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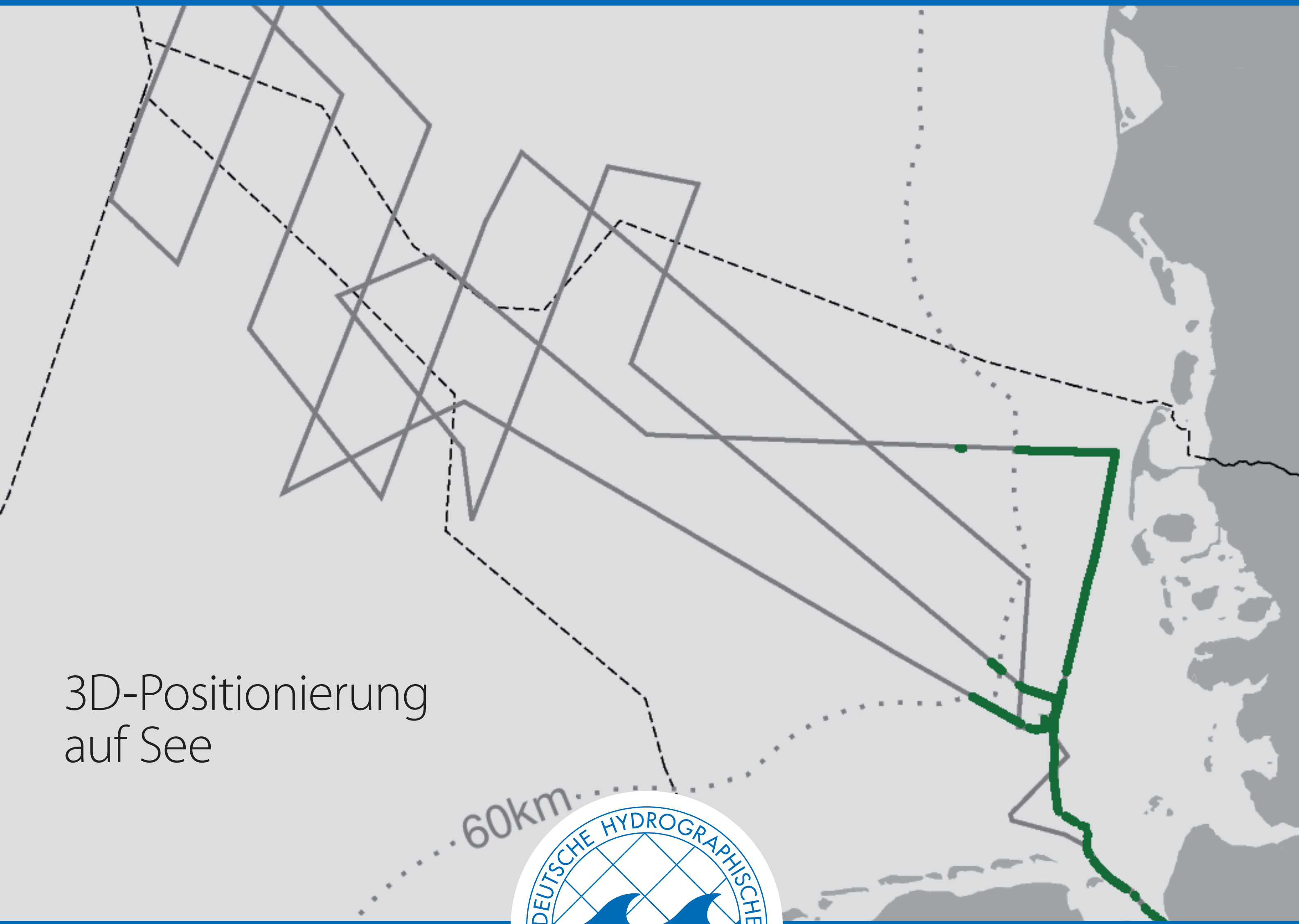

3D-Positionierung auf See

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Fugro Marinestar Precise Point Positioning status update

An article by HANS VISSER

Fugro Marinestar Precise Point Positioning (PPP) utilises a global network of 111 reference stations to provide centimetre-level positioning in real-time to maritime users. The system estimates precise orbit, clock and satellite phase bias corrections for GPS, Galileo, BeiDou and GLONASS satellites. Factors such as ionospheric activity, scintillations, troposphere and radio interference can affect positioning accuracy. Fugro Marinestar offers fast convergence time, multiple L-band tracking and supports various receivers.

