

The background of the slide is a photograph of space. It shows the Earth's horizon on the left, with a bright sun or star creating a lens flare effect. Several satellites with solar panels are visible in orbit against the dark, star-filled background of space.

USE OF FOUR GNSS SYSTEMS IN OPERATIONAL PRECISE POINT POSITIONING SERVICE

Ole Ørpen, Rune Strandli, Javier Tegedor presented by Dr. Lee Ott

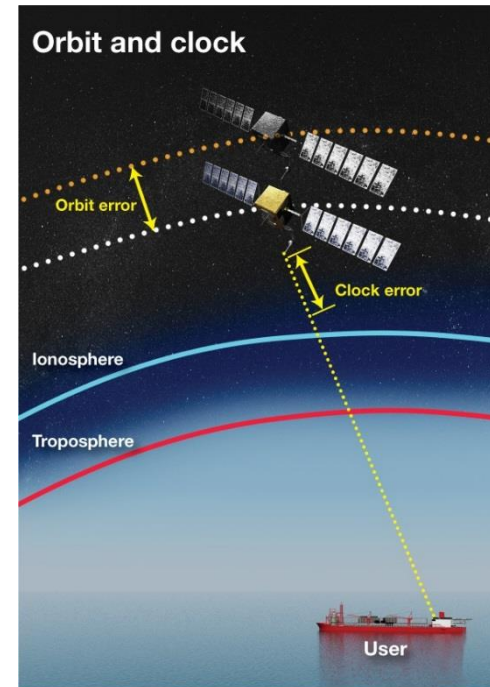
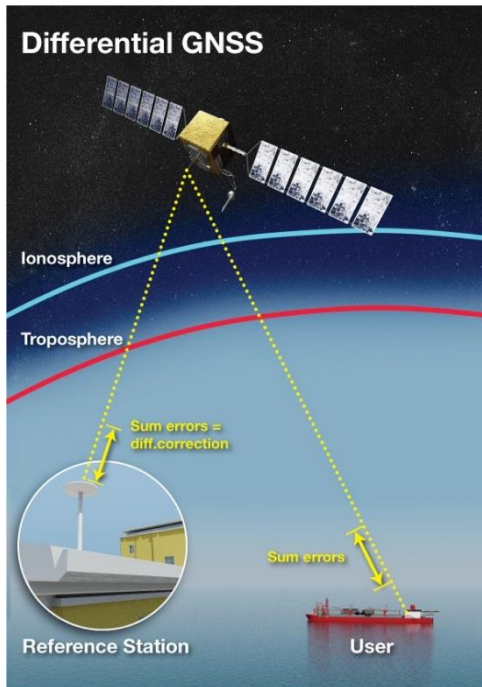
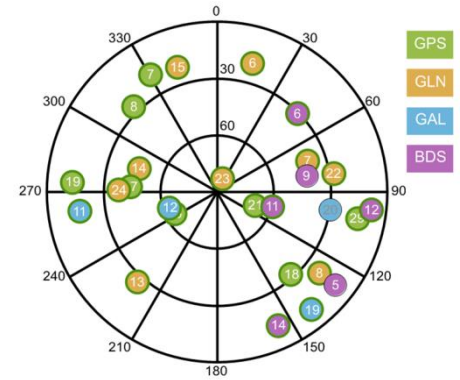
Fugro Satellite Positioning

Summary

- Background
- Galileo
- BeiDou
- Performance examples
- Use of Multi GNSS systems

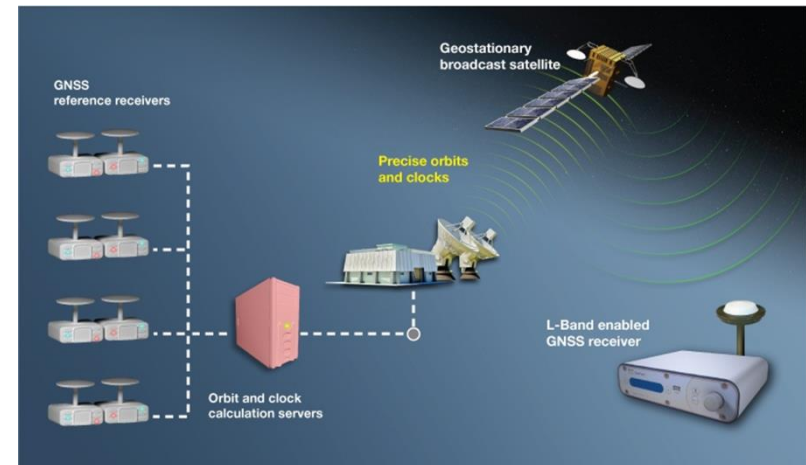
PPP Services are used by Professional High End Users

- Orbit & clock Precise Point Positioning (PPP)
 - *Using more accurate orbits than broadcast ephemeris and very precise real-time satellite clock corrections for world wide coverage*
 - *Using carrier phase dual-frequency measurements to get decimeter accuracy*



Fugro Precise Point Positioning services

- Fugro launched in 2009 the G2 service using GPS and GLONASS:
 - Proprietary worldwide tracking network
 - Real-time estimation of orbits/clocks
 - Broadcast corrections using GEO satellites
 - Maritime professional users
 - Highly redundant service
 - Decimeter level accuracy
- Following GNSS evolution, new services have been introduced in Q1 2015:
 - **G2+**: ambiguity-fixed PPP
 - **G4**: addition of BeiDou and Galileo

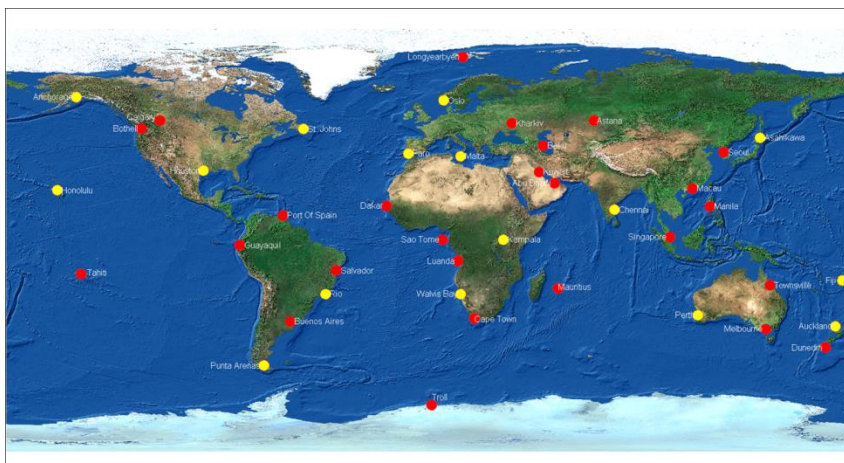


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Fugro's first Galileo Only Positioning, 18 March 2013

