The Galileo Commercial Service, status and plans

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European Commission – DG ENTR
"Reference frames, Positioning and Navigation"
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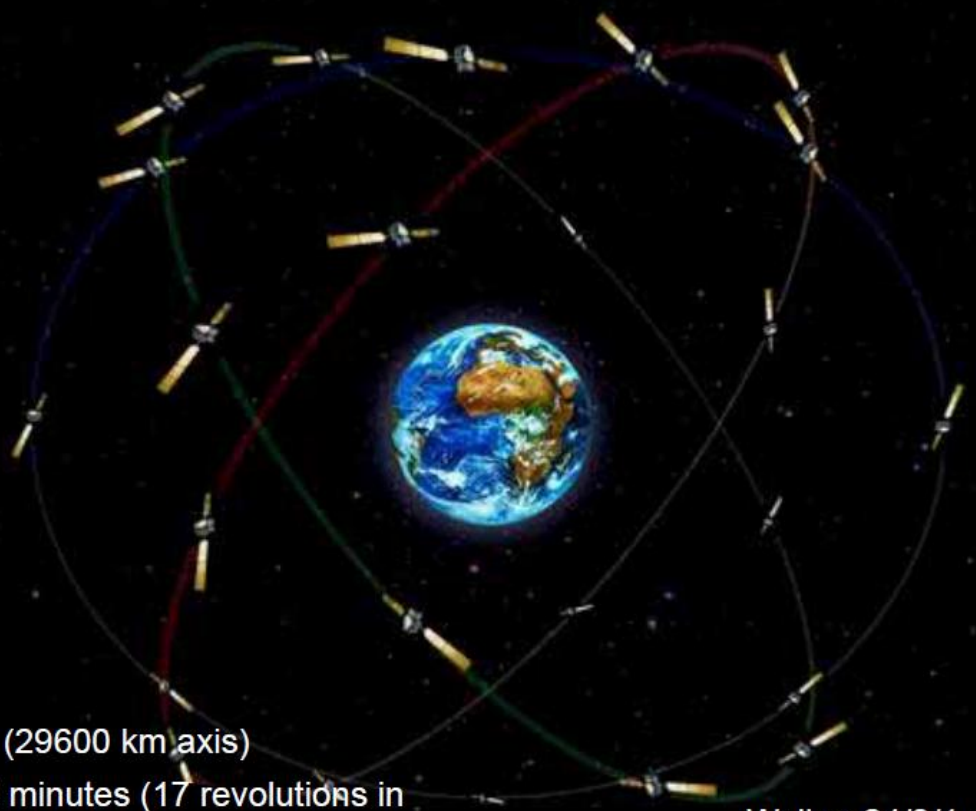
Galileo

Galileo Nominal Constellation

24 satellites in Medium Earth Orbit (MEO)



Altitude: 23 228 km (29600 km axis)

Period: 14 hours 22 minutes (17 revolutions in 10 days)

3 orbital planes inclined at 56° to the Equator

2 spare satellites in each plane

Walker 24/3/1 configuration

Inclination: 56°

15° phasing between planes

Galileo Ground Segments

European Commission

TTCF S-Band 11m dish antenna, Sweden

European Commission

Galileo Services

Open Service (OS)	Freely accessible service for positioning, navigation and timing	
Public Regulated Service (PRS)	Encrypted service designed for greater robustness and higher availability	
Search and Rescue Service (SAR)	Assists locating people in distress and confirms that help is on the way	
Commercial Service (CS)	Delivers authentication and high accuracy services for commercial applications	

The former "Safety-of-Life" service is being re-profiled:

Integrity Monitoring Service	Provides vital integrity information for life-critical applications	

Galileo Commercial Service: Introduction

European Commission

Extracts from the Galileo Regulation on CS (1285/2013) and associated Program documentation:

- *CS shall enable "…the development of applications for professional or commercial use by means of **improved performance** and data with greater added value than those obtained through the open service"*

- *CS based on "commercial ranging and data, whose **access shall be controllable** in order to allow fees to be levied."*

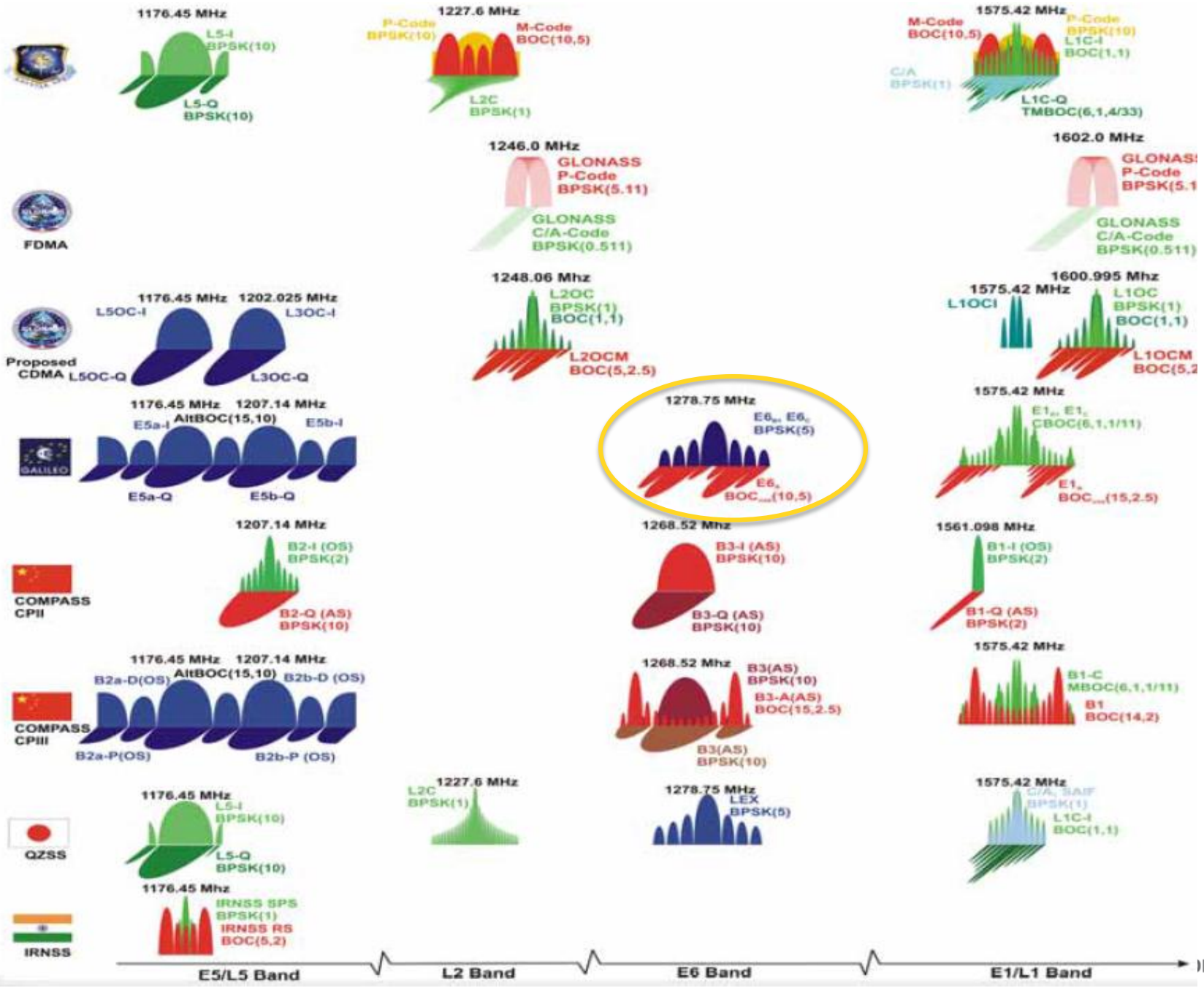
- *"...the CS shall offer a payable added-value service, which can be exploited through a **revenue-sharing mechanism with the private sector**."*

- *"The Commercial Service signals shall be the **Open Service signals, plus two encrypted signals in the E6-band**."*