Fugro Marinestar | GPS | Galileo | BeiDou | GLONASS | PPP | scintillation | L-band
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Fugro Marinestar Precise Point Positioning (PPP) nutzt ein globales Netzwerk von 111 Referenzstationen, um maritimen Nutzern eine zentimetergenaue Positionierung in Echtzeit zu ermöglichen. Das System schätzt präzise Bahn-, Takt- und Satellitenphasen-Korrekturen für GPS-, Galileo-, BeiDou- und GLONASS-Satelliten. Faktoren wie ionosphärische Aktivität, Szintillation, Troposphäre und Funkstörungen können die Positionierungsgenauigkeit beeinflussen. Fugro Marinestar bietet eine schnelle Konvergenzzeit, Mehrfach-L-Band-Tracking und unterstützt verschiedene Empfänger.

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Introduction

Using Fugro's worldwide network of 111 GNSS reference stations, Fugro Marinestar estimates precise orbit and clock and satellite phase bias corrections for GPS, Galileo, BeiDou and GLONASS satellites (Fig. 1). These corrections are broadcast over geostationary satellites and via the Internet to maritime users to provide centimetre-level positioning in real-time.

GPS

GPS typically has 31 satellites available. Currently, the USA are launching the third-generation satellites. The last launches are on the Falcon 9 rocket. Four GPS-III satellites are ready for launch. From 2026 GPS-IIIF satellites will be launched.

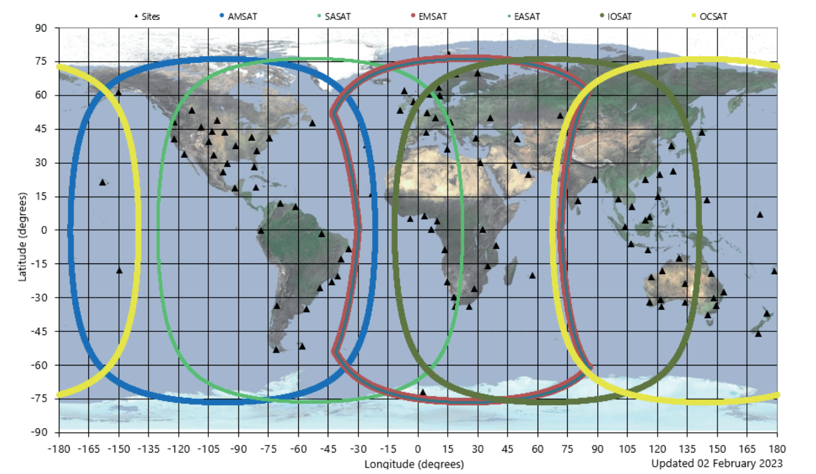

Fig. 1: Fugro Marinestar global network and L-band satellite beams

Galileo

For the European Galileo system, there are 24 healthy satellites. Two (E14 and E18) are unhealthy in an elliptical orbit and E20 and E22 have been unhealthy for a long time. The launch of new Galileo satellites has been postponed till 2024 as Russian Soyuz rockets could no longer be used due to the Russian-Ukraine war. In May 2023, Galileo is still investigating new launch options. Ten new satellites have been built and are waiting to be launched in the coming years. Galileo has started designing the next-generation satellites.

BeiDou

The Chinese BeiDou completed its third constellation in 2020. BeiDou has around 44 healthy satellites. BeiDou II uses satellites B1 to B19 from which there are typically 13 satellites available. C01 to C05 are geostationary (GEO). C06 to C09 and C38 to C40 have an inclined geostationary orbit (IGSO) over China and Australia. The advantage of IGSO satellites is they are high in the sky over China, which is good for inner cities. The high number of BeiDou satellites around the globe is of value during scintillation and local blockage of the sky as in harbours surveying close to large ships or in windfarming projects.

