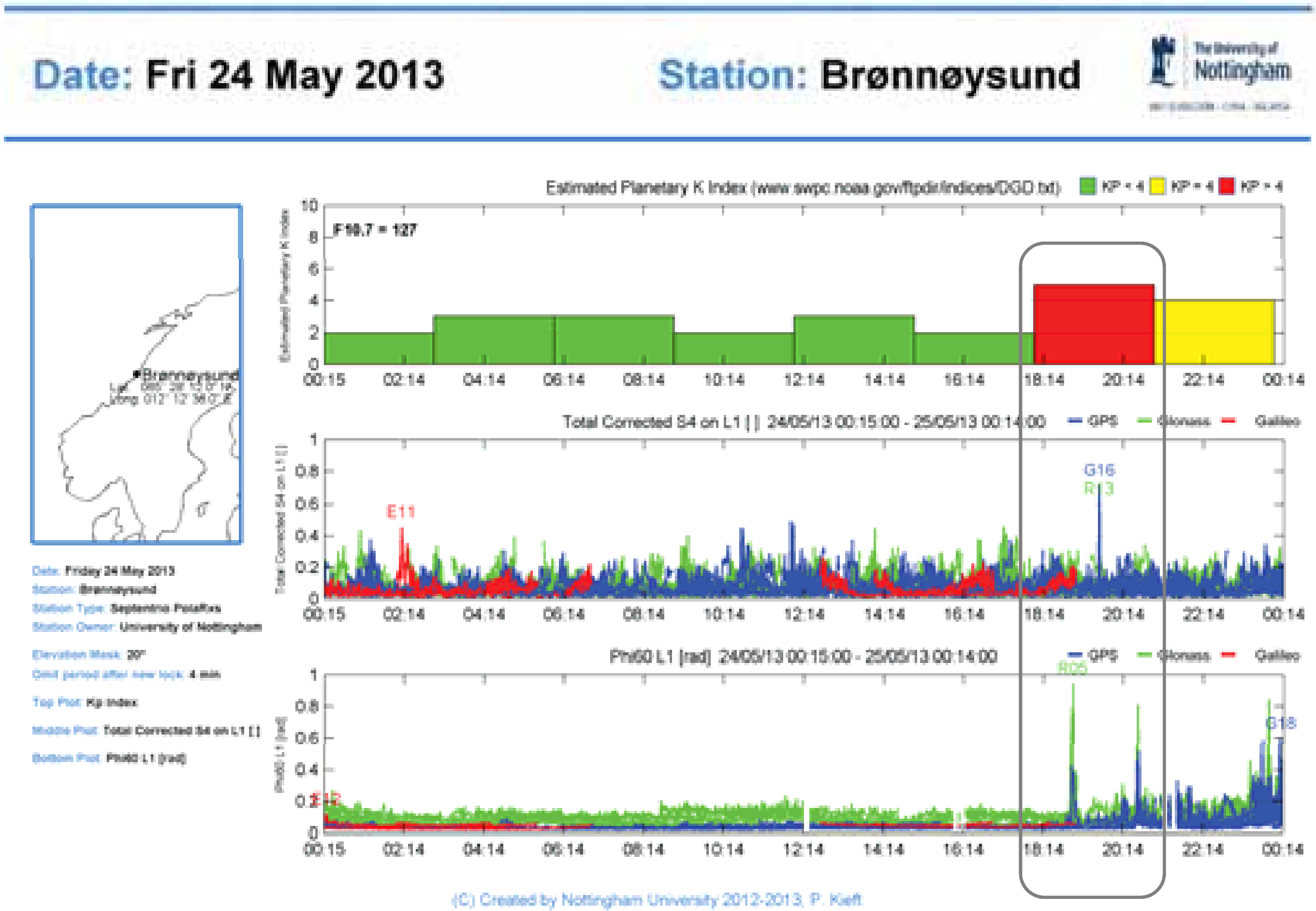
GLONASS tracking Oslo, Sep 24



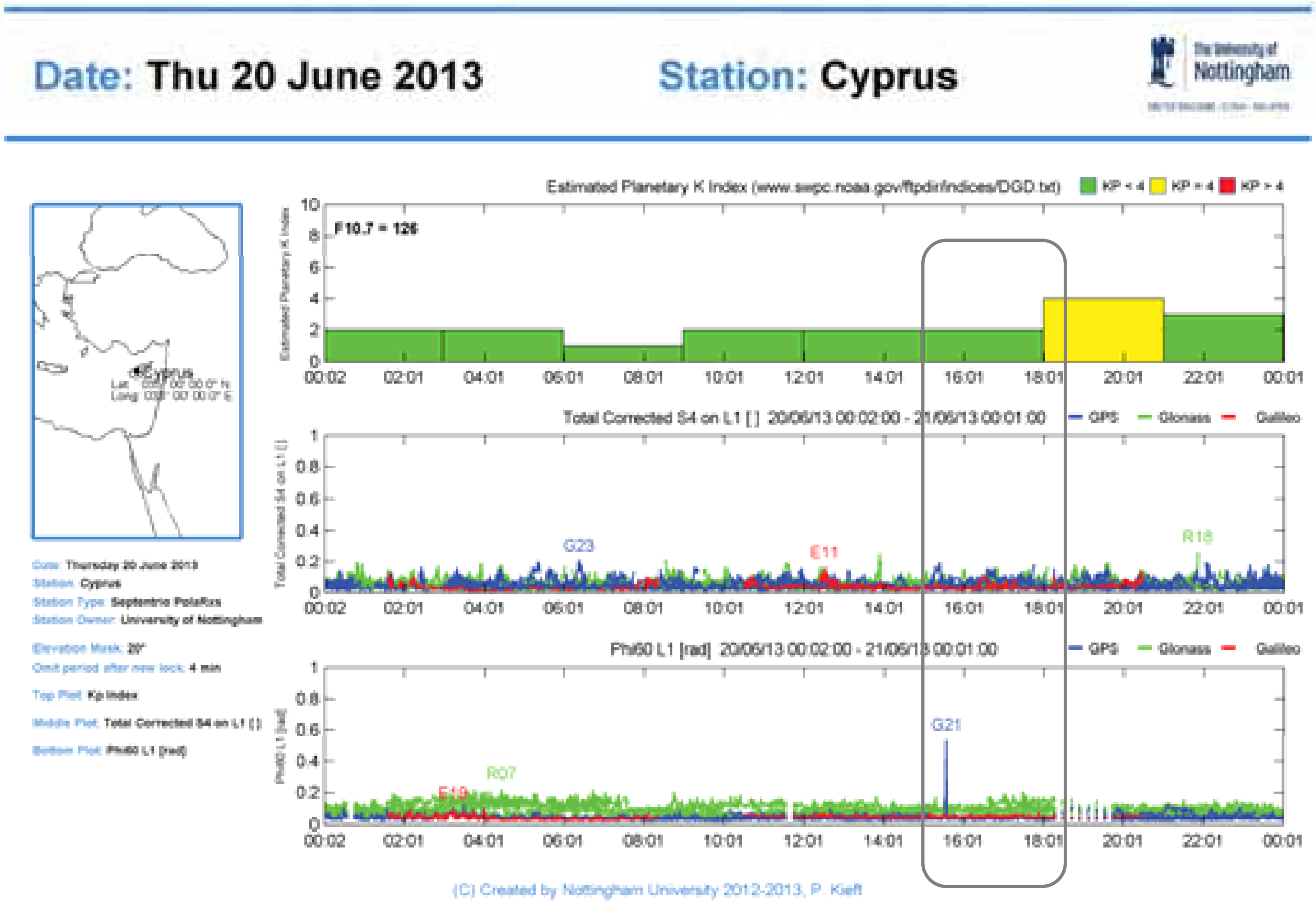
Scintillation monitors

Nottingham University's scintillation monitors

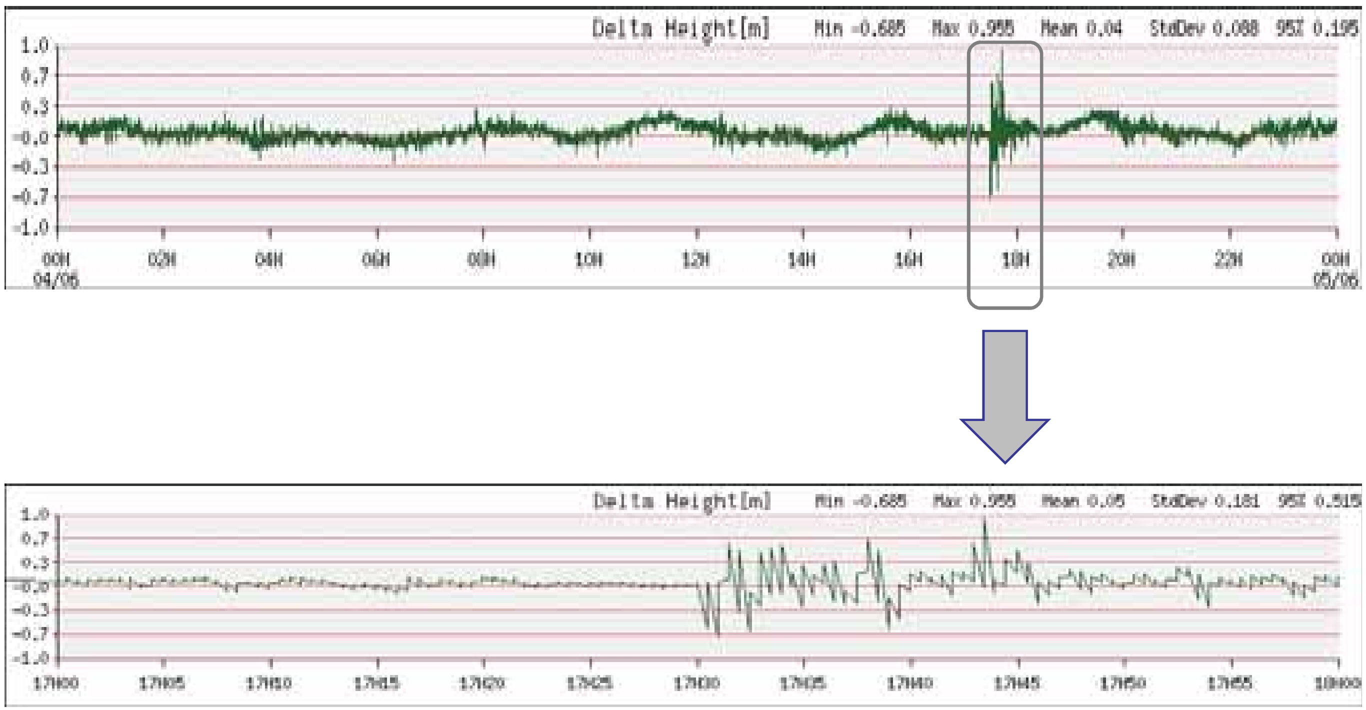
Scintillation monitor Brønnøysund



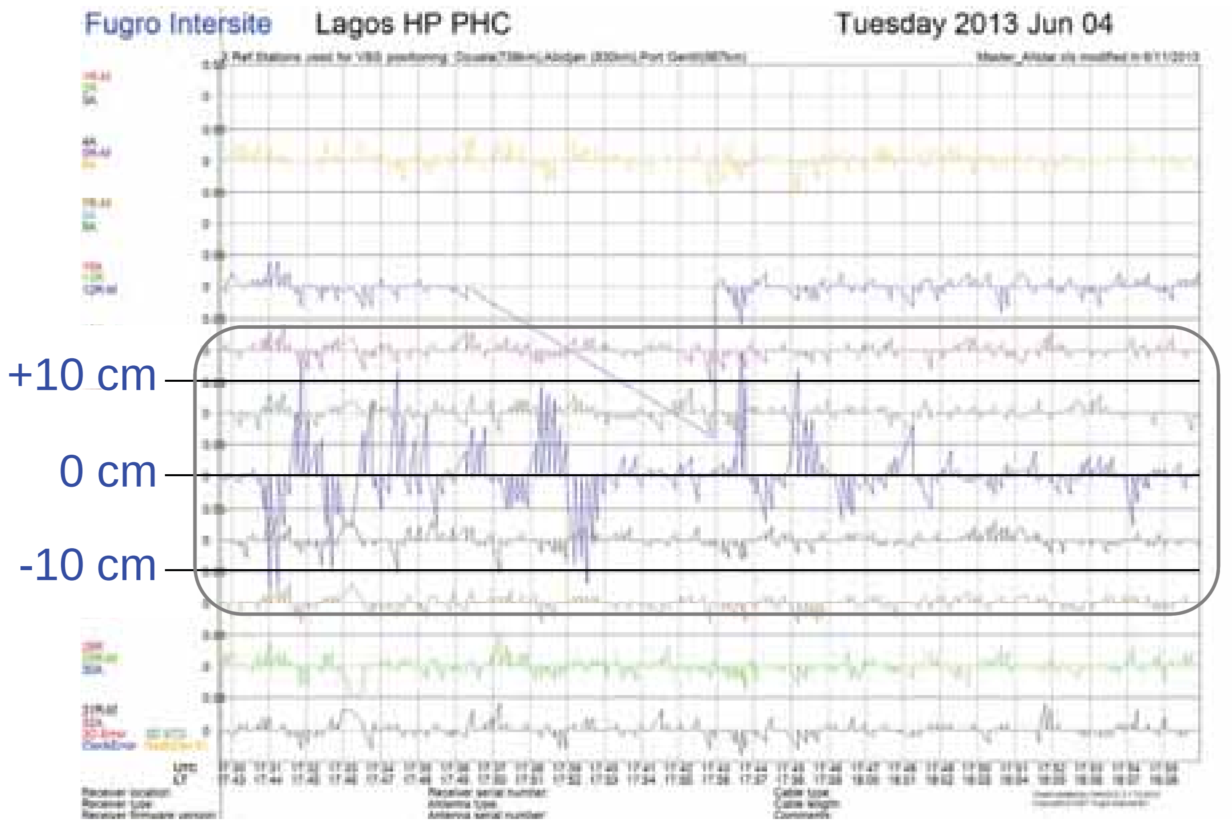
Phase noise – but no scintillation