- Four IOV satellites used in Precise Point Positioning (PPP) at 10 cm level
- Fugro generated high accuracy Galileo orbit/clock data using Fugro's tracking network



Fugro tracking network in March 2013, yellow means Galileo capable stations

NEWS RELEASE

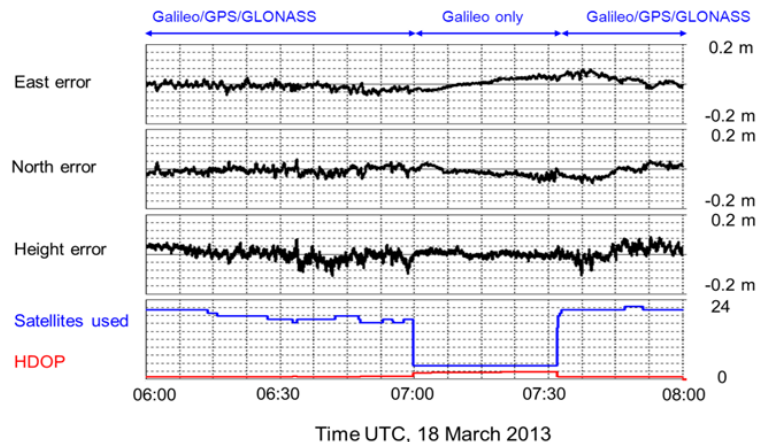


Oslo, Norway, 26 March 2013

REAL-TIME PPP WITH GALILEO IS NOW A REALITY!

Fugro has been looking forward to demonstrating Real-Time Precise Point Positioning (PPP) based solely on Galileo signals since the last two satellites were launched in the autumn. These two satellites brought the constellation to a total of four satellites, the minimum required to permit calculation of a Galileo-only position. Fugro achieved this task on March 18, which was within a week of all 4 Galileo satellites being activated. Fugro is now generating Galileo orbit & clock corrections which can be used in conjunction with the Fugro G2 decimetre-level corrections associated with our GPS/GLONASS PPP service.

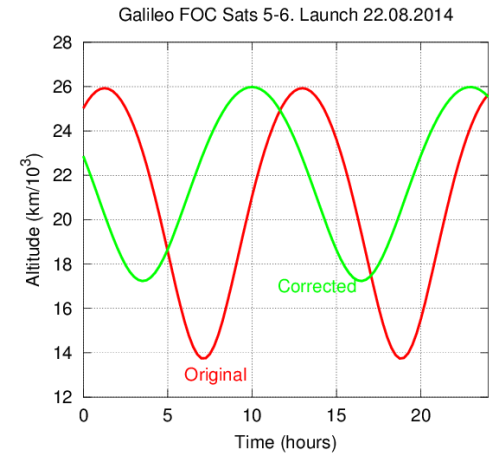
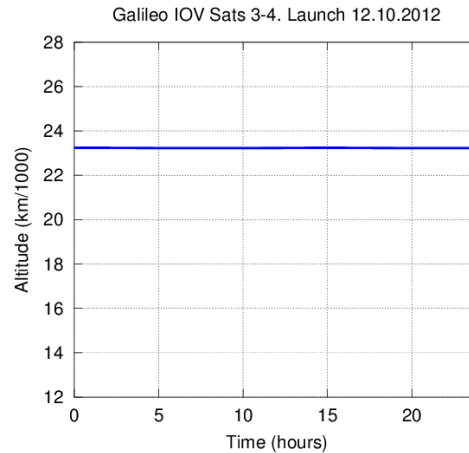
The plot below shows performance of the Fugro orbit & clock service using GPS, GLONASS and Galileo satellites between 06:00 and 08:00 UTC 18 March 2013 in Oslo, Norway. Between 07:00 and 07:30 UTC only the four Galileo satellites were used for the solution, which achieved a similar accuracy to our existing service. It is interesting that the noise level of the position is better with Galileo alone than when GPS and GLONASS satellites are also used. This is very encouraging as with only four satellites to choose from, the geometry of the Galileo based solution is much weaker than the solutions before and after the Galileo-only period. This performance exceeds our expectations and suggests a strong future for Fugro's Galileo PPP solution.



For further questions or information, please contact:
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Galileo current status

- G4 system has been qualified for Galileo
- No Galileo corrections delivered to customers yet
- Galileo will be added to G4 when operational (Early Services 2016)