GLONASS

The Russian GLONASS has around 20 satellites that are usable for Fugro Marinestar. It is now the weakest constellation in terms of the number of satellites. R06,

Constellation	Orbit height	Planes	Inclination	Repeat time for user	NSAT	Usable	Not useable
GPS	20.200 km	6	55°	11:58 / 1 day-4 minutes	32	31	22
Galileo	23,222 km	3	56°	14:20 / 14 days	28	24	1, 14, 18, 20, 22
BeiDou MEO	21,500 km	3	55°	26:30 / ~7 days	29	27	31
BeiDou GEO	35,800 km	3	0°	Stationary	8	5	57, 58, 61
BeiDou IGSO	38,300 km	2	55°	~1 day	11	10	
GLONASS	19,000 km		66°	11:15	24	20	6, 10, 23
Inmarsat L-band	35,800 km	1	0°	Stationary	6	6	

Table 1: Overview of GNSS constellations

R10 and R23 do not have L2. Normally, two satellites are launched together. In 2022, two satellites were launched on separate rockets. On average there are six to seven GLONASS satellites visible around the globe. There are moments during the day when only three GLONASS satellites are visible for a brief period. The GLONASS constellation is ageing.

G4

In total, there are for all four constellations (G4) around 120 satellites available (Table 1). For a user combining all constellations, there are typically 40 satellites usable with a minimum of 32 over the Americas and up to 55 in the Far East (Fig. 2).

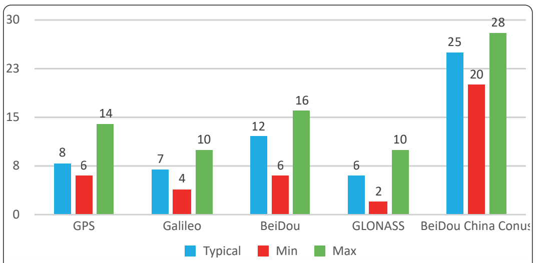

Fig. 2: Typical number of satellites available over the world above 5 degrees elevation

Reference stations

The 111 reference stations consist of NetR5 receivers, which track GPS and GLONASS, NetR9 which track GPS, Galileo, BeiDou, GLONASS and QZSS, and new generation PolaRx5 and Alloy receivers. Two independent receiver brands are used to assure that tracking of measurements continues in case of a firmware issue with one of the brands. The reference stations are hosted at Fugro offices, locations at Internet service providers and third party sites around the world. At the reference stations, an uninterruptable power supply (UPS) is used as a backup for sites with regular power outages, e.g., in South Africa. The antennas are placed with a clear view of the sky. This must be checked over time as new buildings can be built close by, and surrounding trees can grow over the years. Most sites are not affected by radio interference. Typically radio interference at the sites is short in the L1 band if GPS L1 jammers pass by cars. Interference can be constant for instance when, e.g., a nearby aviation radar or amateur radio is broadcasting a continuous signal. The data communication is to multiple network control centres over the Internet and 4G Cell phone communication.

Coordinate datum

The coordinates of the reference stations are calculated using the International GNSS Service (IGS) and the Canadian CSRS (as independent comparison) in the International Terrestrial Reference Frame (ITRF) 2020 coordinate system. The precise coordinates of all reference sites are updated with continental movement velocities. This gives coordinates in ITRF2020(Epoch Now). ITRF2020 and the previous ITRF2014 differ at the 3 to 4 mm level. To calculate the coordinates into the national datum a 14-parameter coordinate transformation from ITRF2020(Now) to, e.g., Europe ETRF1989 is needed. And then the local map projection to, e.g., for Germany Gauss-Kruger. These transformations are typically done by survey software.

Orbits

At three orbit and clock centres, all GNSS measurements are processed in hourly orbits. These orbits are predicted for the next 24 hours. Orbit manoeuvres do happen. Mostly the satellites are first set unhealthy, but not always. Twice annually, satellites enter the earth's shadow for a few days and the solar panels start to rotate. This rotation can be modelled but the modelling is not always correct. Then the solution is to auto-disable the satellite for this period. The orbits for GPS and Galileo are the most accurate at the 3 cm level. BeiDou Medium Earth orbit satellites at 20,000 km height are 3 to 4 cm accurate. The BeiDou stationary and inclined geostationary satellites at 36,000 km are typically at sub-metre level. The GLONASS orbits are at the 5 to 10 cm level. The new GLONASS-K satellites R09, R11, R16 and R22 are smaller than the GLONASS-M satellites and hence the orbit is more difficult to estimate. The orbit errors are in the 10 to 20 cm range. The procedure is to exclude satellites with larger orbit errors from the broadcast.