Lagos (Nigeria) – height errors due to PRN21

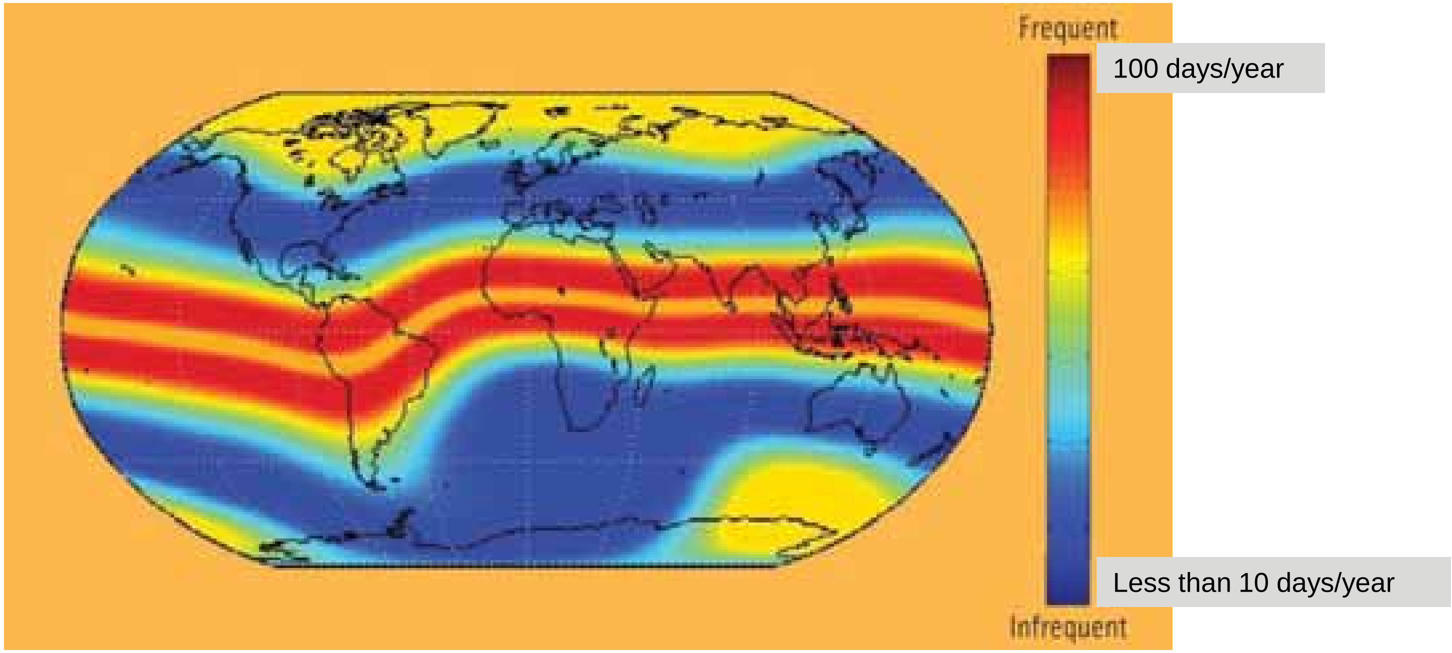


Lagos (Nigeria) – PRN21 phase jitter



Ionospheric scintillation

Scintillation frequency at solar maximum



Map taken from: Kintner et al, GNSS and ionospheric scintillation – How to survive the next solar maximum. InsideGNSS, July/August 2009.