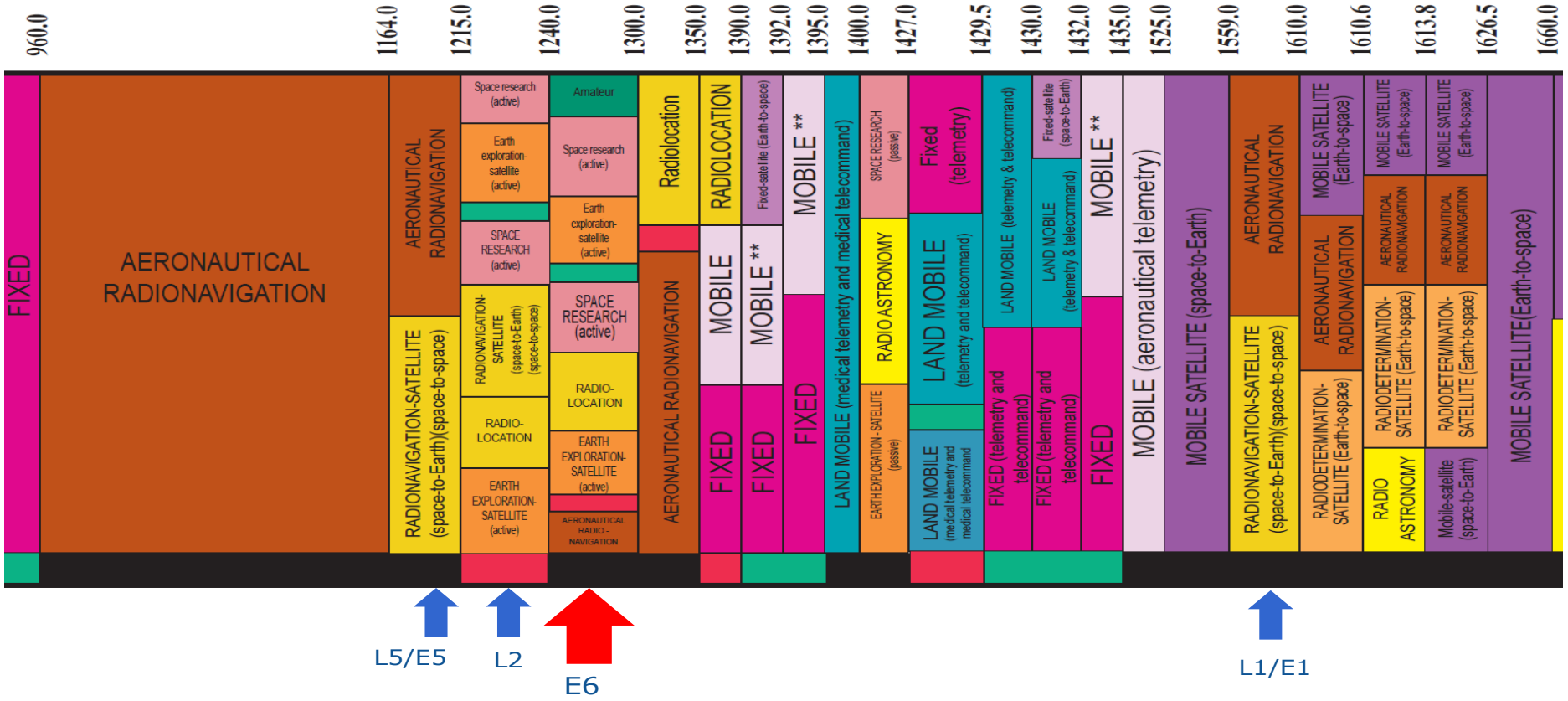
CS High Level Objectives

- Maximize satnav **public benefits**
- Creation of **economic value**
- Provide the best **navigation performance** possible with the Galileo infrastructure
- Promote **innovation** by offering new functionalities
- Provide a **revenue source** to offset Galileo costs

Galileo Commercial Service: Frequency, Signals and Data


1176.45 MHz
L5-I
BPSK(10)
L5-Q
BPSK(10)
1227.6 MHz
P-Code
BPSK(10)
M-Code
BOC(10,5)
L2C
BPSK(1)
1575.42 MHz
M-Code
BOC(10,5)
P-Code
BPSK(10)
L1C-I
BOC(1,1)
C/A
BPSK(1)
L1C-Q
TMBOC(6,1,4/33)
FDMA
1246.0 MHz
GLONASS
P-Code
BPSK(5.11)
GLONASS
C/A-Code
BPSK(0.511)
1602.0 MHz
GLONASS
P-Code
BPSK(5.1
GLONASS
C/A-Code
BPSK(0.511)
Proposed
CDMA
1176.45 MHz
L5OC-I
L5OC-Q
1202.025 MHz
L3OC-I
L3OC-Q
1248.06 Mhz
L2OC
BPSK(1)
BOC(1,1)
L2OCM
BOC(5,2.5)
1575.42 MHz
L1OCI
1600.995 Mhz
L1OC
BPSK(1)
BOC(1,1)
L1OCM
BOC(5,2
GALILEO
1176.45 MHz
E5a-I
AltBOC(15,10)
1207.14 MHz
E5b-I
E5a-Q
E5b-Q
1278.75 MHz
E6, E6
BPSK(5)
E6
BOC(10,5)
1575.42 MHz
E1, E1
CBOC(6,1,1/11)
E1
BOC(15,2.5)
COMPASS
CPII
1207.14 MHz
B2-I (OS)
BPSK(2)
B2-Q (AS)
BPSK(10)
1268.52 Mhz
B3-I (AS)
BPSK(10)
B3-Q (AS)
BPSK(10)
1561.098 MHz
B1-I (OS)
BPSK(2)
B1-Q (AS)
BPSK(2)
COMPASS
CPIII
1176.45 MHz
B2a-D(OS)
AltBOC(15,10)
1207.14 MHz
B2b-D (OS)
B2a-P(OS)
B2b-P (OS)
1268.52 Mhz
B3(AS)
BPSK(10)
B3-A(AS)
BOC(15,2.5)
B3(AS)
BPSK(10)
1575.42 MHz
B1-C
MBOC(6,1,1/11)
B1
BOC(14,2)
QZSS
1176.45 MHz
L5-I
BPSK(10)
L5-Q
BPSK(10)
1227.6 MHz
L2C
BPSK(1)
1278.75 MHz
LEX
BPSK(5)
1575.42 MHz
L1C-I
BOC(1,1)
IRNSS
1176.45 Mhz
IRNSS SPS
BPSK(1)
IRNSS RS
BOC(5,2)
E5/L5 Band
L2 Band
E6 Band
E1/L1 Band

CS frequency band: E6



Several actions ongoing to insure proper E6 reception:

- Discussions with IARU (International Amateur Radio Union)
- Discussions U.S., Japan and China
- E6 reception characterisation actions and testing plans (JRC & industry support)
- ITU-level actions under consideration.

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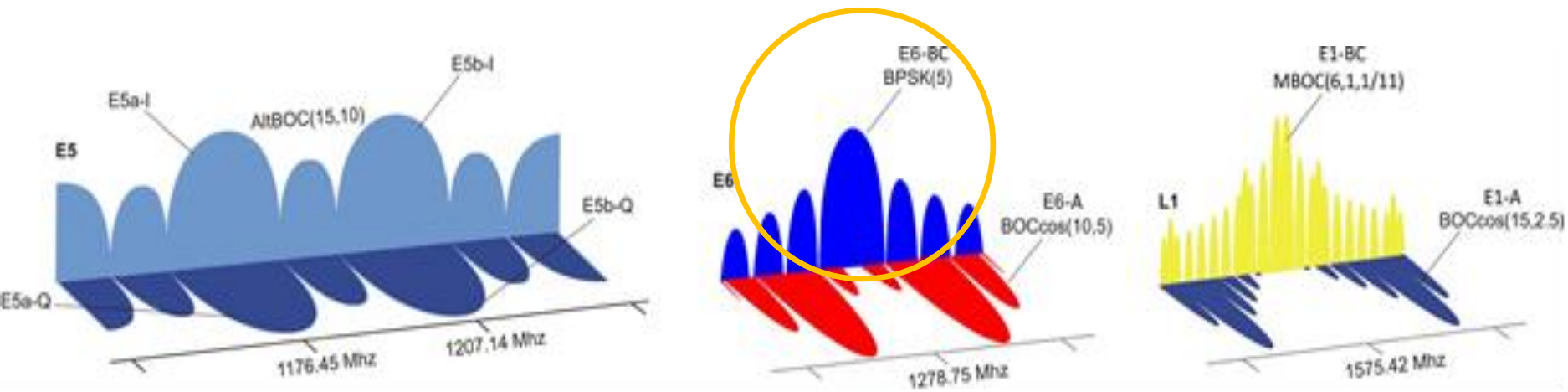
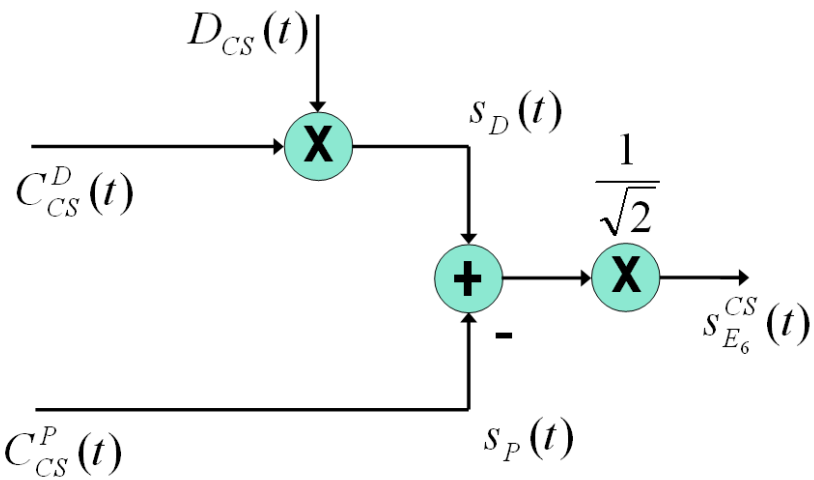
- *CS signals in Galileo signal baseline:*
  - **E6-B: data component (448 bps)**
  - **E6-C: pilot tone component**