Clocks

After the orbits are calculated, a real-time clock filter estimates the clock offset of all satellites. Clocks

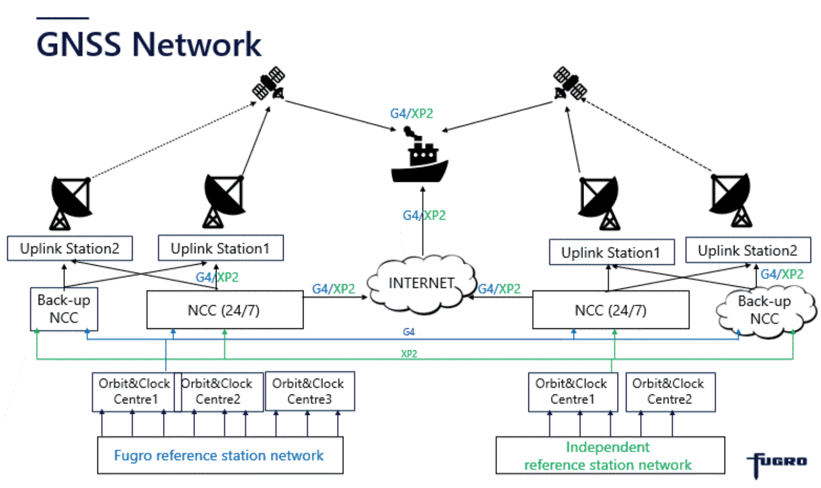

Fig. 3: Simplified overview of GNNS network infrastructure

can have sudden jumps. Some satellites, e.g., GPS SVN45(G21) have a daily cycle slip. GPS SVN43(G13) does have clock-jitter, which can last for 20 minutes and is in the 10 cm range. Field firmware does mitigate these effects.

Satellite bias

The small fractional wavelength distance between the satellite antenna phase centre and the generator is estimated using the global network. This bias is also named Uncalibrated Phase Delay (UPD). The wide lane (L1–L2) ~86 cm and narrow lane (L1+L2) ~12 cm are used to fix the complete cycles for the user. When the correct number of cycles is fixed the solution reaches centimetre-level accuracy.

Network Control Centres

At two Primary Network Control Centres, all data is collected and scheduled to be sent over satellites and the Internet. There are two active backup NCC, one physical and one in the cloud.

For L-band satellite beams dual satellite uplinks are available. In case of, e.g., severe weather, power outages or Internet problems at one uplink one can switch to another uplink location.

L-band satellites for broadcast to vessels

The fourth generation Inmarsat satellites have an L-band as does the new Inmarsat 6 F1 launched in 2021 and the F2 launched in 2023. Inmarsat will continue to launch L-band capable satellites in the coming years. Having Ntrip (Networked Transport of RTCM (Real Time Correction Messages) via Internet Protocol) Internet as an alternative correction data delivery path is good to improve redundancy. In spring 2023, Fugro Marinestar upgraded two beams from 600 bits per second (bps) to match all the other beams at 1,200 bps. The higher update reduces the maximum age of satellite clock corrections and improves accuracy, as well as permitting addition of new services.

Redundancy

To make sure customers always have solutions the whole network and all parts are duplicated to ensure redundancy. This is achieved by using six L-band satellites where three would be sufficient. Two NCCs with two independent backups. Independent operating systems and independent software and primary and backup uplinks (Fig. 3).

Ionospheric activity

The sun has an 11-year cycle involving minimum and maximum active periods. The last solar minimum period lasted from 2017 to 2021, and now solar activity is increasing again towards a peak in 2024 to 2027 after which the solar activity will decrease again (see Fig. 4). The use of dual frequencies reduces the effect of the ionosphere to 1 % of its size. This means the coming years PPP (precise point positioning) may become slightly less accurate in areas around the equator and during geomagnetic storms.