Scintillation at Fugro reference stations – 2012

Recife (Brazil), 180 days

Port Gentil (Gabon), 167 days

Sao Tome, 164 days

+25 additional stations with more than 40 days with two or more lost satellites

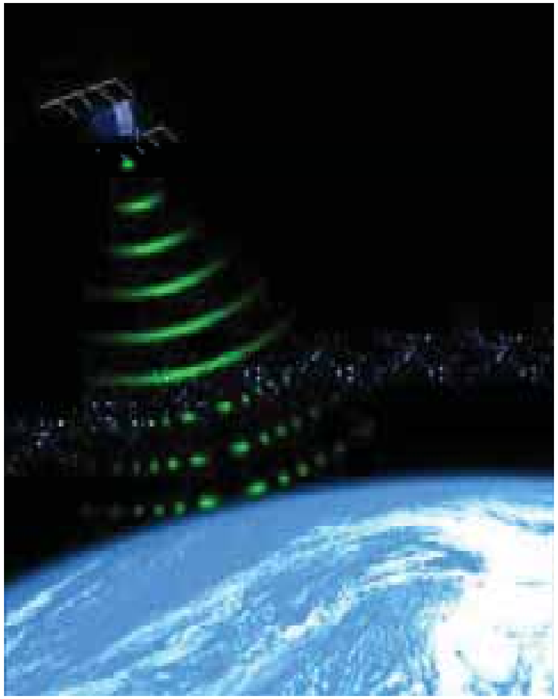
Ionospheric scintillation

Plasma bubbles diffract and refract GNSS signals leading to

- Phase scintillation (phase jittering, characterized by $\sigma_{\varphi 60}$)
- Amplitude scintillation (rapid fluctuations in the signal intensity fading amplitude, characterized by S4)

resulting in degraded GNSS receiver performance

- Signal power loss (or even loss of lock)
- Increased measurement noise level

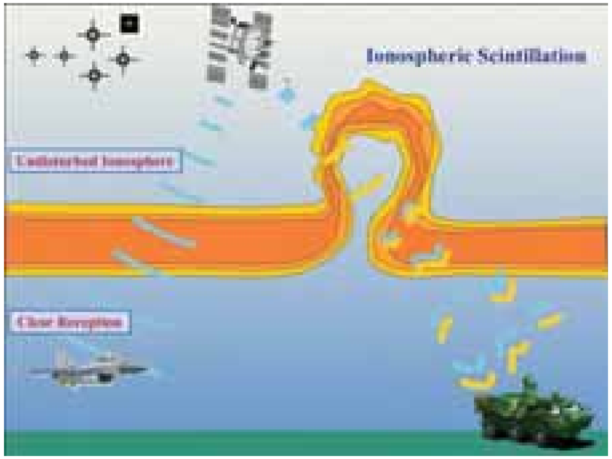


Notes:

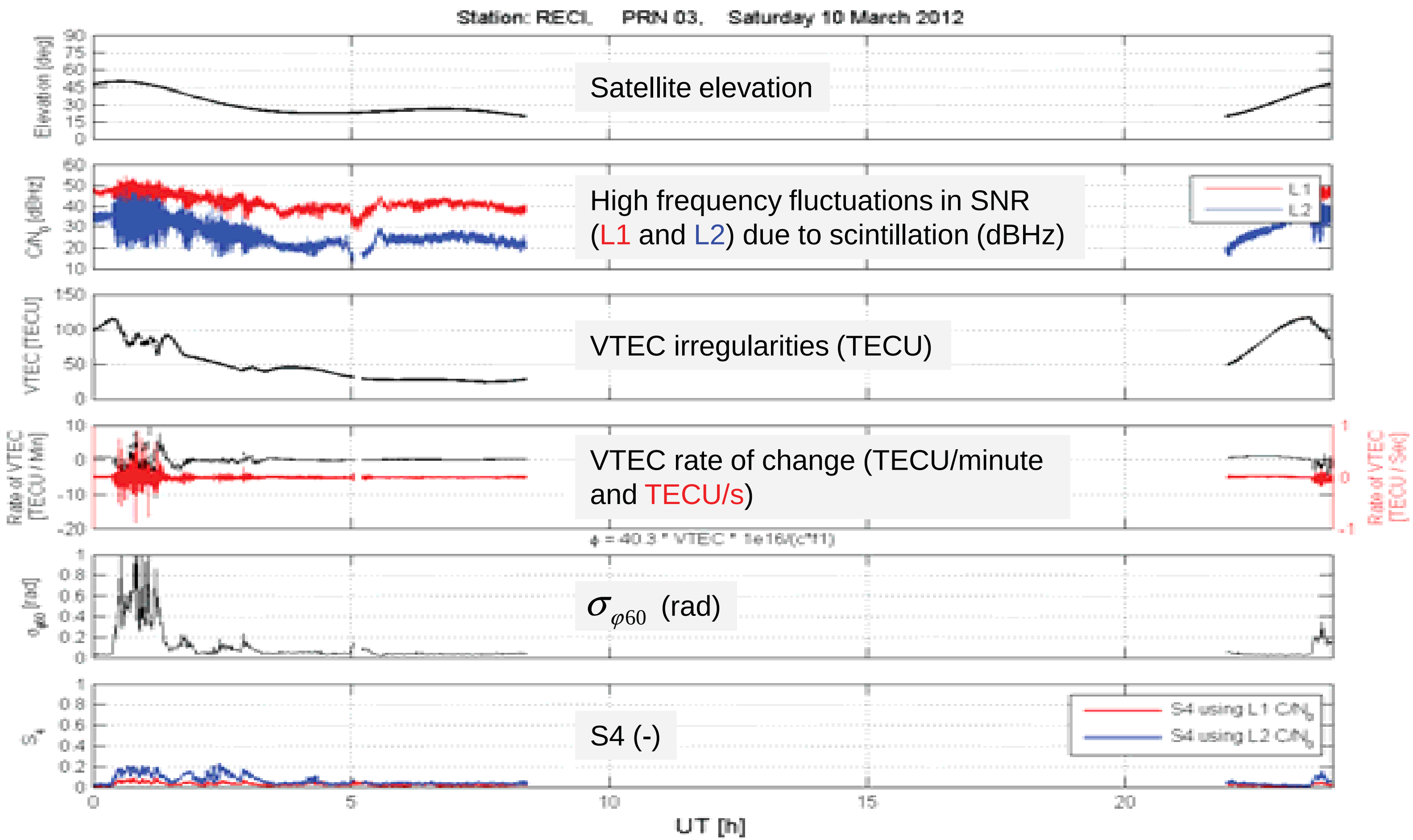
- Amplitude scintillation is more common at equatorial regions
- Phase scintillation is more common at high latitudes
- More severe at lower frequencies