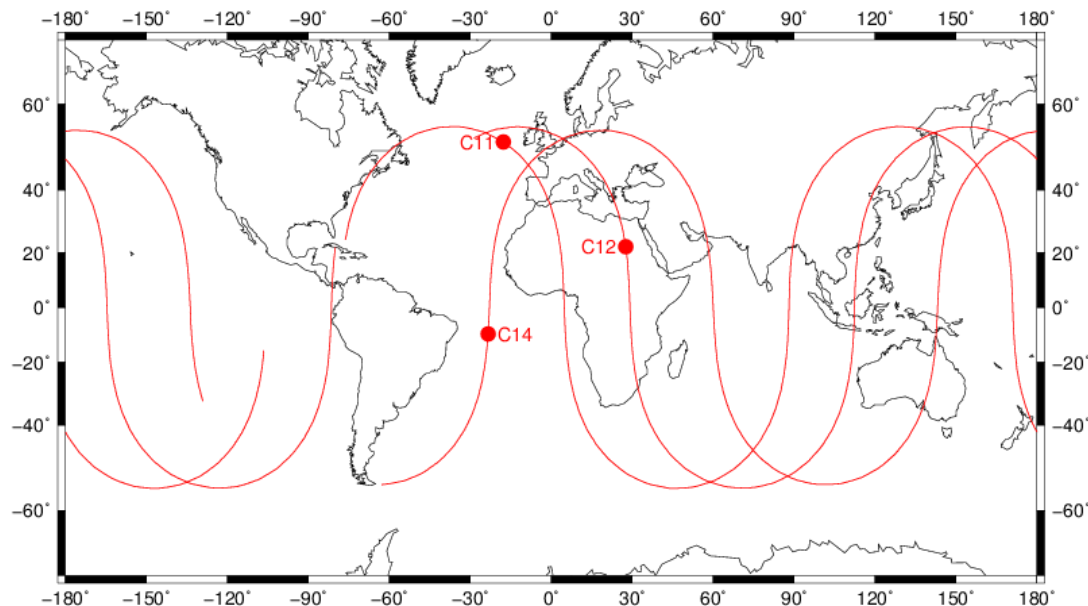
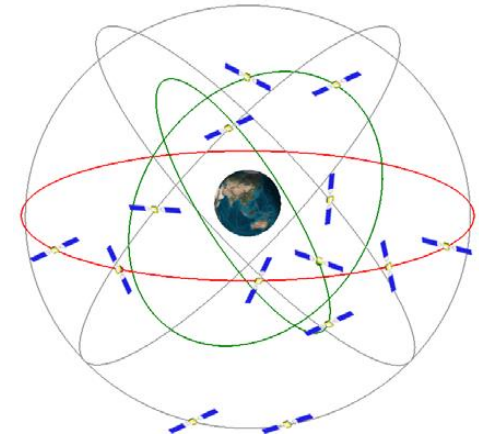
Satellite	PRN	Launch	Status
IOV PFM	E11	Oct 2011	OK
IOV FM2	E12	Oct 2011	OK
IOV FM3	E19	Oct 2012	OK
IOV FM4	E20	Oct 2012	Only transmitting in E1
FOC FM1	E18	Aug 2014	Non-nominal orbit
FOC FM2	E14	Aug 2014	Non-nominal orbit
FOC FM3	E22	Mar 2015	Under commissioning
FOC FM4	E26	Mar 2015	Under commissioning

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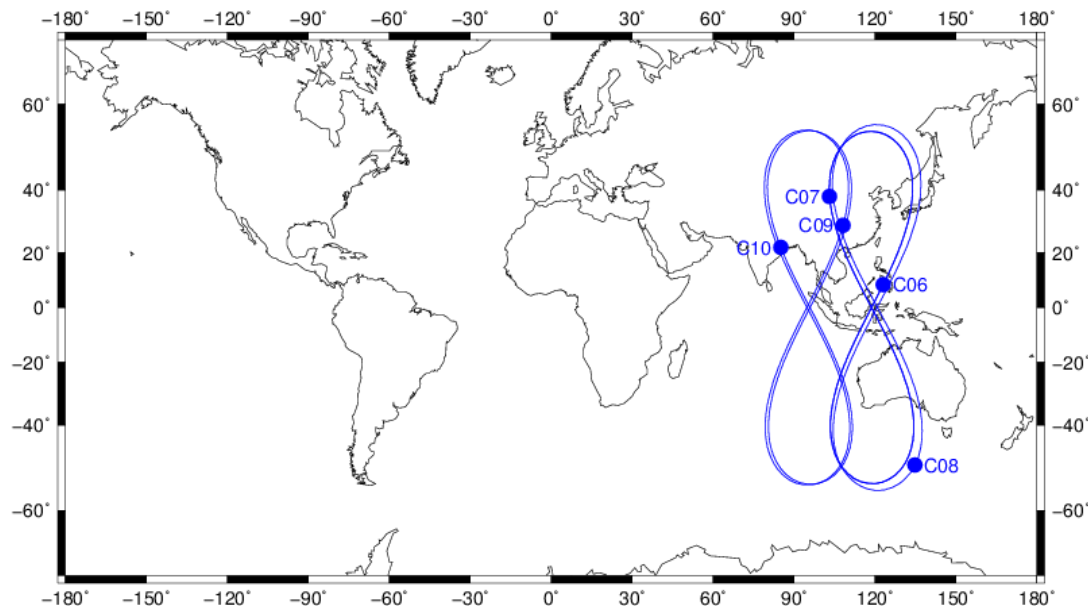
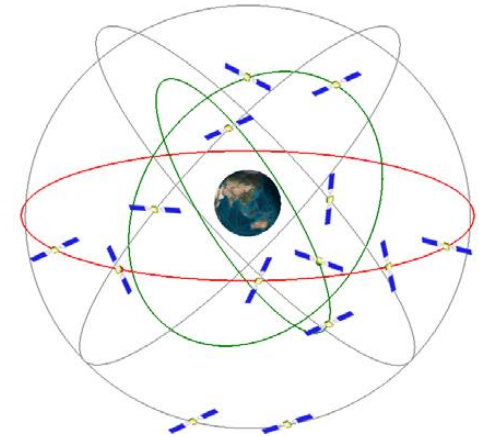
BeiDou, Chinese Satellite Navigation System

- Regional coverage in Asia
 - 3 MEO (Medium Earth Orbit)
 - 5 IGSO (Inclined Geosynchronous Orbit)
 - 5 GEO (Geostationary Orbit)
- Full worldwide Coverage (30 satellites) by 2020
- First BeiDou-3 satellite launched on March 31st