Scintillations

Scintillations start with movement of ions in the layer between 100 and 1,000 km above the earth's surface, occurring after sunset in the equatorial zone. During the day, the ionosphere gets ionised and after sunset, there is a transport of ions to neutralise the ionosphere. This horizontal movement

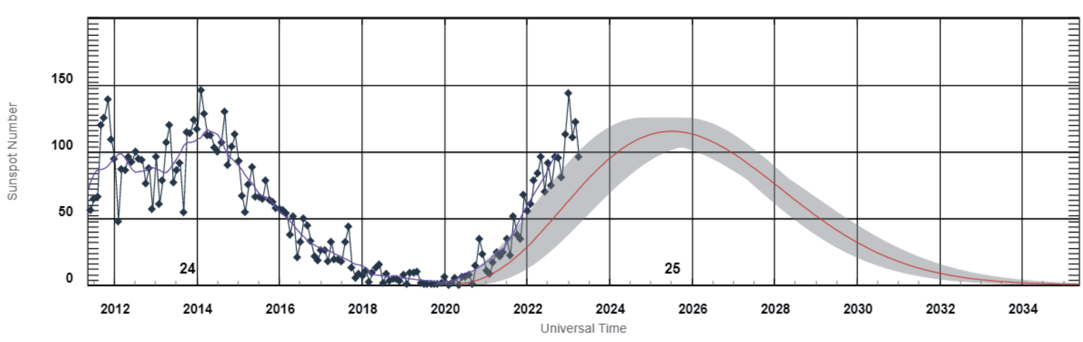

Fig. 4: ISES (International Space Environmental Services) solar activity solar cycle sunspot number

Source: www.swpc.noaa.gov/products/solar-cycle-progression of ions interferes with the GNSS signals of L-band frequencies. This causes fast alternate fading and amplification of the signal strength. The stronger Alt-BOC signals of Galileo and GPSIII can track better, but also these signals are affected. Scintillation is more severe two to three days after a coronal mass ejection (CME) of the sun. If the CME is directed towards the earth the scintillation can last for several days.

The effect is most severe in South America where the geomagnetic field is weaker. The effect of scintillation is seen globally around the equator in Africa, India, Indonesia, the Philippines and the Pacific (see Fig. 5). To reduce the effects of scintillation, use an elevation mask of 5 degrees and have as many satellites available as possible. From the user's perspective, scintillation is an invisible »cloud« blocking a part of the sky. If at least six to seven satellites from different constellations are visible from an uninterrupted area it is possible to prevent a restart of the position. During scintillation, the position noise can increase from centimetre level to decimetre level due to phase noise. Robust de-weighting of phase measurements minimises the effect of scintillation. Marinestar has a paid scintillation prediction service.

In polar regions, scintillation is typically much shorter, but the number of tracked satellites can reduce fast.

Troposphere

During heavy tropical rain, PPP positions can degrade, e.g., on the west side the signals are extra delayed by the rain. The passing rain front typically shows an increase in height as the signals are delayed by the raindrops. At mid-latitudes, the effect of the troposphere is normally within the system noise.

Phase multipath

Metal objects in the near field of the GNSS antenna can degrade the performance. This is a challenge on board ships, where in the masts there are many antennas. Preferably the antenna is on a one-metre pole free from metal objects.

Radio interference

Radio interference is a major problem in 1 % of the surveys. If it does affect the receiver, the user does have a real problem. On ships, the main source of radio interference is Iridium and Globalstar at 1,616 to 1,625 MHz. Narrow bandwidth filtering of the antenna can resolve this. In general, self-interference of badly designed GNSS antennas is another source of interference as are receiver antenna connectors which are not well terminated. Further is amateur radio in the 1,240 to 1,300 MHz a problem for GLONASS L2, BeiDou B3 band and Galileo E6. Any piece of electronic equipment, e.g., computers, Wi-Fi