Computation of scintillation indices

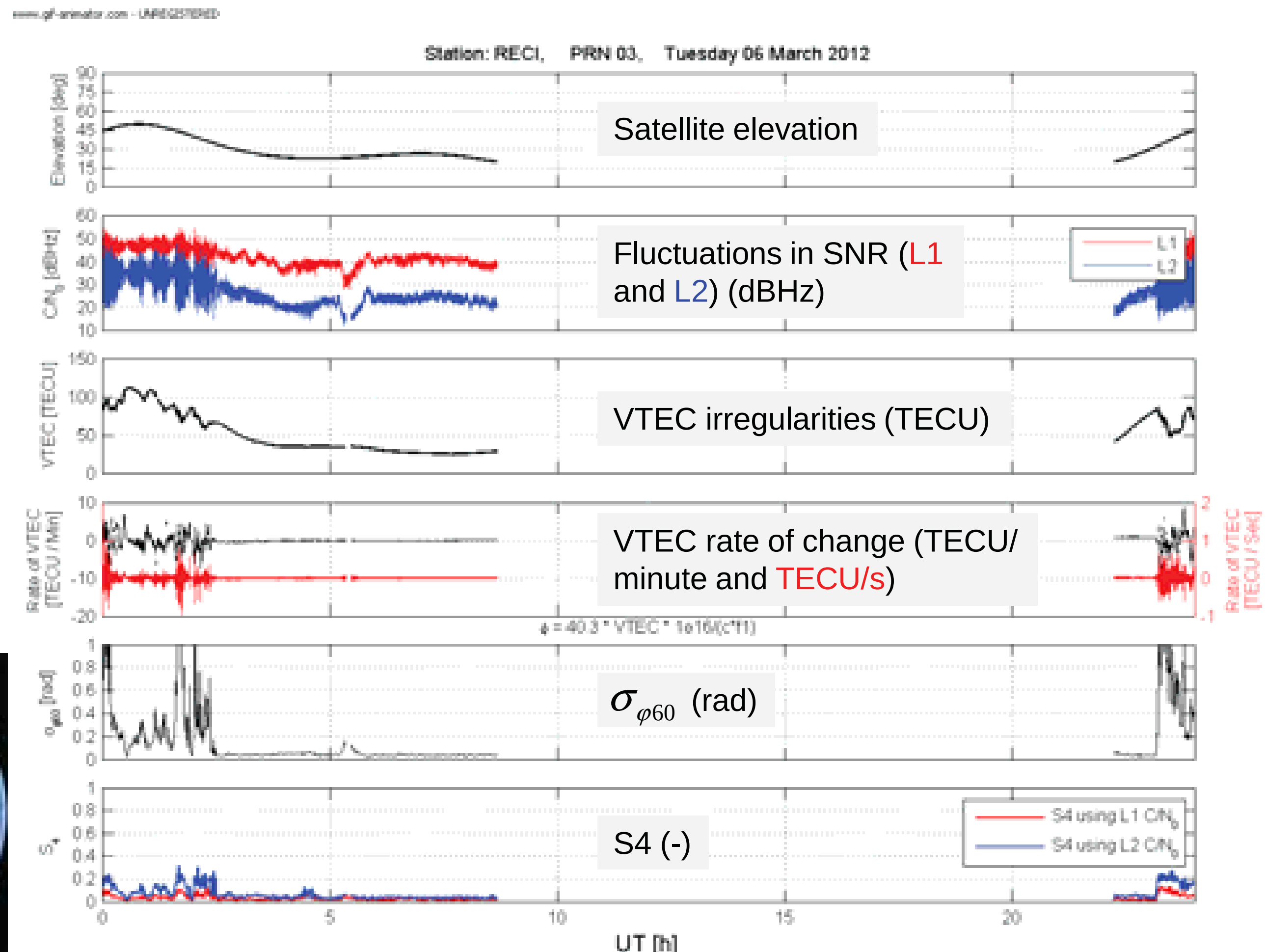
- Use L1&L2 phase and code at 1 s interval to compute TEC
- Compute $\Delta TEC(t) = TEC(t) - TEC(t-1)$
- Convert to phase delay on L1 [rad/s] $\varphi(t) = \frac{40.3}{c \cdot f_{L1}} \cdot \Delta TEC(t)$
- Compute $\Delta VTEC$ by mapping slant $\Delta VTEC$ to vertical
- Standard deviation of φ over every 60 seconds is the phase scintillation index $\sigma_{\varphi 60}$ along signal path between receiver and satellite
- Standard deviation of SNR values over 60 seconds is the amplitude scintillation index $S4$ along signal path between receiver and satellite