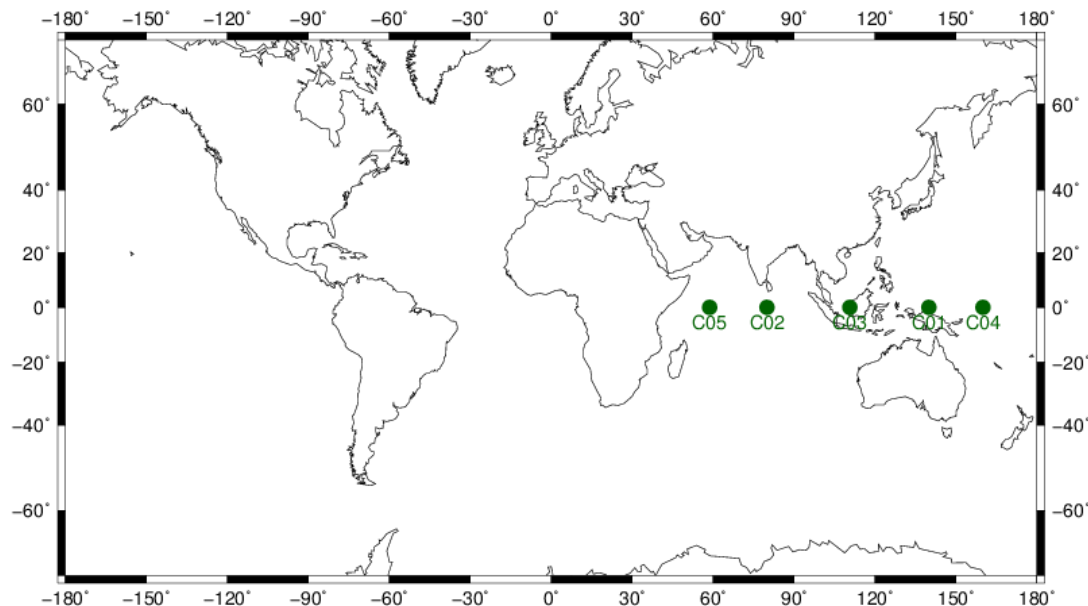
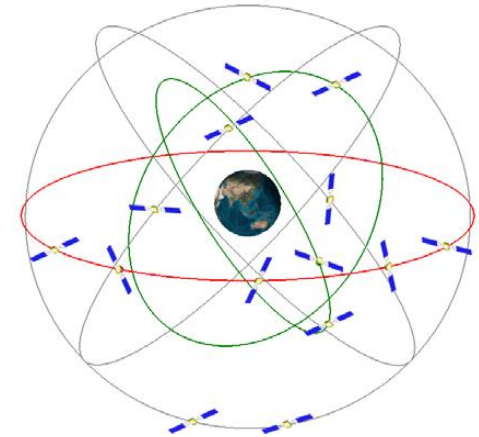
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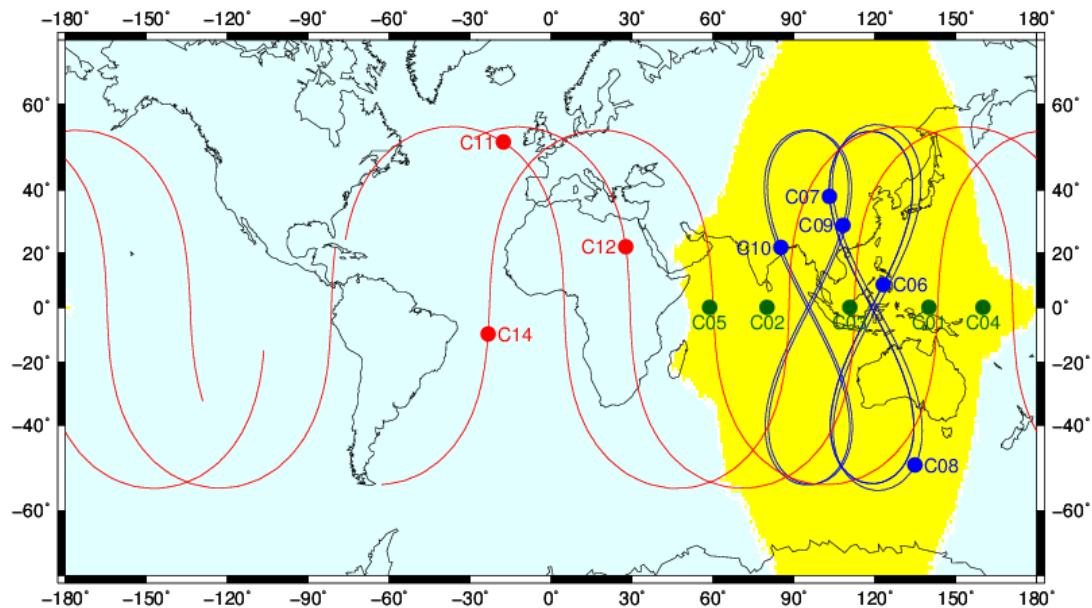
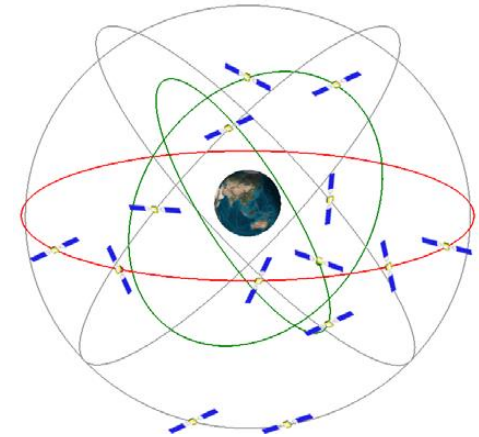
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Examples of BeiDou Coverage 14 October 2015

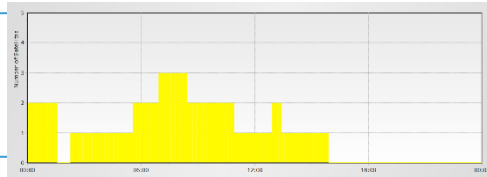
Houston

Satellites

10

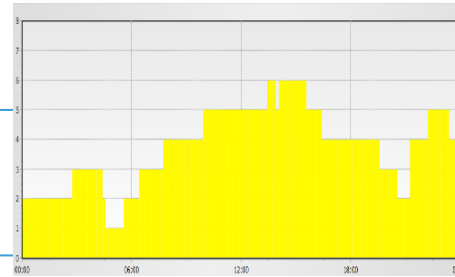
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0