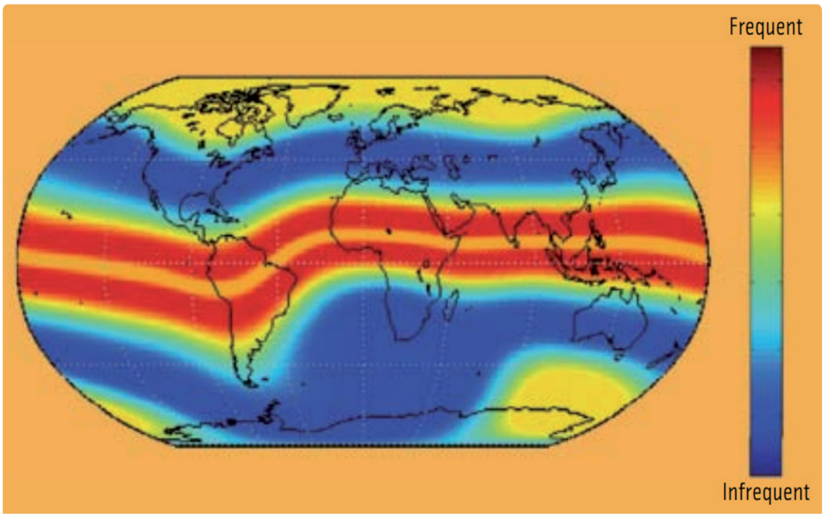

Fig. 5: Scintillation map showing a frequency of disturbances at solar maximum

Source: www.insidegnss.com/auto/julyaug09-kintner.pdf

routers can be the cause of radio interference. Also, GPS jammers on land are a source of interference as are military activities near Russia, Syria, Israel and Egypt. Using narrowband filters in antennas, wideband interference rejection and using notch filters can help to mitigate interference. Built-in spectrometers can help to identify the type of interference, but finding a source require skilled personnel.

Antenna cable length

GNSS signal strength reduces in a cable. Customers should make sure sufficient signal arrives in the receiver. Low-loss cables can help here. Use of N- or TNC adapters should be avoided if possible. Amplifiers can keep the signal within the required range of 33 to 50 dB (receiver dependent values).

Maximum age of corrections

With the GPSII and GPSIII satellites, the excellent-quality Galileo clocks and the BeiDou clocks it is possible to extend the age of corrections by changing the receiver settings. In the early days of DGPS (Differential Global Positioning System), the max-age was 10 seconds later followed by PPP to 60 and 300 seconds. A threshold of 900 seconds can now be used (see Fig. 6).

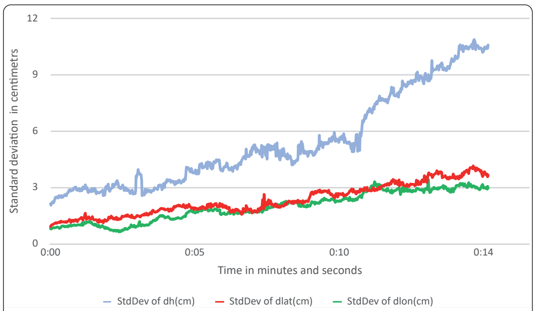

Fig. 6: Position accuracy versus age of corrections. One hour corrections followed by 15 minutes without corrections. 35 samples (Netherlands 2022)