Galileo CS signals

- Modulation



- Signal characteristics

	E6-B	E6-C
Component	Data	Pilot
Carrier Frequency	1278.75 MHz	1278.75 MHz
Spreading Modulation	BPSK(5)	BPSK(5)
Chip Rate	5.115 Mcps	5.115 Mcps
Primary Code Length	5115 chips	5115 chips
Secondary Code Length/Duration	N/A	100 chips/100ms
Symbol/Data rate	1000 sps / 500 bps	N/A

- *E6-B data structure (C/NAV): 448 bps effective*

Sync	Symbols	Total [symbols]
16	984	1000

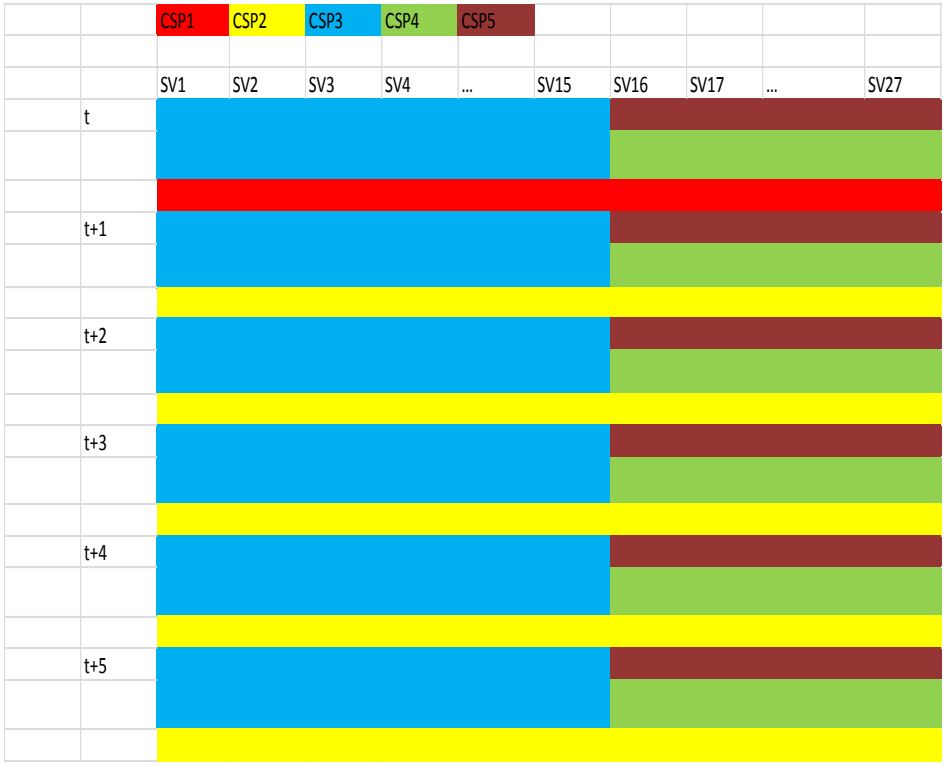
Word			Tail	Total [bits]
Page type	Commercial Data / key Management	CRC		
14	448	24	6	492

- Other information:
  - **Spreading codes can be encrypted**
  - Convolutional encoding and interleaving: same as OS SIS ICD
  - Interleaving block size: 984 symbols (123 x 8)
  - Minimum Power: -155dBW (50% data, 50% pilot)

Code Parameter	Value
Coding Rate	½
Coding Scheme	Convolutional
Constraint Length	7
Generator Polynomials	*G1*=171o *G2*=133o
Encoding Sequence	*G1* then *G2*

Data transmission

- Data can come from an external source through the GNSS Service Centre with few sec. Latency.
- Data transmission scheme from several sources under discussion.
- **EXAMPLE** of data transmission scheme (CSP = CS provider): would allow multiple providers vs multiple time slots/satellites.



Galileo Commercial Service: High Accuracy

High Accuracy:

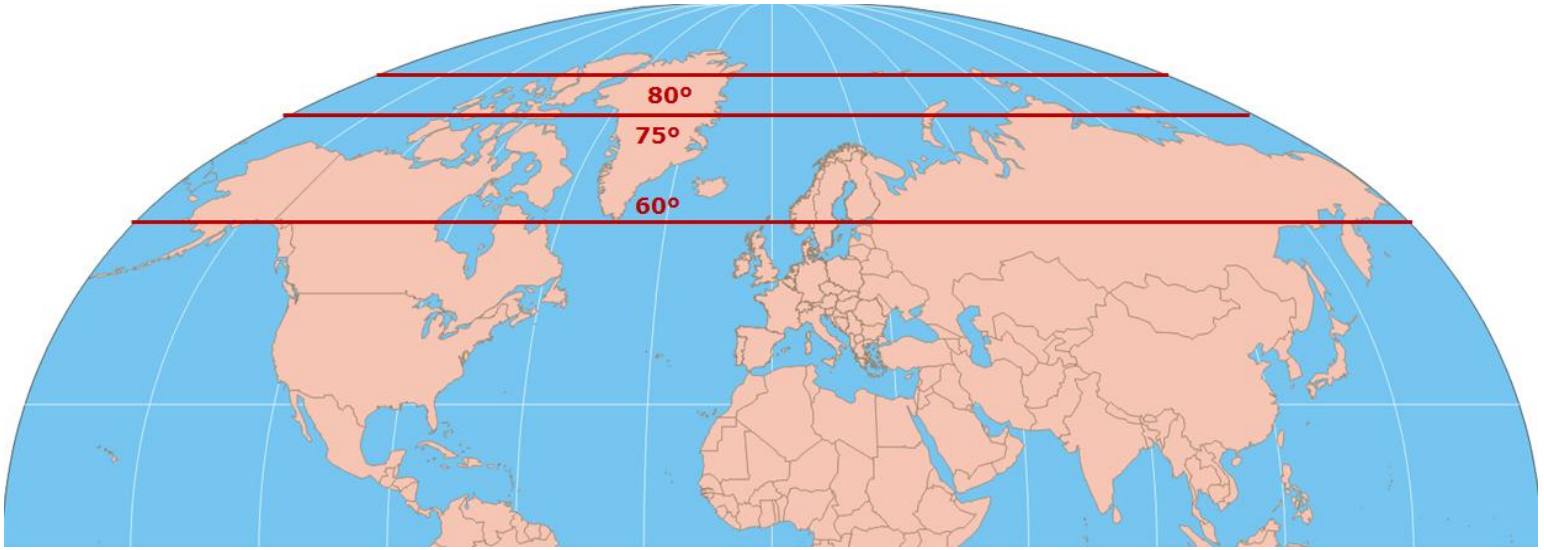
- Available data bandwidth (448 bps per satellite at most) is adequate to broadcast High Accuracy data (mainly clocks and orbits) for Precise Point Positioning.

- Data latency achievable: few seconds (exact number TBC).