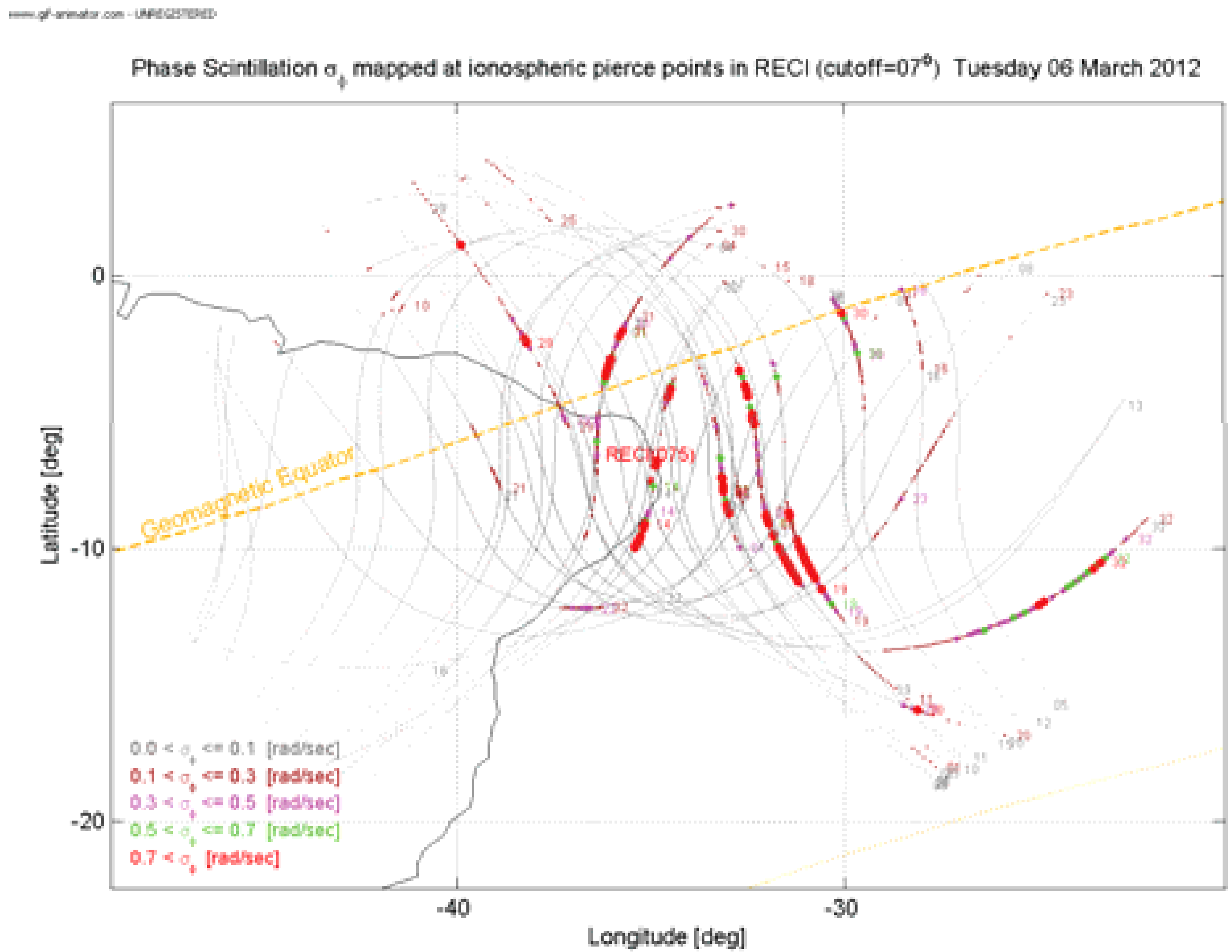
Scintillation effects on GNSS signals



Temporal scintillation – Recife, 6-16 March 2012

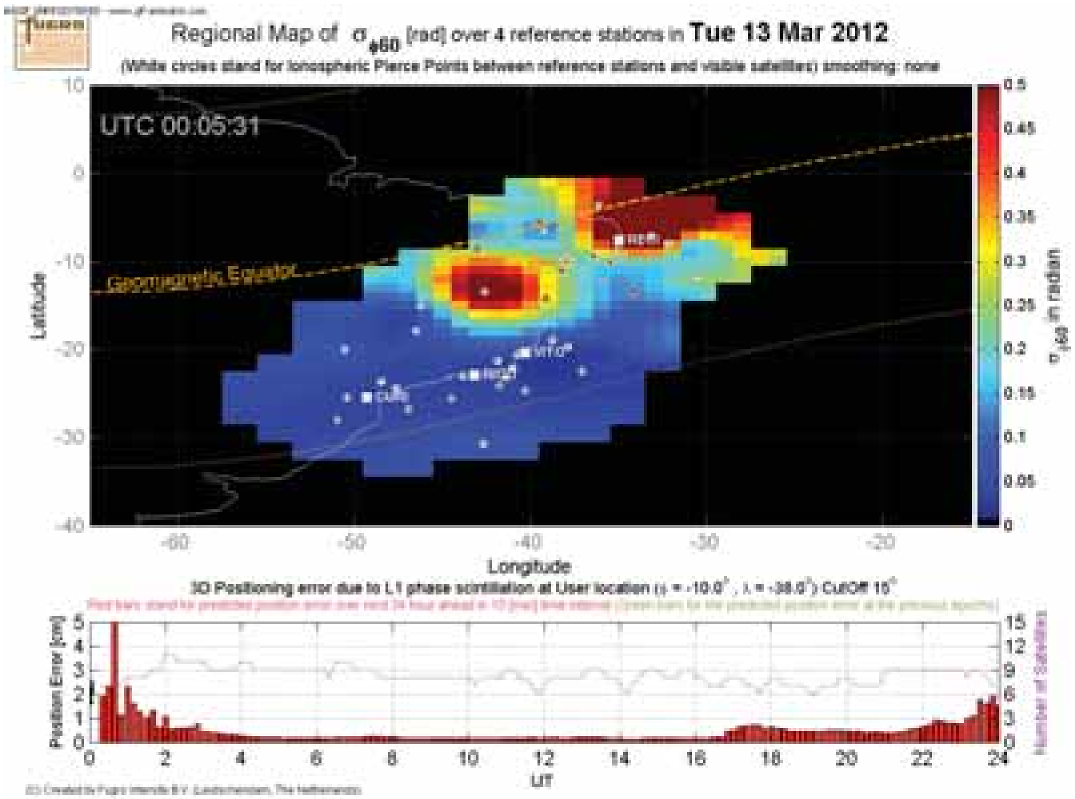


Spatial scintillation – Recife, 6-16 March 2012

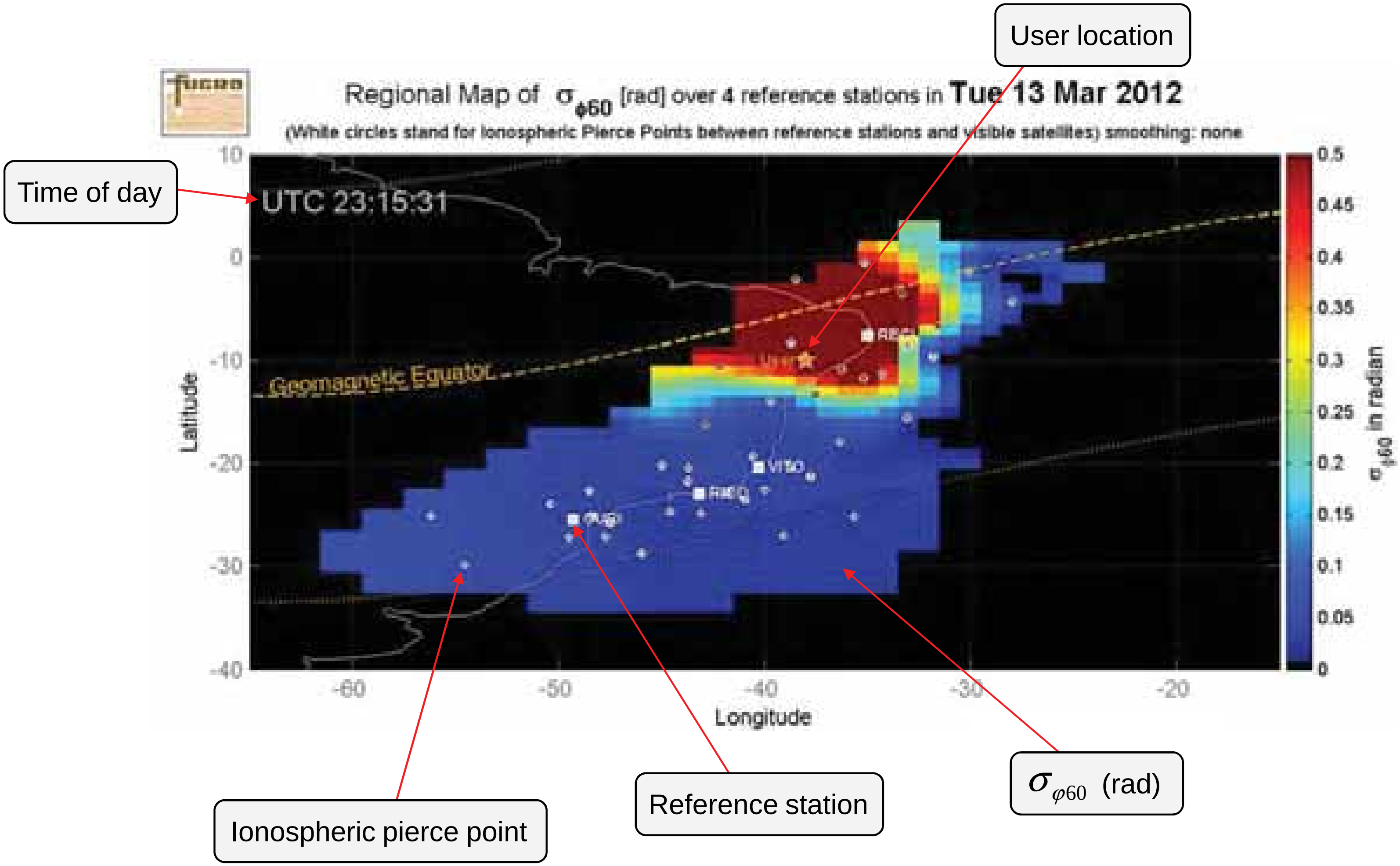


Scintillation prediction – Initial results

24 hour scintillation prediction using four reference stations in Brazil for user location Lat = 10°S and Lon = 38°W



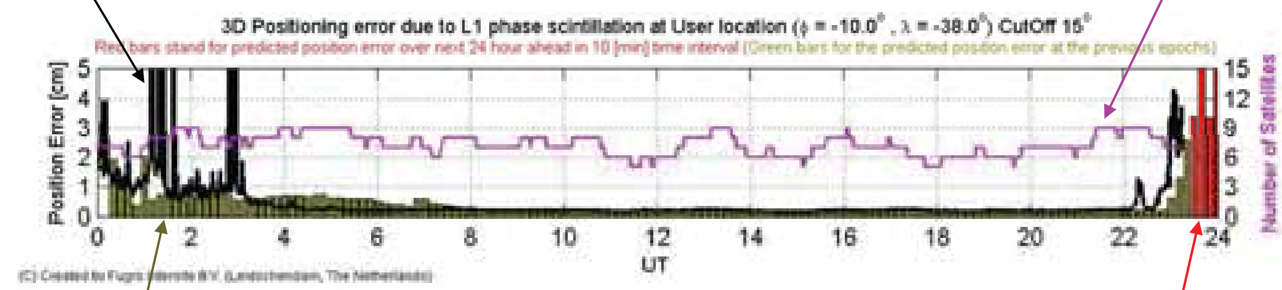
Scintillation prediction



Scintillation prediction

Actual position error

Number of satellites

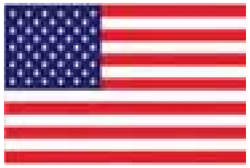


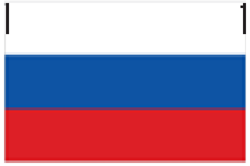
Predicted position error at previous epochs