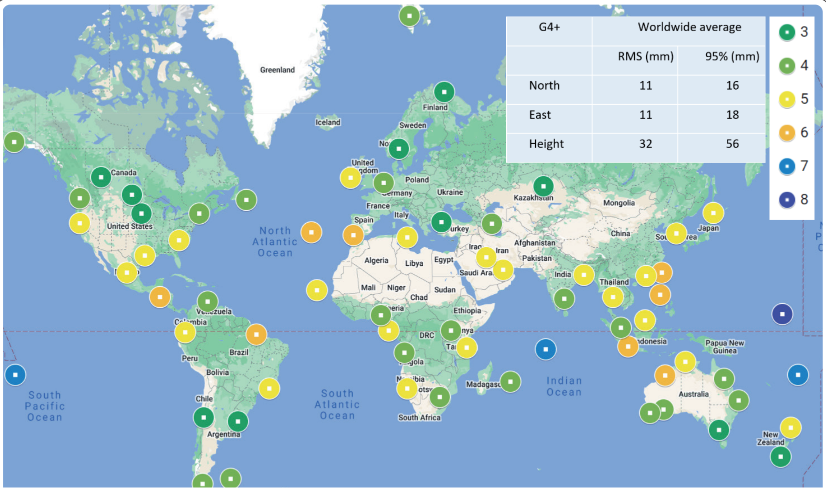

Fig. 7: G4+ 95 % height accuracy in centimetres

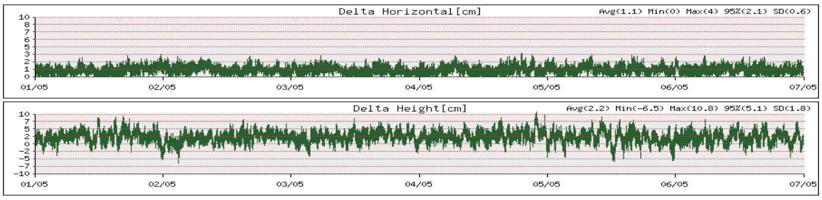

Fig. 8: Horizontal and vertical static accuracy for one week 1-7 May 2023. Septentrio AsteRx-M3 Fg in the Netherlands

Fugro Marinestar accuracy

Using around 90 G4 reference stations the G4+ accuracy is measured in 2023 from 1 January to 8 May (see Fig. 7). Only sites with 99 % availability and no resets are used (see the example from the Netherlands in Fig. 8).

Convergence time

By using UPDs (uncalibrated phase delays) from GPS, GLONASS, Galileo and BeiDou the convergence time has improved from 20 minutes to 6 to 8 minutes. See Fig. 9 where the results of 27 receivers around the world are plotted. The time to reach 10 cm accuracy North, East is 7 minutes. For the height this is 11 minutes in 95 % of the cases.

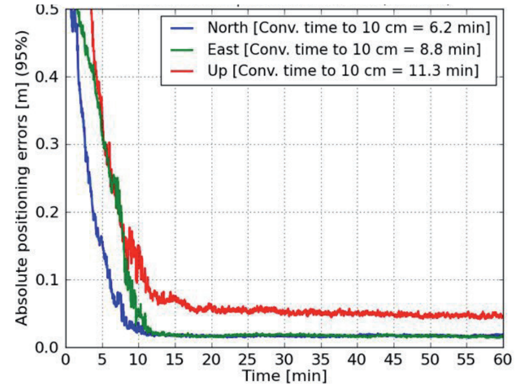

Fig. 9: Convergence time of 27 receivers around the globe

Field receivers

Fugro Marinestar-capable receivers are available from Applanix, Kongsberg, SBG, Septentrio, Trimble and OEM (original equipment manufacturer) board from application manufacturers such as Norbit, R2Sonic and others.

Multiple L-band

Modern receivers do support tracking of multiple L-band correction signals in parallel, up to three beams per antenna. With two separate L-band antennas the likelihood that the L-band signal is blocked or disturbed by scintillation becomes very low (see Fig. 10). Especially as Ntrip over (satellite) Internet (VSAT, Starlink, Iridium, cell phone) is also available.

Fast position update rate

Typically positioning has been ten times per second (10 Hz) for multibeam use. Now the update rates are going up to 20 Hz. 20 Hz has value for fast-moving survey vessels. For the many satellites tracked and used and the higher update rates, more computer power is needed within the receiver and more clever algorithms.

RTK versus PPP

The PPP positions come close to the accuracy of RTK (real-time kinematic) after convergence. When the RTK baselines get larger than 5 to 10 km both

L-Band Tracker Status

	Beam 1	Beam 2	Beam 3	Beam 4	Beam 5	Beam 6	Beam 7
Beam Name	EMSAT	SASAT	IOSAT	EMSAT	SASAT	IOSAT	NTRIP
Frequency	1545.9275 MHz	1545.8150 MHz	1545.8075 MHz	1545.9275 MHz	1545.8150 MHz	1545.8075 MHz	N/A
Baudrate	1200 Baud	1200 Baud	1200 Baud	1200 Baud	1200 Baud	1200 Baud	N/A
Service ID	0xC685	0xC685	0xC685	0xC685	0xC685	0xC685	LBAS2
Freq. Offset	1886.529 Hz	1643.160 Hz	1535.453 Hz	1886.836 Hz	1643.510 Hz	1534.936 Hz	N/A
C/N0	43.10 dB-Hz	43.50 dB-Hz	38.40 dB-Hz	43.50 dB-Hz	44.60 dB-Hz	34.50 dB-Hz	N/A
AGC Gain	26 dB	26 dB	26 dB	43 dB	43 dB	43 dB	N/A
Status	Locked	Locked	Locked	Locked	Locked	Locked	Locked
Source/Tracker	LBR board	LBR board	LBR board	Internal	Internal	Internal	NTRIP
Lock Time	>18h12m15s	5h22m12s	>18h12m15s	>18h12m15s	5h48m28s	14h37m28s	>18h12m15s