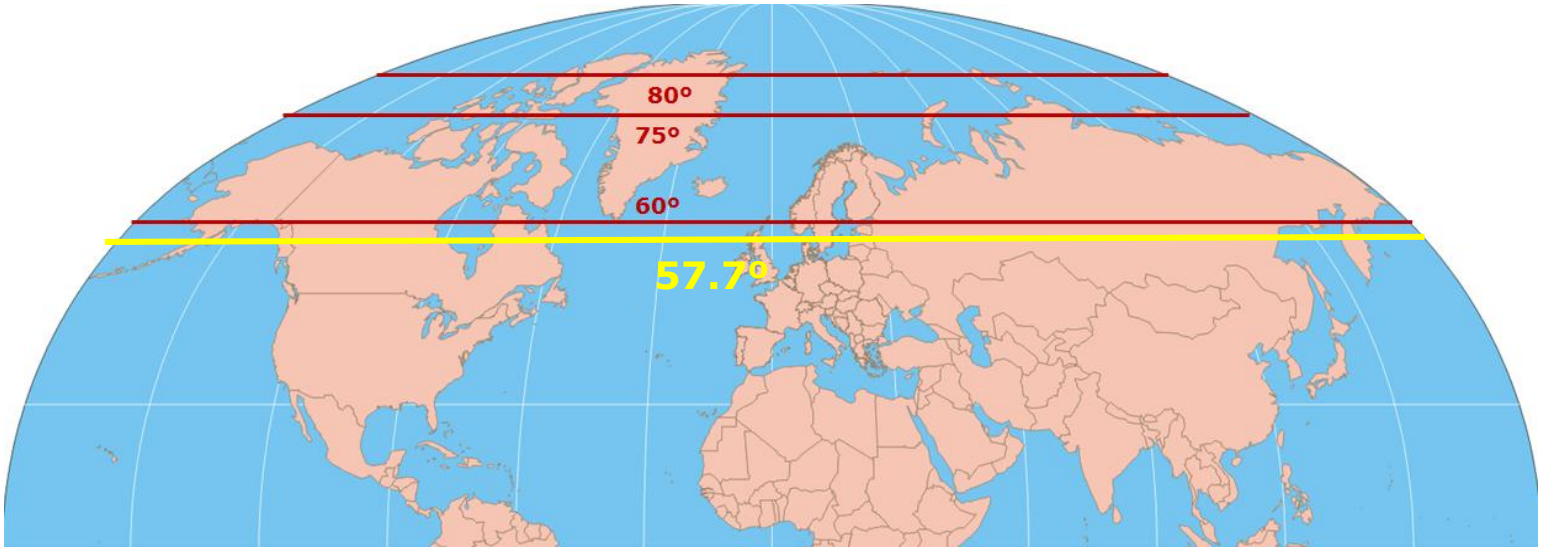
- Good complement to existing GEO transmission systems, especially at high latitudes and in difficult environments.

- Only satellites connected to ground (ULS) can transmit CS data.

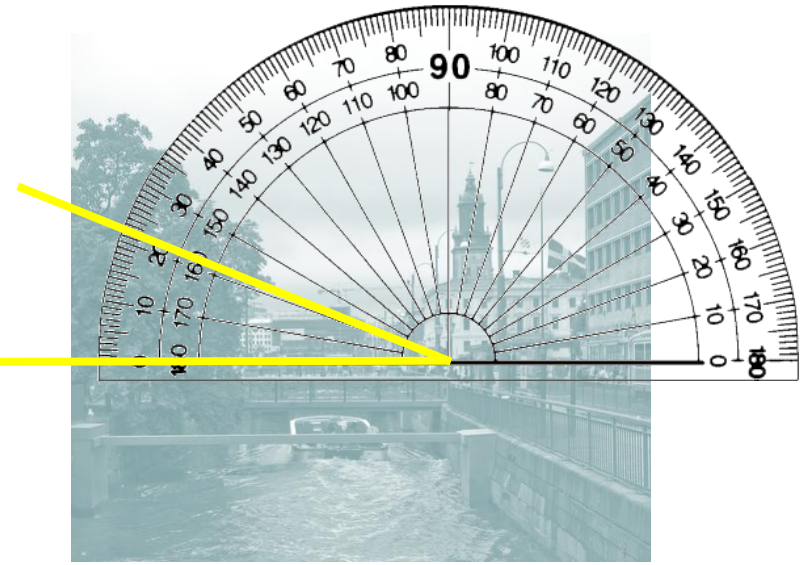
- Performance achievable:
  - Centimeter-level accuracy
  - Availability and coverage (target):
    - 2 satellites at an elevation of 20º or higher, with a 99% availability worldwide
    - 1 satellite at an elevation of 40º or higher, with a 99% availability worldwide



latitude[°]	Best possible GEO elevation [°]
55	27.3
60	21.9
65	16.6
70	11.5
75	6.4
80	1.3
81.3	0.0



- *Chalmers U.T., Gotëborg:* ***Lat 57.69º, Lon 11.97º***
- *Best-case Geostationary satellite elevation:* ***22º***



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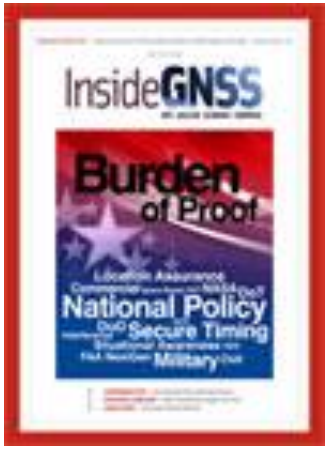
Galileo Commercial Service: Authentication

Source: **insidegnss**

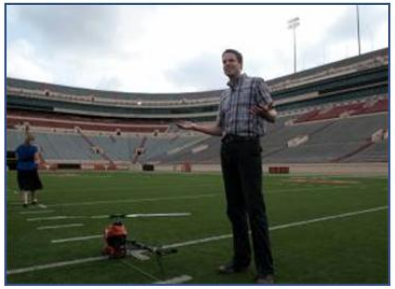
Sept-Oct 2012



Mar-Apr 2012

Jul 2012

INSIDE GNSS NEWS



Professor Todd Humphreys and UAV before GPS spoofing demonstration in UT-Austin stadium *(Click image to enlarge.)*

UAVs Vulnerable to Civil GPS Spoofing

Subject of a House subcommittee hearing this week

Latest News • July/August 2012 issue

July 16, 2012

Inside GNSS, July/August 2012

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In June a research team from the University of Texas at Austin (UT-Austin) demonstrated for the first time that a civilian unmanned aerial vehicle (UAV) can be commandeered in mid-flight by a civil GPS spoofing attack. The result will likely factor into the Federal Aviation Administration's (FAA's) plans to draw up rules for integrating

TECHNICAL ARTICLE • JANUARY/FEBRUARY 2013

(Click image to enlarge.)

Developing a GNSS Position and Timing Authentication Testbed

GNSS Vulnerability and Mitigation Techniques

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Authentication

- GNSS Authentication purpose is to insure that the processed signals are the ones transmitted from the satellites.
- The CS signal includes GNSS spreading code encryption capability for civil purposes:
  - Access control
  - Authentication
- Exact service performance and provision scheme under analysis. Elements available:
  - CS signal encrypted spreading codes
  - CS data bandwidth of some tens of bps (not all 448 bps may be used for high accuracy)
  - Additional ground infrastructure (GNSS Service Centre) for key management, service exploitation, etc.
  - Spare bandwidth from E1-B I/NAV: 20 bps from "Reserved 1" (ERIS) field.

- Authentication performance: Similar accuracy, availability and TTFF as standard PNT, but authenticated

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- **Galileo CS + OS Authentication concept (under analysis)**

OS Authentication:

- Based on asymmetric data origin authentication (eph, clk, iono…) Can support mass market applications: road, handheld location-based services, e-commerce, etc.
- Ideally transmitted in E1B I/NAV spare bits (20bps).