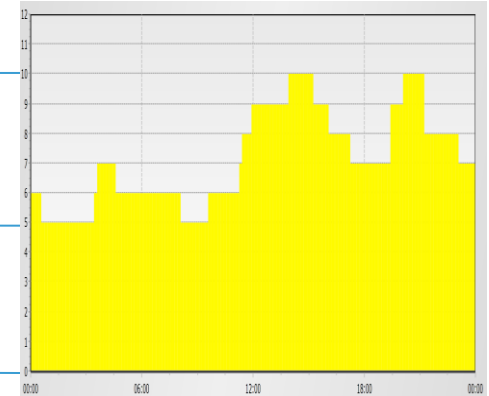
24 Hours

Oslo



24 Hours

Kuwait



24 Hours

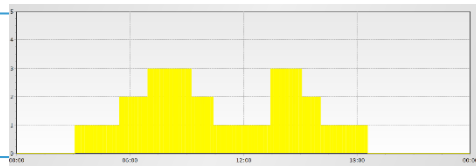
Rio

Satellites

10

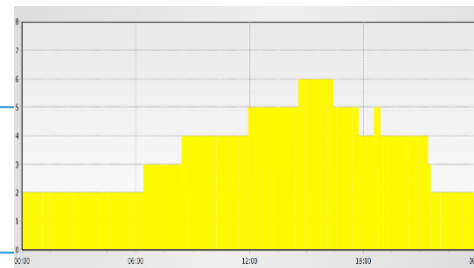
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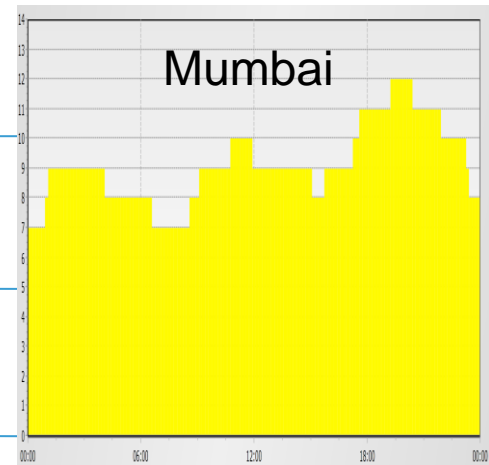
24 Hours

Douala



24 Hours

Mumbai

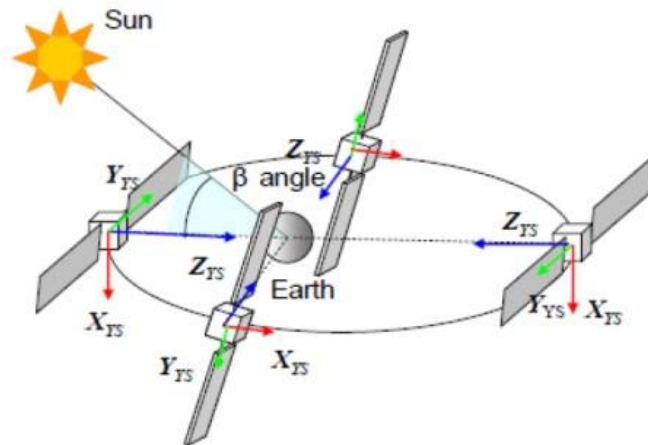


24 Hours

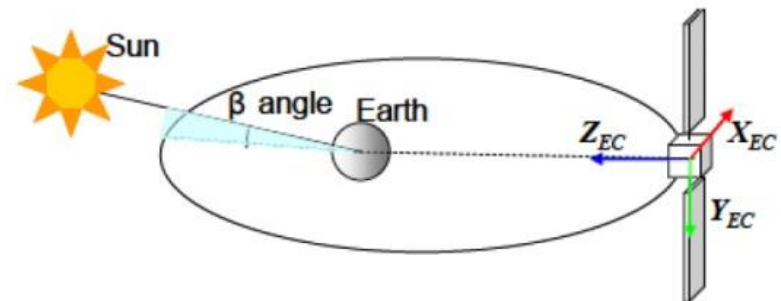
GNSS planning: <http://www.trimble.com/gnssplanningonline/#/Settings>

Challenges for BeiDou PPP

- Challenges for precise orbit determination
 - Geometry
 - Orbit determination for GEOs is particularly challenging due to the static position with respect to the reference station network
 - Satellite attitude:
 - Orbit normal mode used by GEOs



Yaw-steering Mode



Orbit-normal („Earth-centered“) Mode

Source: IGS MGEX

- BeiDou has gained approved for use at sea by the International Maritime Organization (IMO)
- Third IMO approved system after GPS and GLONASS



IMO Marine Safety Committee (MSC) has during its 94th session 17-21 Nov. 2014:

- recognized the BeiDou Navigation Satellite System (BDS), operated by China, as a component of the World-Wide Radionavigation System (WWRNS)