Predicted position error

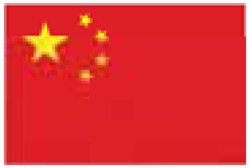
Multiple GNSS – benefits

USA: GPS

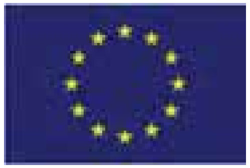




Russia: GLONASS



China: BeiDou



Europe: Galileo

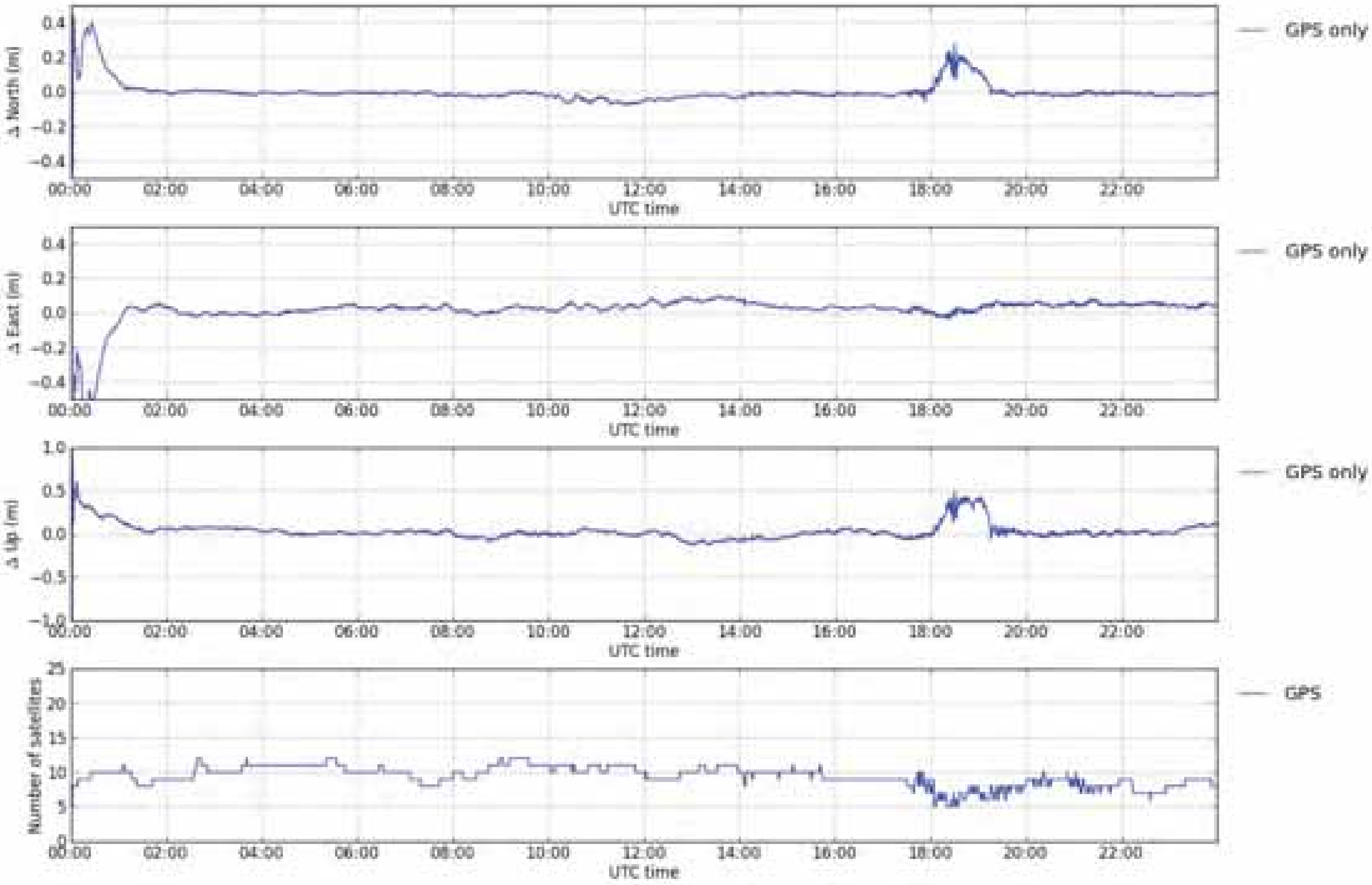
Multiple GNSS

The US GPS and Russian Glonass are operational Global Navigation Satellite Systems (GNSS). Europe is developing Galileo, China BeiDou. BeiDou currently (2013) consists of 15 satellites, for Galileo there are four satellites in orbits. Once all systems are operational, there will be more than 100 satellites available for precise positioning.

Even though the current Galileo and BeiDou constellations are not complete, they already help in case satellite signal reception is disrupted, due e.g. to scintillations, as will be shown on the following slides.

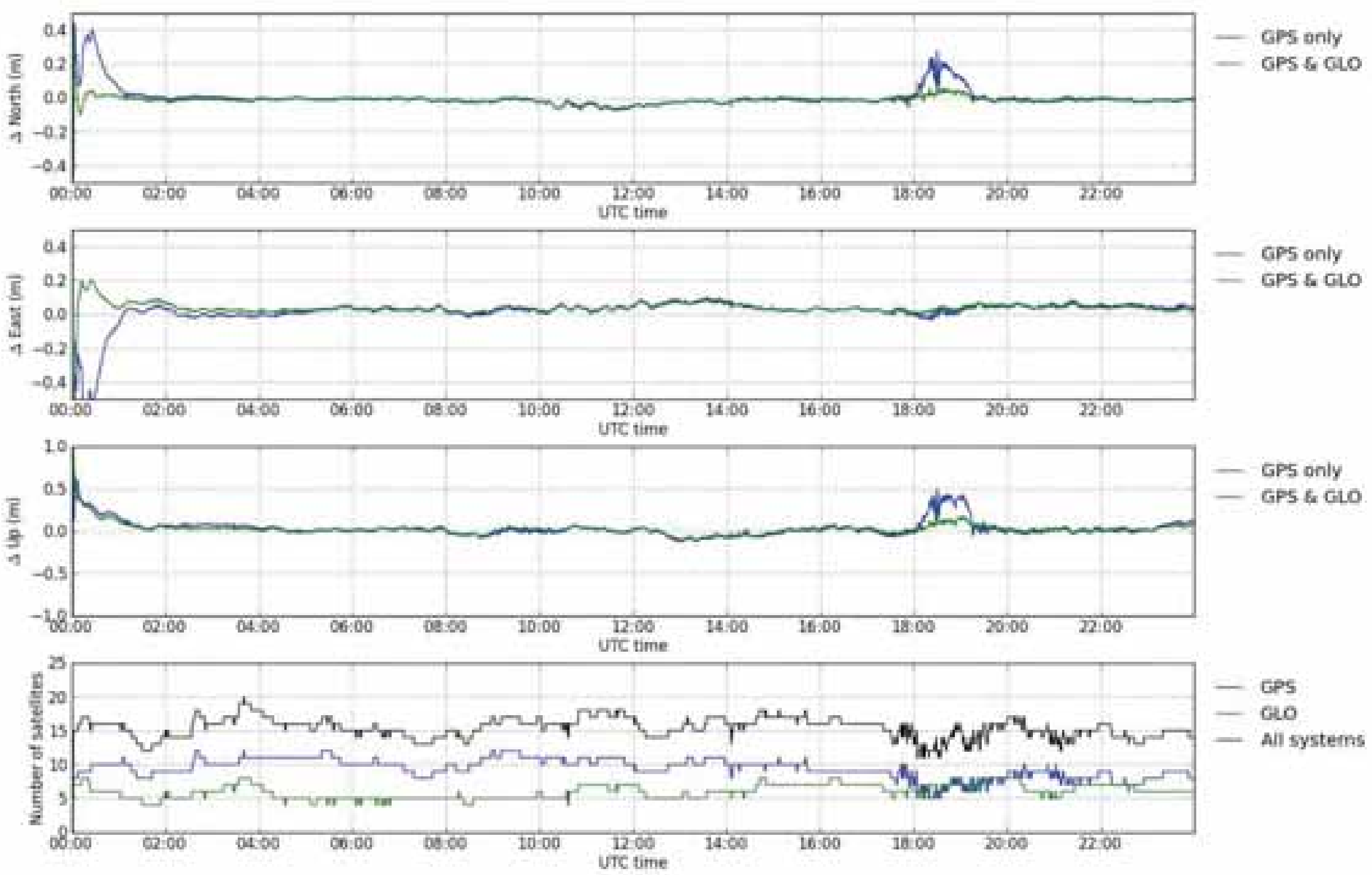
GPS and GPS/Glonass solutions show anomalies between 18:00-19:00. The situation improves when BeiDou is added (Galileo does not contribute to this improvement, as no satellites are available for this period).