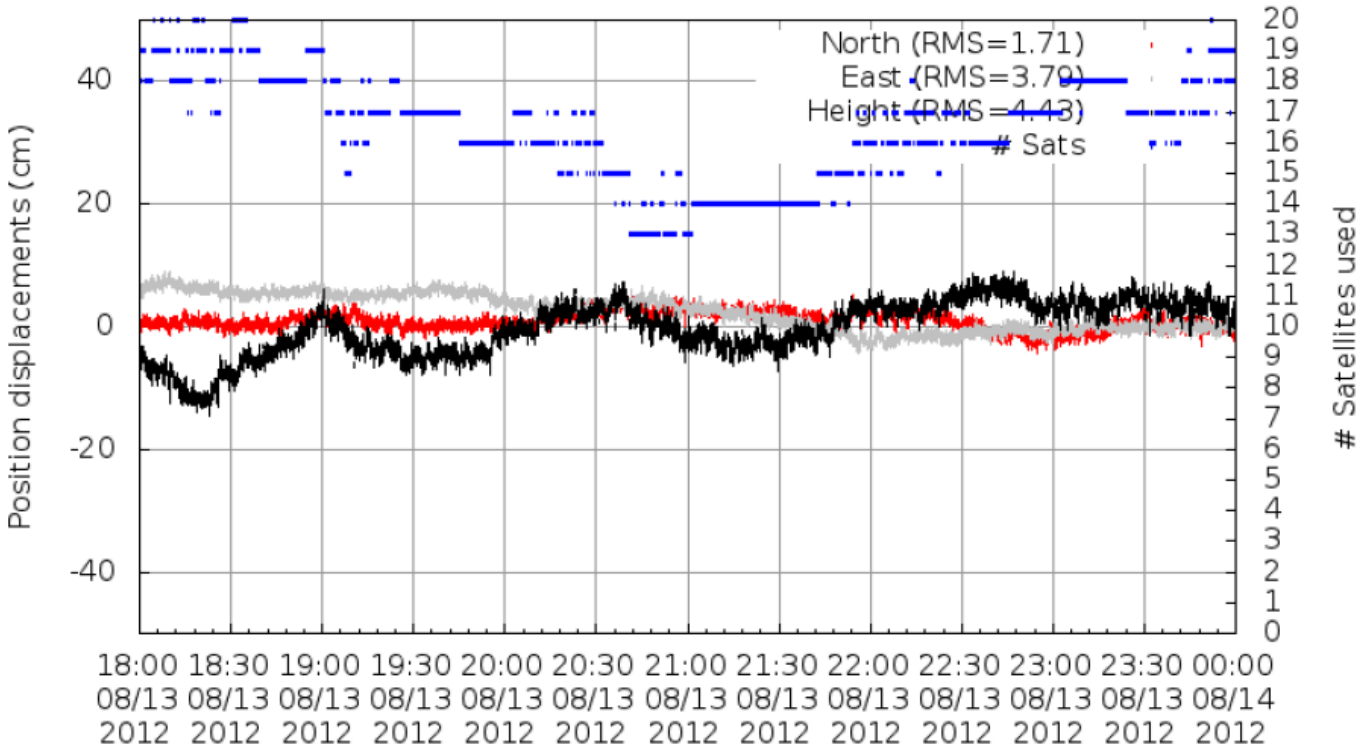
CS Authentication:

- Based on symmetric spreading code encryption, but can rely on OS authentication for data.
- A priori higher robustness/receiver/key management complexity.
- Can be adequate for surveying, tracking & tracing, maritime, civil security, etc.
- Based on E1B I/NAV (data) + E6 (code, data).

Results: CS Studies (2013)

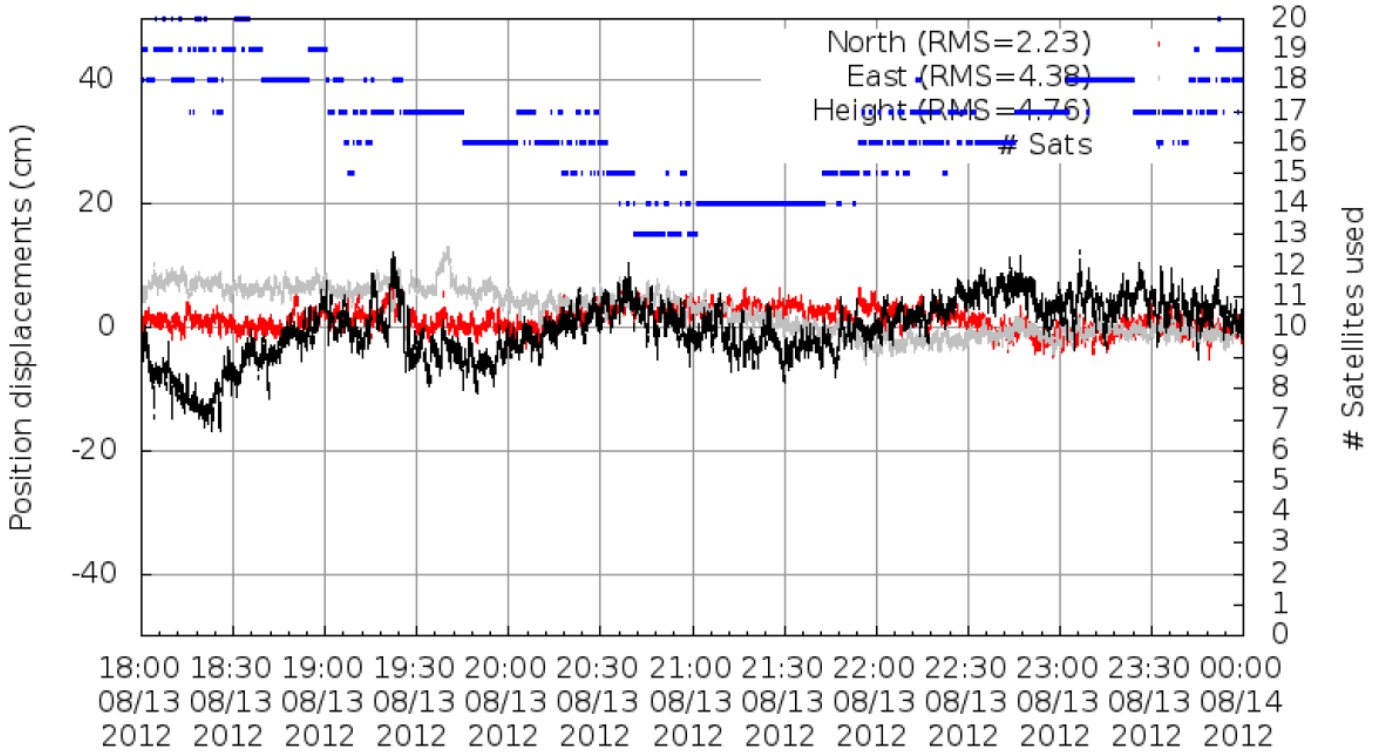
- EC launched two parallel studies during 2013.
- Duration: 1 year. Budget: 400k€ aprox. Each.
- CESAR: managed by FDC. Included TAS-F, Fugro, Keynectics, Trimble-Terrasat, BHO.
- GALCS: managed by GMV. Included CGI, Helios.
- The studies analysed service concepts and performance of High Accuracy and Authentication under certain Galileo system assumptions (satellite number, system latency, allocated bandwidth, etc).
- The studies included simulated and real SIS results.
- Today's presentation:
  - **Example of achievable PPP performance**
  - **Real E6B/C tracking performance**

Example 1 – PPP performance *(GALCS project, GMV, magicPPP)* **:**



- 50 worldwide stations
- GPS/GLO real data
- 5-s latency**, 5-s clock update rate**
- Realistic BW conditions (<400bps); same data by all satellites
- After convergence.

Example 2 (*GALCS project, GMV, magicPPP)* **:**

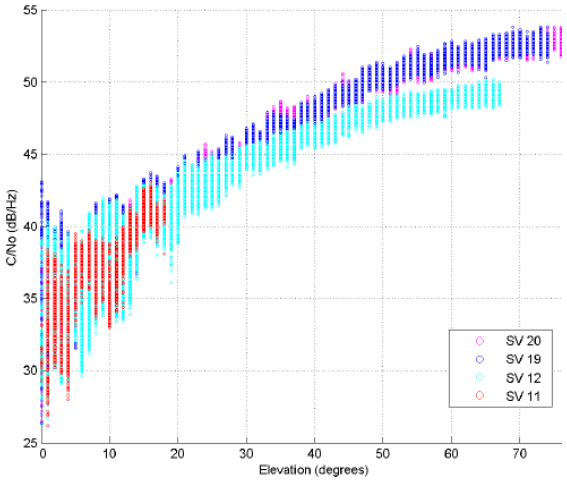


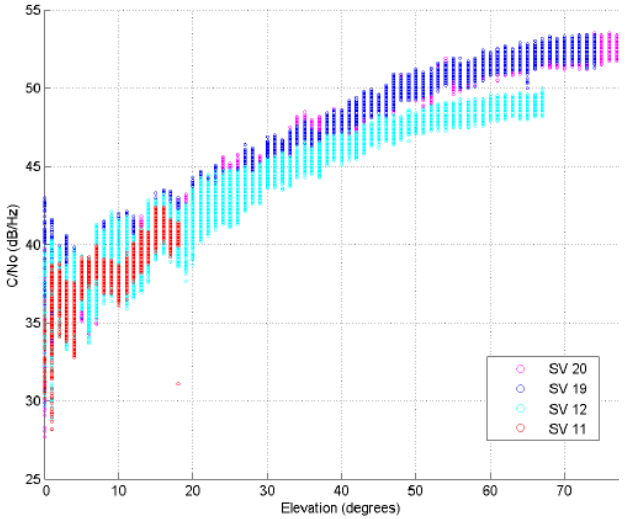
- 50 worldwide stations
- GPS/GLO real data
- 5-s latency**, 30-s clock update rate**
- Realistic BW conditions (<400bps); same data by all satellites
- After convergence.