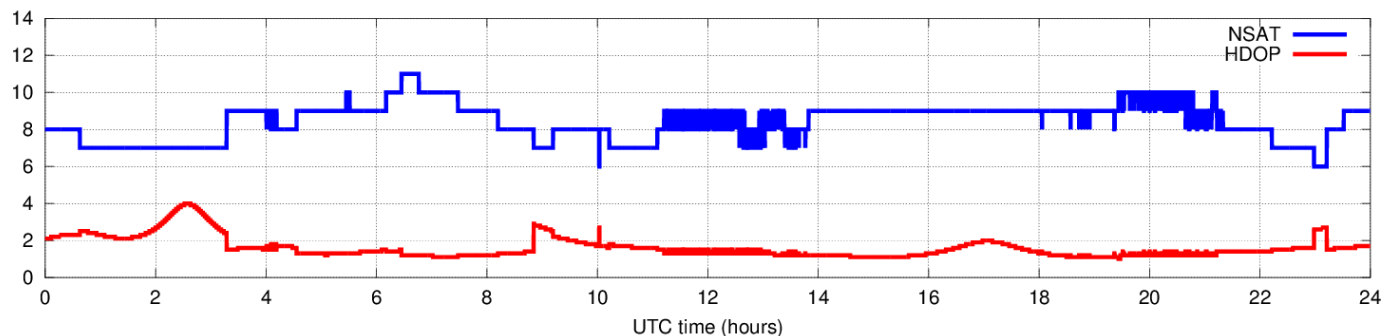
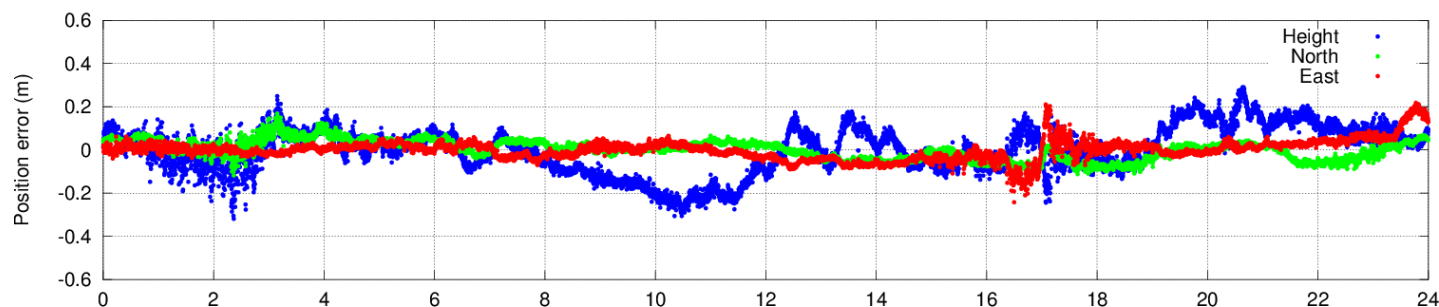
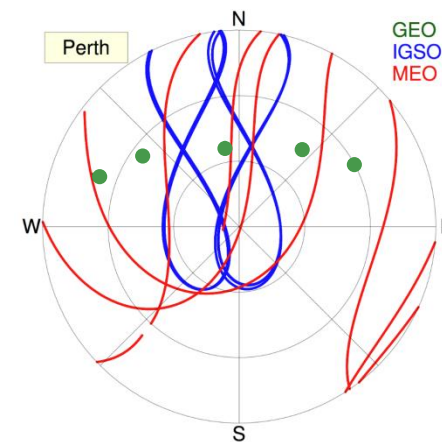
http://issuu.com/imo-news/docs/24494_imo-news-01-15_6/1 (page 18)

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Precise Point Positioning using only BeiDou – Perth (Australia)

- The use of GEO satellites in the G4 service allows you to obtain 24/7 PPP using only BeiDou
- Very good horizontal accuracy (<10cm)
- Vertical accuracy is a bit more variable due to GEO orbit errors



Satellite visibility from Oslo 31 July 2015

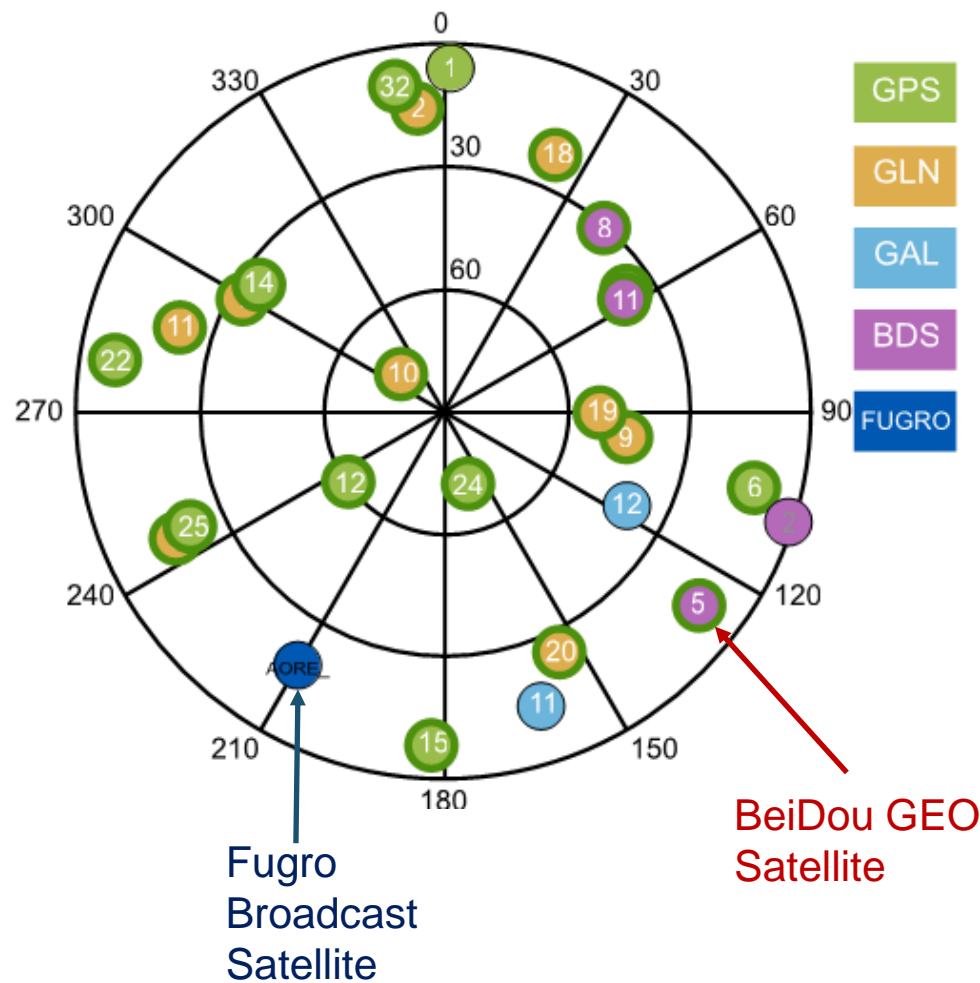
UTC: **2015-Jul-31 07:35:17**
 Latitude: **059° 55.117' N**
 Longitude: **010° 41.161' E**
 Height Above MSL: **37.35 m**