GPS only

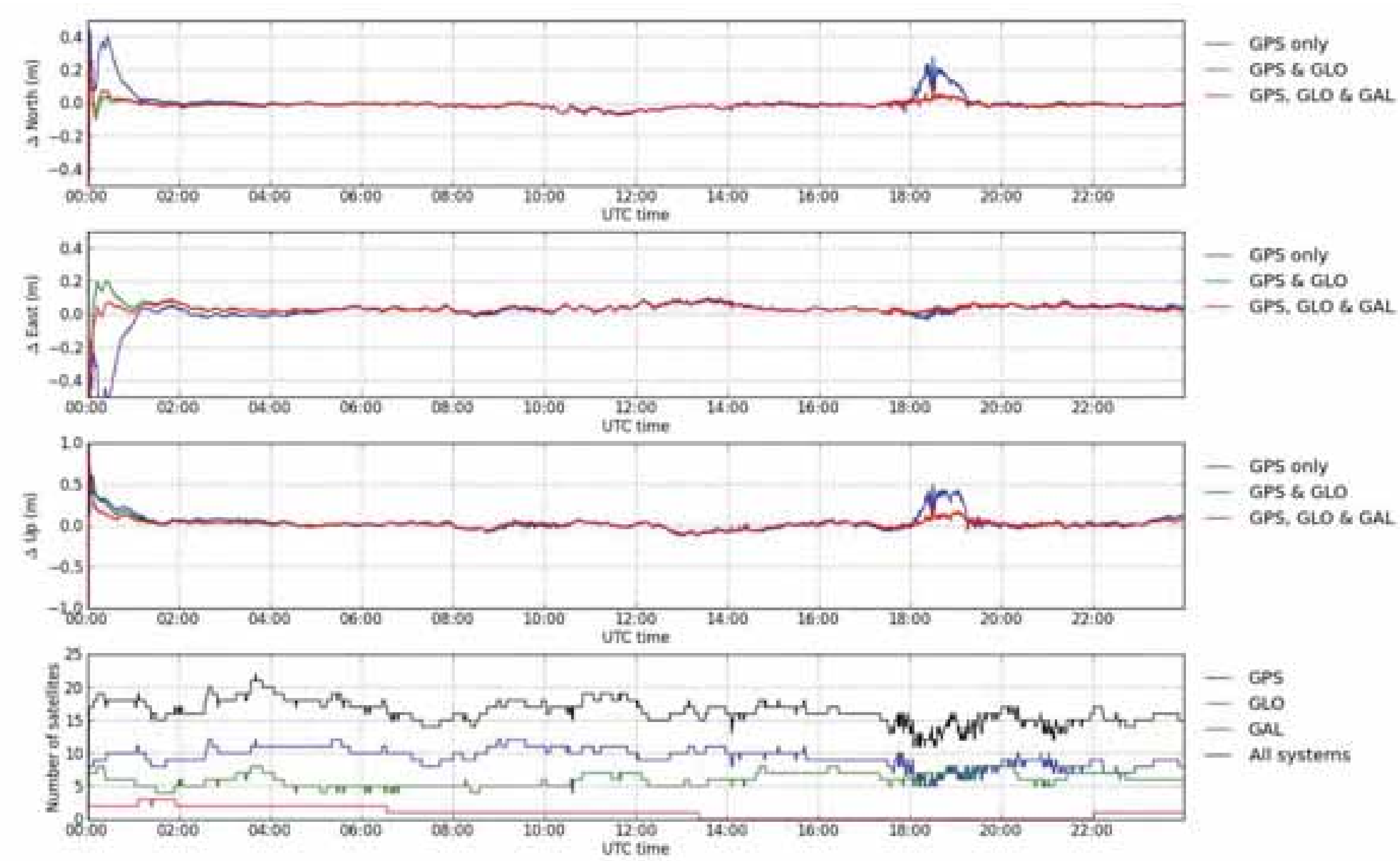


Δ North (m)
0.4
0.2
0.0
−0.2
−0.4
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
UTC time
GPS only
Δ East (m)
GPS only
Δ Up (m)
1.0
0.5
−0.5
−1.0
GPS only
Number of satellites
25
20
15
10
5
0
GPS