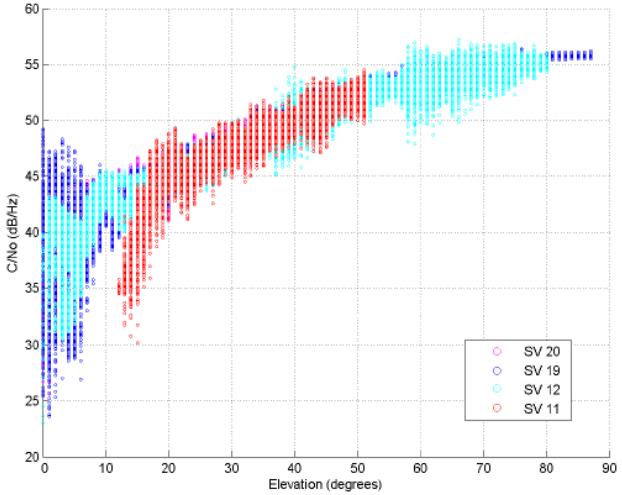
Tracking Performance

*Results obtained **thanks to TRIMBLE** through a prototype firmware installed ad-hoc in the receivers. Galileo codes provided through CESAR project*

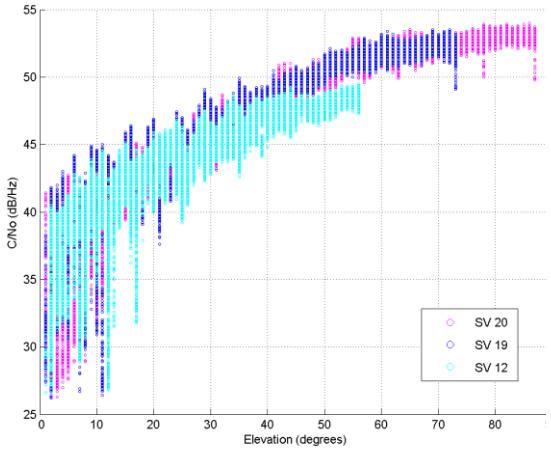
- *Chennai, India (E6B, E6C, E6B+C)*

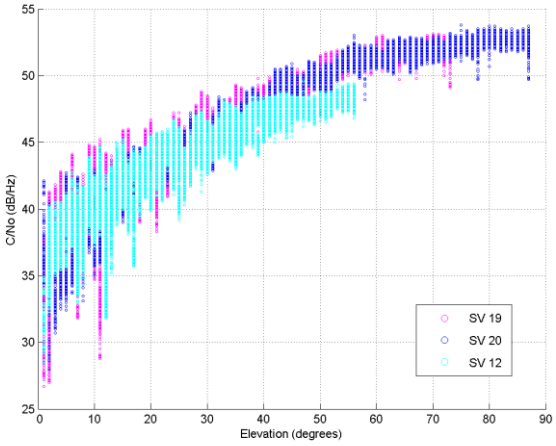


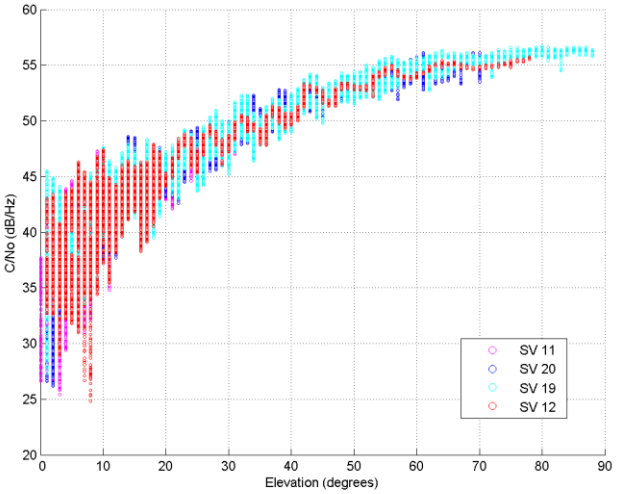




- *Melbourne, Australia (E6B, E6C, E6B+E6C)*







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Results: CS Demonstrator (2014)

The AALECS (CS Demonstrator) project

- EC launched the CS Demonstrator by Jan 2014.
- AALECS project stands for "Authentic and Accurate Location Experimentation with the Commercial Service".
- Foreseen duration: 2.5 years (1/14-6/16). Total budget: 4m€.
- Objective: develop & test CS with real SIS and support future service providers.
  - The EPOC ("Early Proof-Of-Concept") provided first real SIS results.
  - The project is developing a real-time platform for few second-level latency SIS tests (2015-2016)

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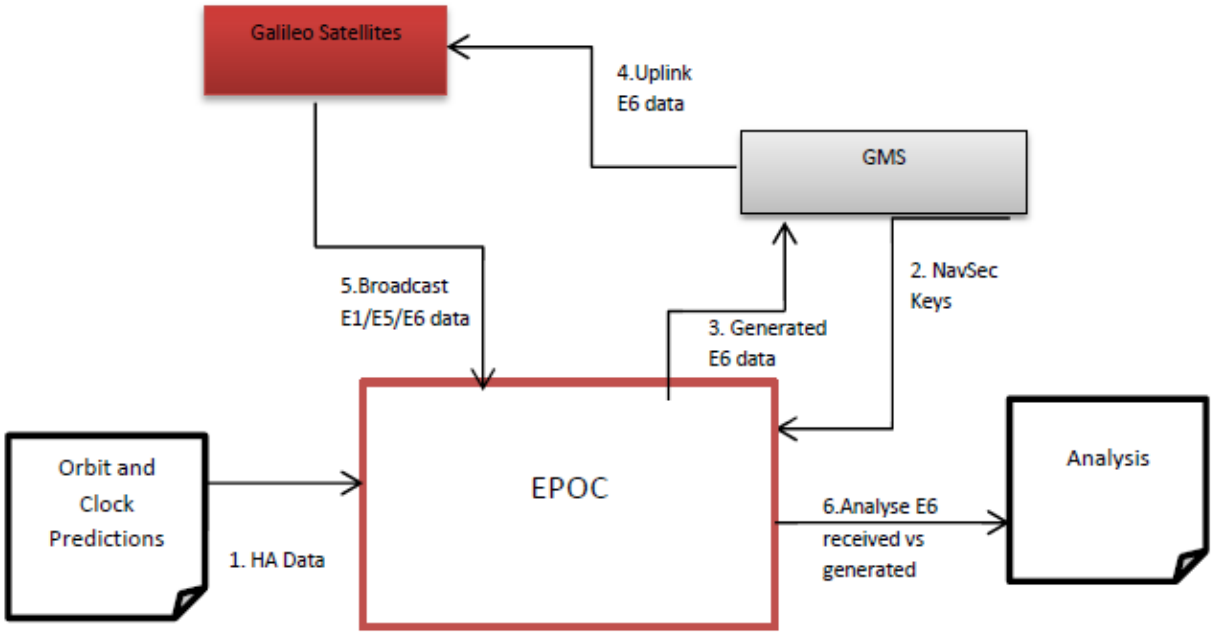
EPOC process

- Agree between EC/EPOC/Galileo Ops the weekly test slots of several hours, where 3 sats in view over EU.
- Generate authenticated orbit & clock predictions (1-2 days in advance) for GPS + Gal satellites & provide to Galileo Ops.
- Galileo Ops., to upload predictions during test slot.
- Galileo Satellites E11, E12, E19, to transmit data in E6B signal
- EPOC Rx (L1C/A, L2, E1, E5, E6) to receive results and compute data-authenticated PPP.