SOG: **0 Kn**
 COG: **119°**

Quality:
 RAIM: **Safe(0.3m)**

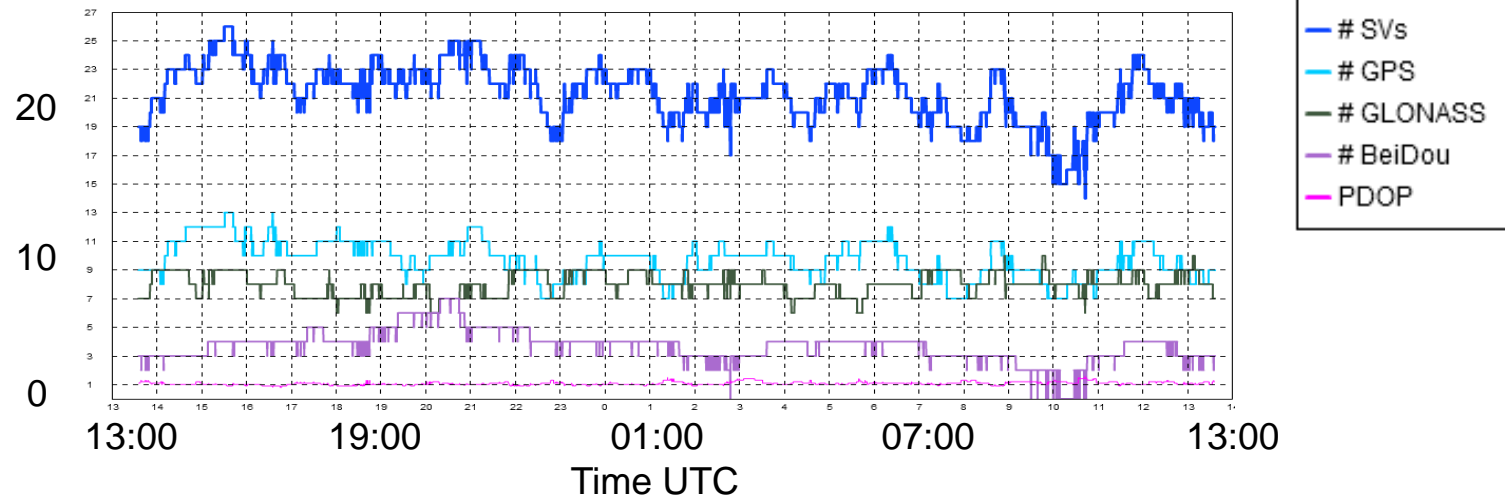
Accuracy of Solution:
 Position: **0.08 m**
 Height: **0.10 m**
 Position Type: **G4**
 Corr. Age: **14 s**
 HDOP: **0.6**

G2/XP Expiration Date: **2016-6-4 0:0:0**
 Expiration Date: **2016-6-4 0:0:0**

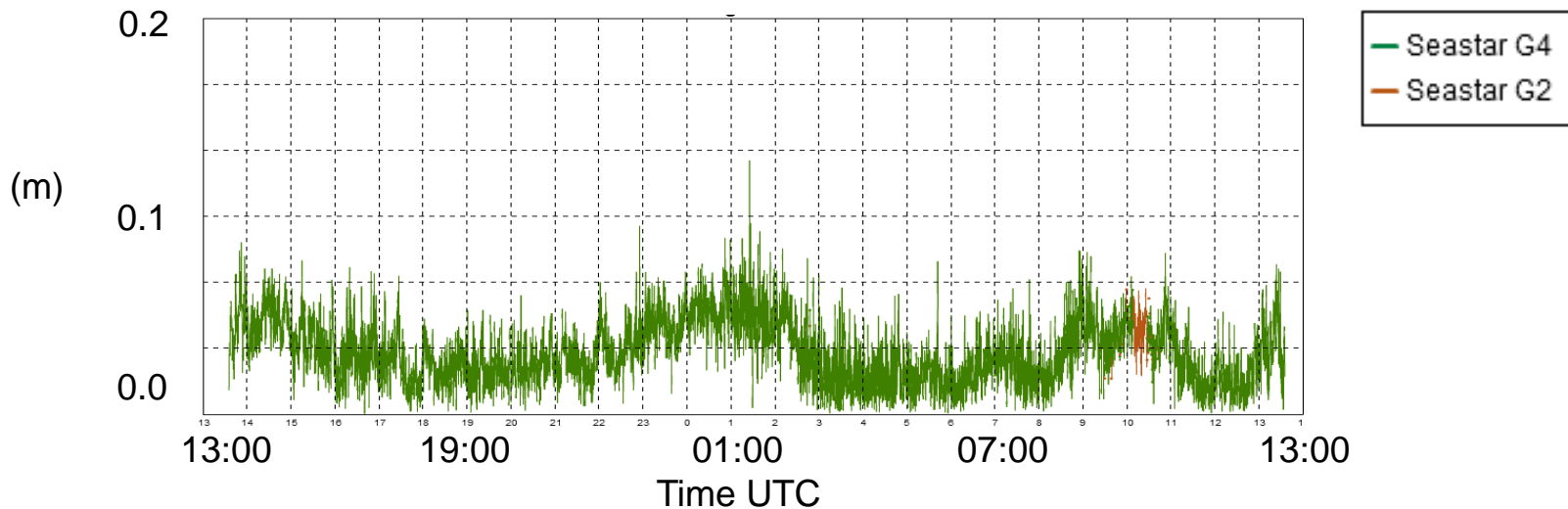


Satellites used in solution:

Number of satellite and PDOP



Horizontal Position Error

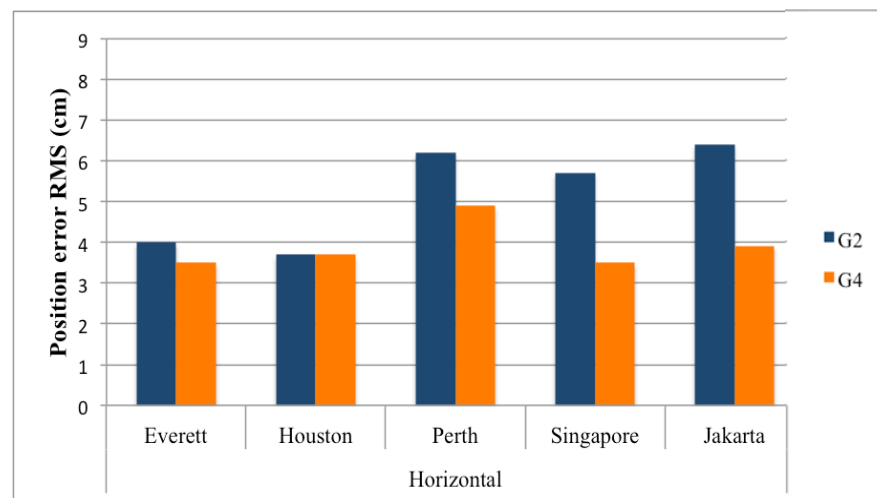
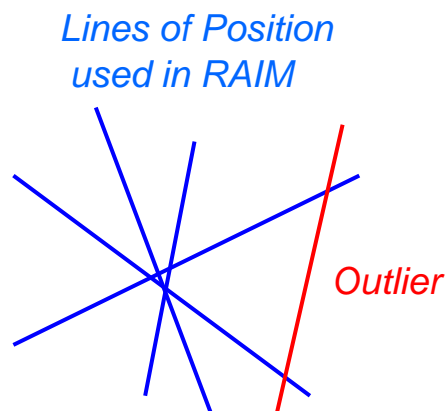
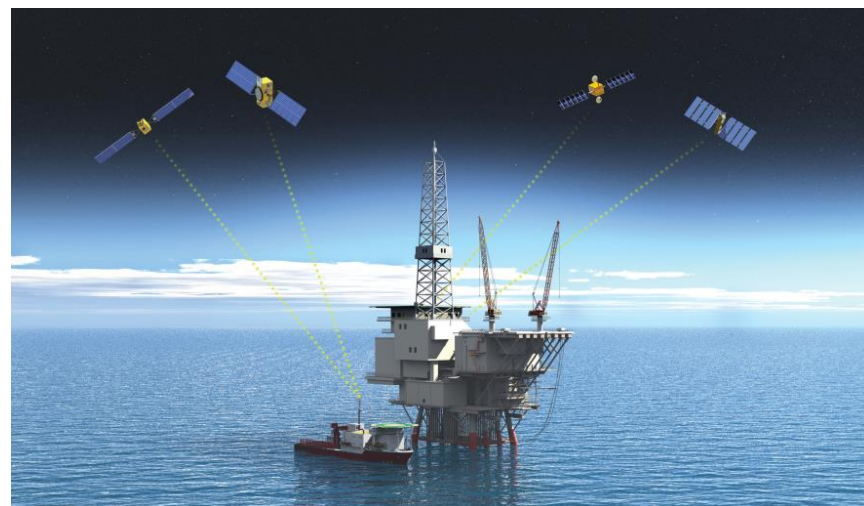


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Advantages of multi-constellation PPP

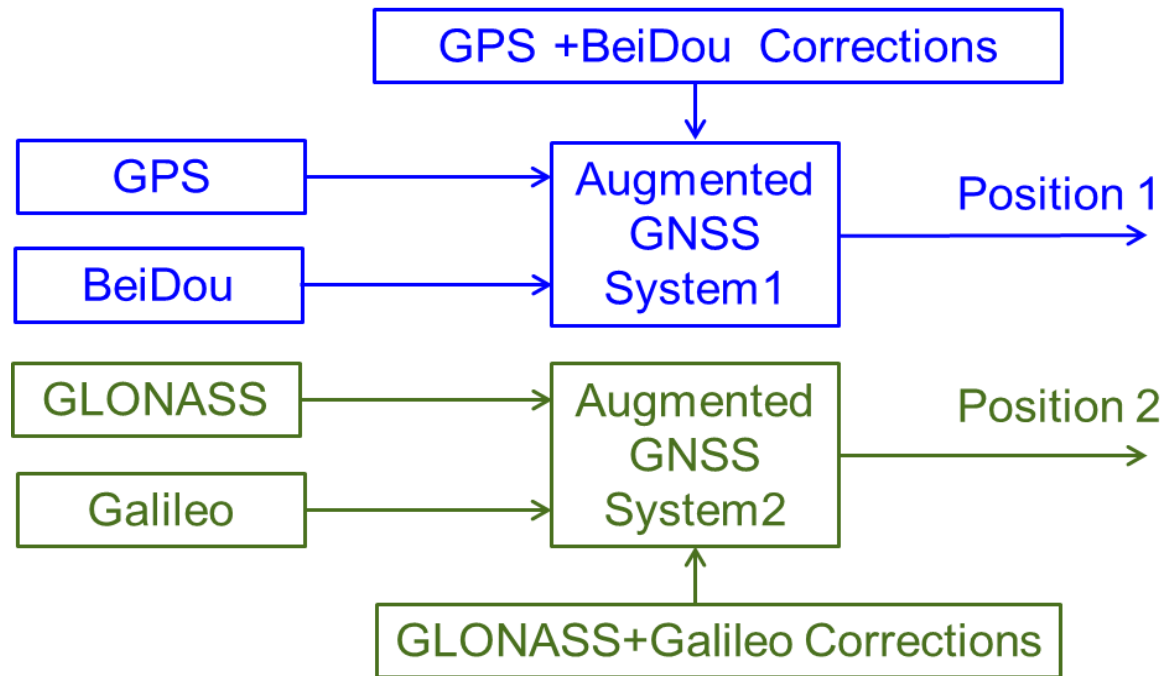
- Increased accuracy and reduced convergence time
- More robustness against:
 - Interference
 - Scintillations
 - Partial sky visibility
 - Spoofing
- Better RAIM protection (increased redundancy)



RAIM: Receiver Autonomous Integrity Monitoring

Possible future Multi-GNSS Integration

- When Galileo and BeiDou are fully deployed, new positioning scenarios can be envisaged:
 - Deliver two independent solutions
 - Independent GNSS's and independent corrections
 - Independent of single-system failure
 - Integrity detection is possible by checking the two positions



Conclusions

- BeiDou has completed a constellation for regional 24 hour coverage in Asia.
 - 13 operational satellites
 - Coverage being extended worldwide (2020)
- Galileo moving towards Early Services (2016)
- Fugro introduced the G4 service with BeiDou in Feb. 2015
- Additional GNSS provides an opportunity for improved performance
 - Higher accuracy, reliability and availability
 - Independent solutions

Thank you for your attention!

Lee Ott

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