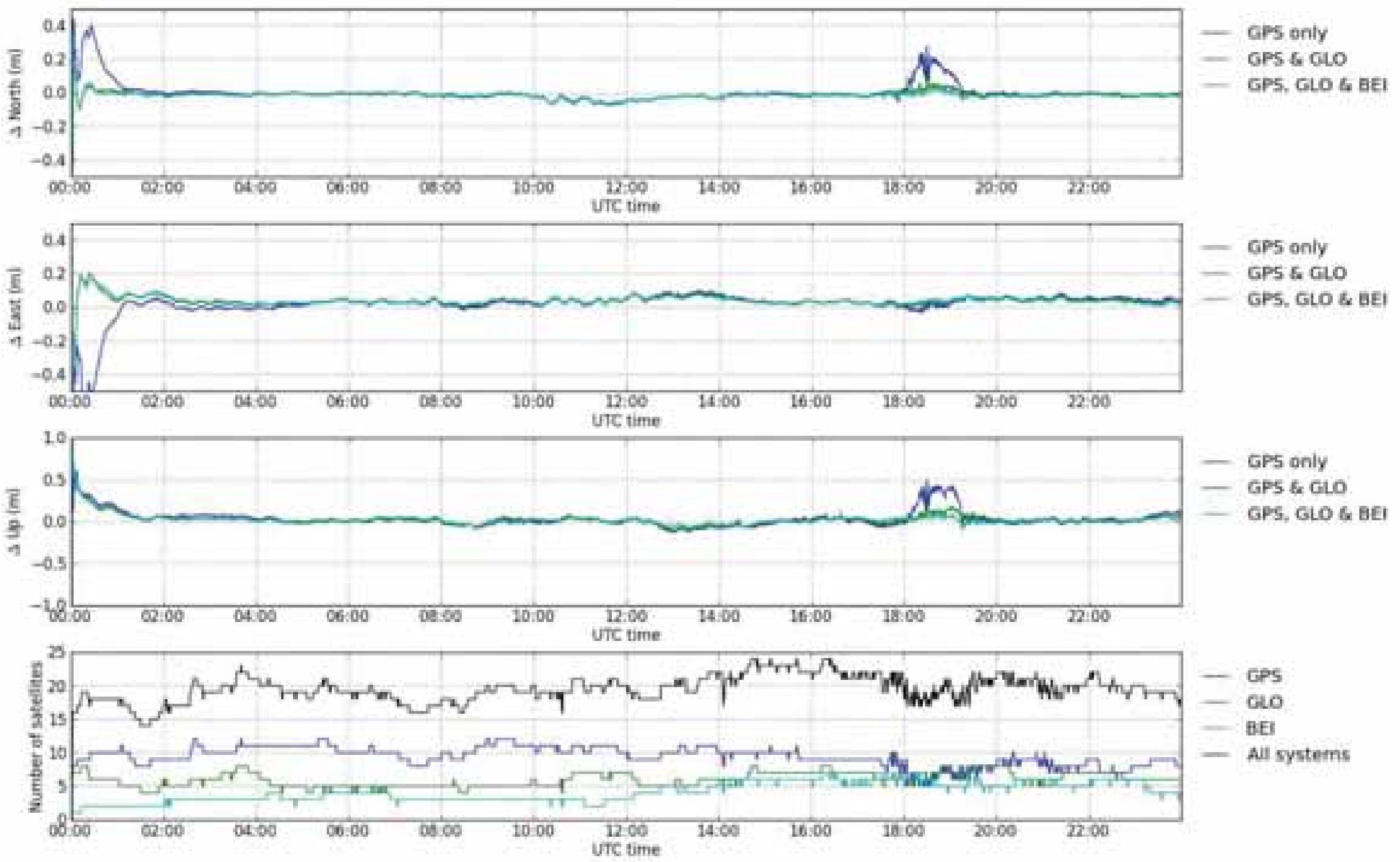
GPS and Glonass



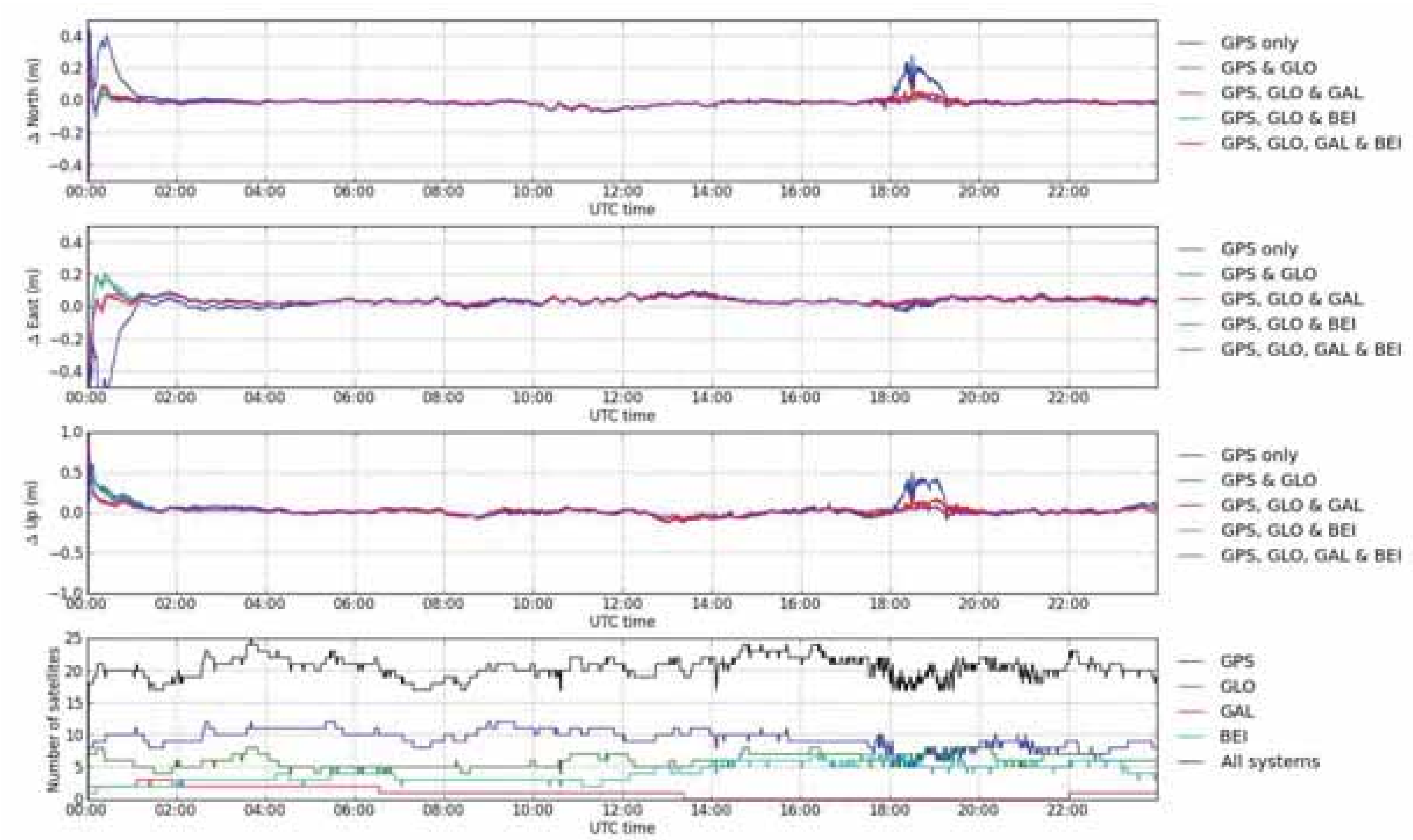
GPS, Glonass and Galileo



GPS, Glonass and BeiDou

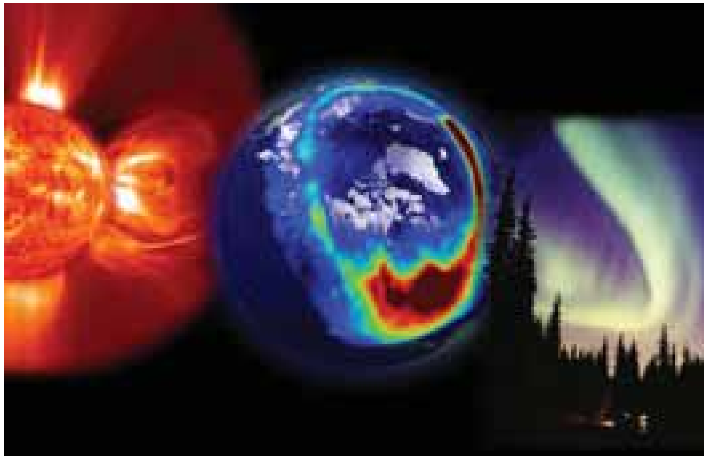


GPS, Glonass, Galileo and BeiDou

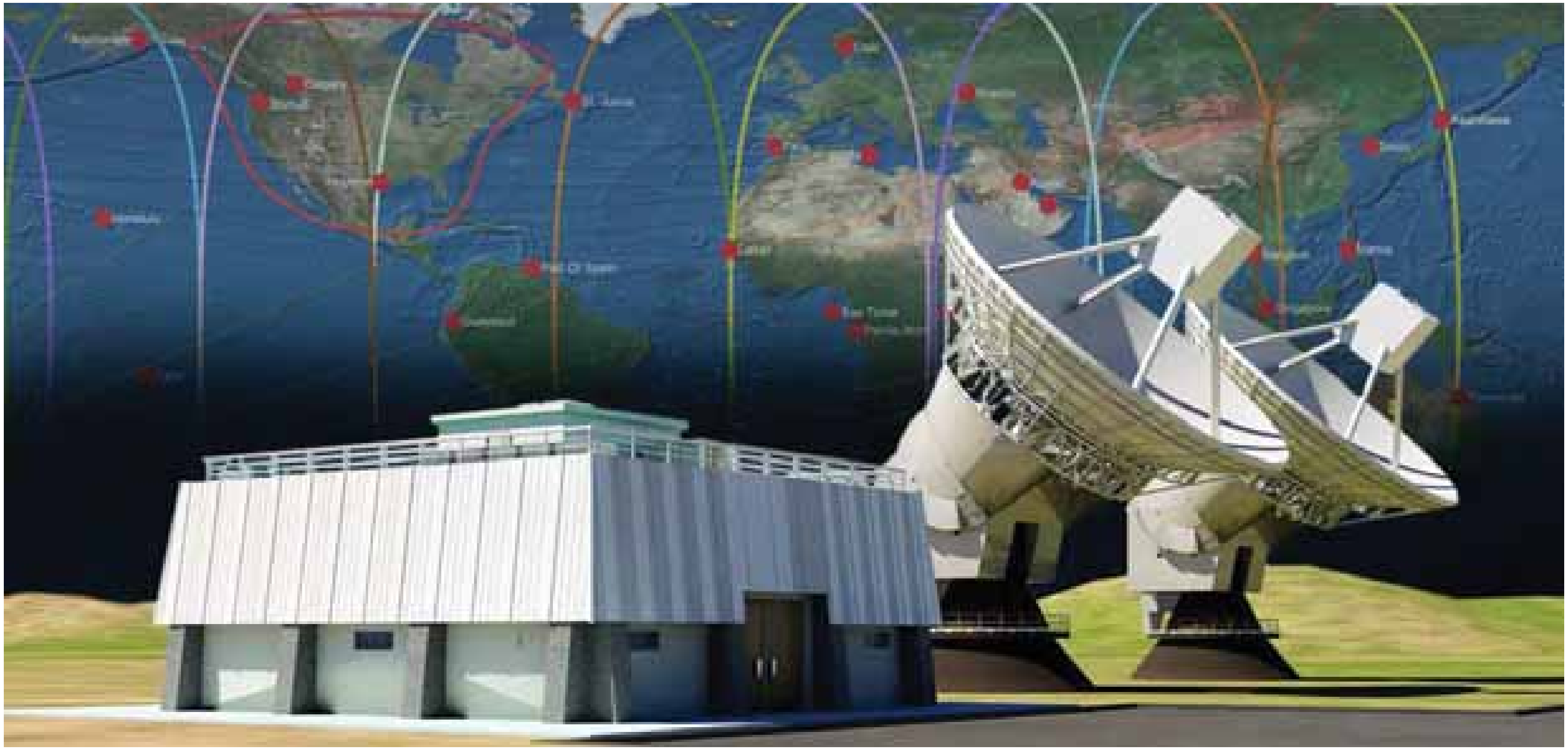


Mitigating increased solar activity

- Multiple satellite positioning systems
- More and stronger GNSS signals
- Redundant networks, data links and positioning services
- Monitor and predict ionospheric disturbances



Conclusions



Fugro delivers precise positioning services for a wide variety of offshore activities, using a highly redundant infrastructure and in-house developed hard- and software.

Thank you