EPOC test setup



EPOC transmitted data format (only for testing purposes!):

- High Accuracy (HA) field (SVID for GPS and Galileo)

SVID	Epoch	X	Y	Z	Clock Bias

- Data message structure (448 bps total)

t [s]	HA_1 (160 bits)	$HMAC_1$ (64 bits)	HA_2 (160 bits)	$HMAC_2$ (64 bits)
t+1	HA_3 (160 bits)	$HMAC_3$ (64 bits)	HA_4 (160 bits)	$HMAC_4$ (64 bits)
t+2	HA_5 (160 bits)	$HMAC_5$ (64 bits)	HA_6 (160 bits)	$HMAC_6$ (64 bits)
t+3	HA_7 (160 bits)	$HMAC_7$ (64 bits)	HA_8 (160 bits)	$HMAC_8$ (64 bits)
t+4	Bit Pattern (96 bits)	WN+TOW (32 bits)	K_j (256 bits)	HMAC (HAPs, K_{j+C}) (64 bits)
…	HA_9 …			

- All sats transmitted the same information.

Examples of EPOC results

- Performance computed using Galileo SIS data (E6b) and GPS/Galileo measurements.
- The results show the real-time performance obtainable by a GNSS standalone receiver (no GEO or ground channel).
- Accuracy is very sensitive to age of data. Here 1 to 3-day age of orbit and clock data (!). To be reduced to seconds in the operational system.
- GMV's magicPPP tool used.
- Tests included static/kinematic, open sky/rural/urban tests. All gathered data is currently under thorough study.

Example 1, 22/7: EPOC CS Results – data transmission & tracking

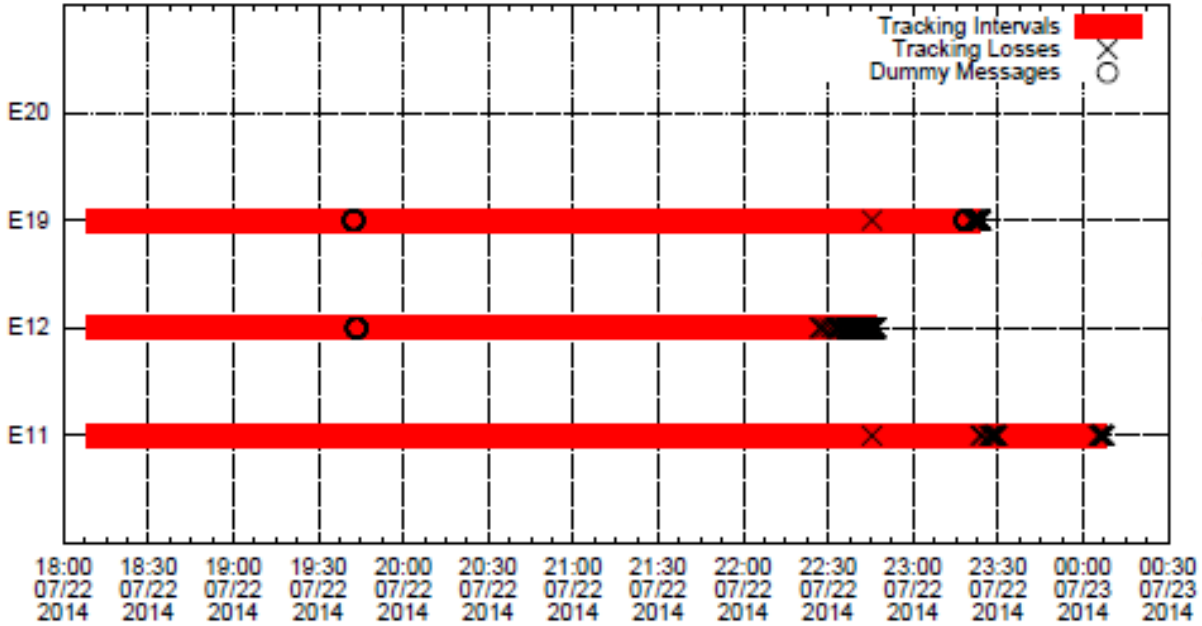


Figure 3–1: Tracking Profile

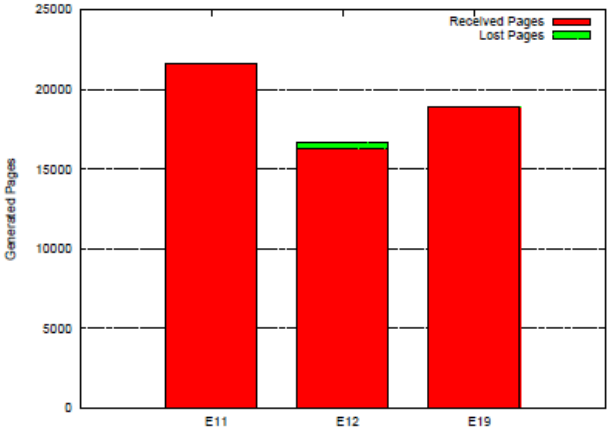


Figure 3–2: Transmission Performance

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Example 1, 22/7: EPOC CS Results – CN0 and Authentication Error Rate

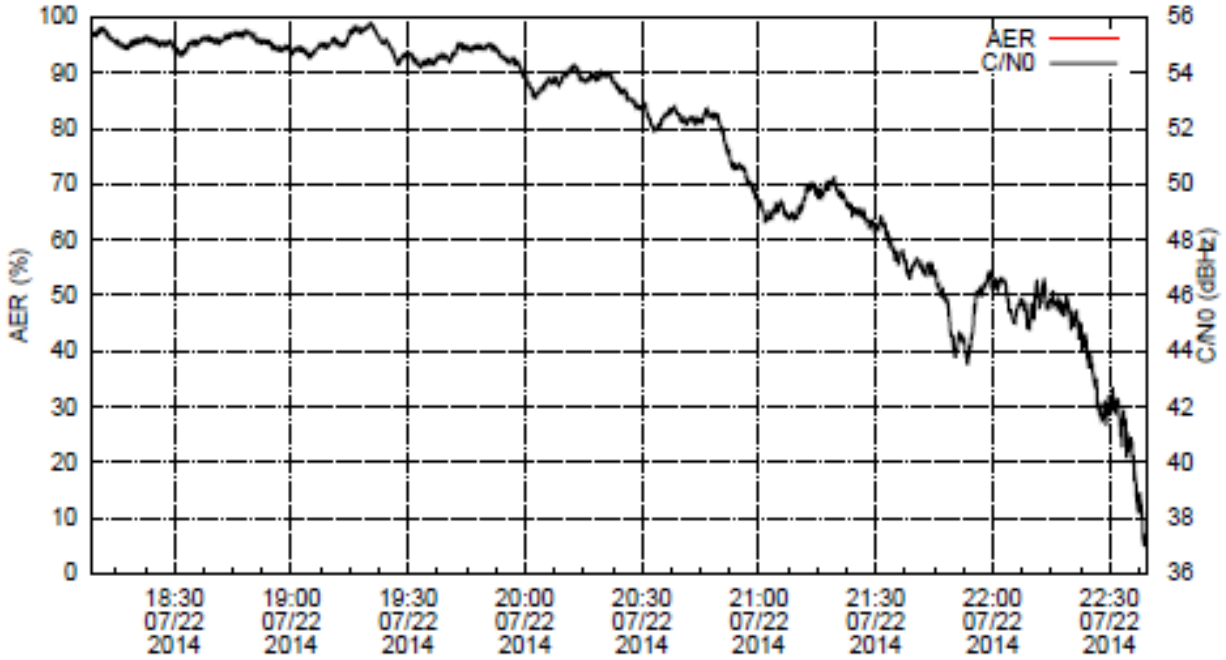

Figure 3–6: Short-Term Authentication for Satellite E12

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22/7: EPOC CS Results (magicPPP)