Fig. 10: Example of Septentrio U3 Marine with up to seven parallel L-band channels using two separated antennas

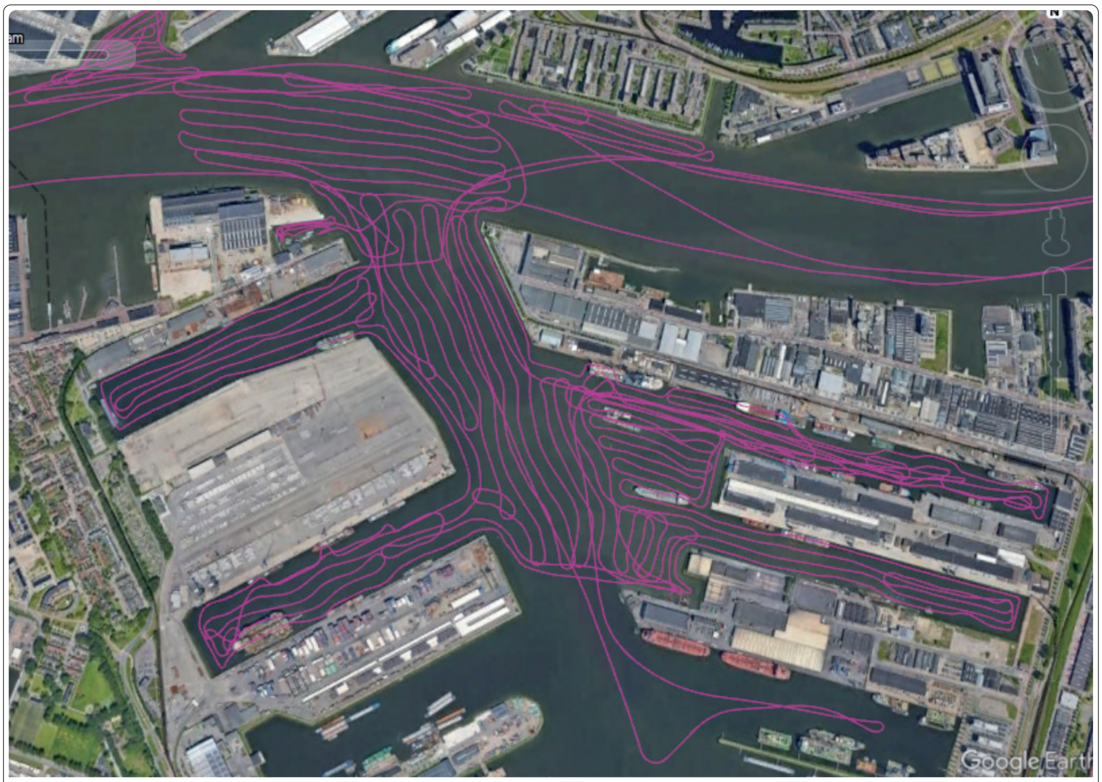

Fig. 11: Hydrographic survey in the Port of Rotterdam (Waalhaven) with Septentrio M3+ Fugro Marinestar data. With support of Willem Snoek

solutions have the same level of accuracy. RTK has the advantage of an accurate position within one minute. PPP has the advantage of global availability.

Applications

Fugro Marinestar PPP positioning is used in dredging, hydrography, oceanographic research, wind farming, site monitoring, cable and pipe laying and piling activities.

In Fig. 11 a hydrographic survey in the harbour of Rotterdam is shown which was conducted in May 2023 with seven days of good data.

Conclusion

In 2023, there are around 120 satellites allowing tracking of up to 50 satellites giving centimetre-level accuracy converging in 10 minutes towards 10 cm. Still, all GNSS satellites are of value to make positioning more accurate and robust. //

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Galileo: https://www.gsc-europa.eu/system-service-status/constellation-information

BeiDou: http://www.csno-tarc.cn/en/system/health

GLONASS: https://glonass-iac.ru/glonass/day_monitoring