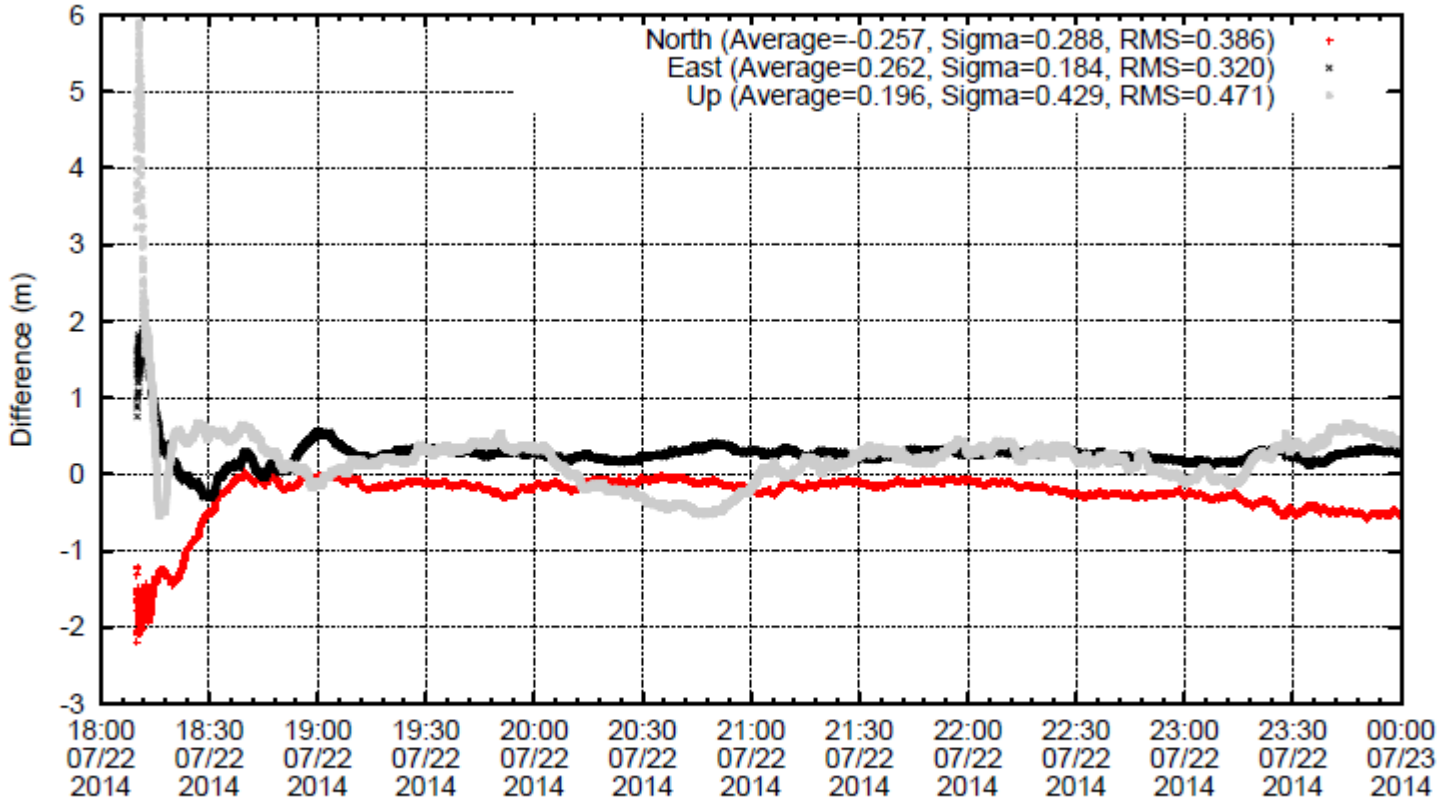

Figure 3–22: Difference from Reference Position to the Data-Authenticated Positioning Solution

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28/8: EPOC CS Results (magicPPP)

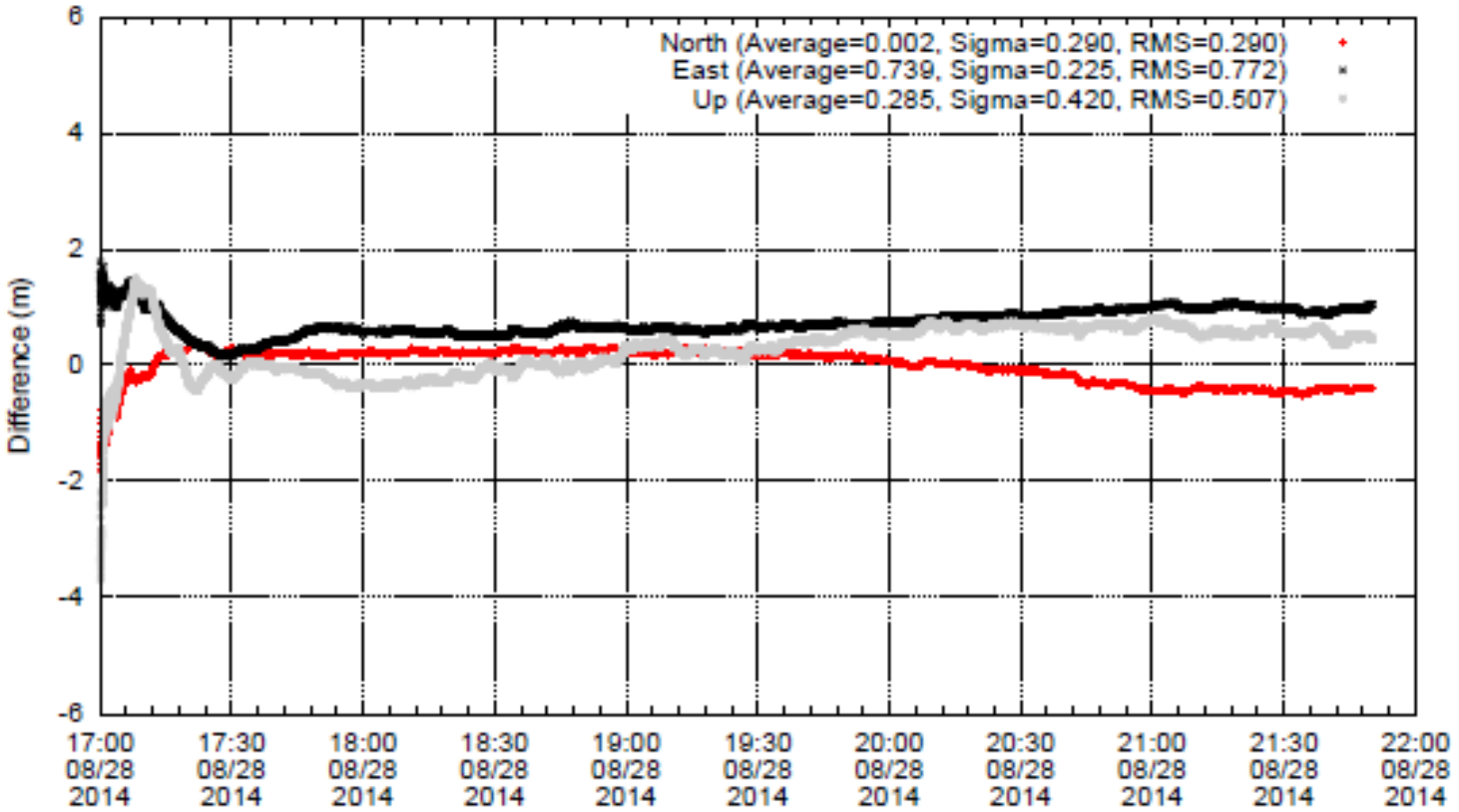

Figure 3–22: Difference from Reference Position to the Data-Authenticated Positioning Solution

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Next Steps

From Demonstrator to Operational service:

- Continue CS Demostrator (AALECS) development and testing.
- GSC development and accreditation to allow E6b external data transmission.
- Agree on exploitation model for HA and Authentication, currently under discussion with EC/GSA/MS.
- Galileo system to implement system changes required to improve service provision.
- Commission Decision formal process with Member States to approve service definition.
- Open the CS Demo platform to potential service providers: 2015/2016.
- 2016/2017: Early CS operational with a subset of satellites.

Commercial Exploitation

- Authentication and High Accuracy are foreseen to be provided and exploited separately.
- Commercial exploitation scheme is under definition by EC & GSA (Market Development Dept. and Exploitation Depts). It will be consolidated once the CS technical & service definition is confirmed.
- Degree of involvement of Public/Private sector is under definition and may be different in each case:
  - For High Accuracy, Galileo could be used as a data transmission channel to support existing services.
  - For Authentication, Galileo may have a stronger role in the service provision (security reasons, key management, service definition, combination with OS, etc.).

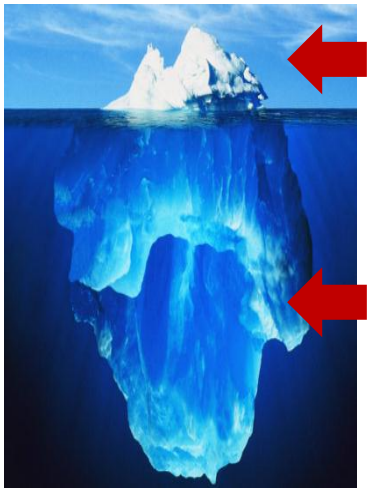
Conclusions

Conclusions

- The CS is "on track".
- CS studies (2013) showed the way: from "*what can we do*" to "*what do we want to do*" with the CS.
- CS Demonstrator (2014): Early results with SIS are encouraging, including first GNSS-only PPP, and Authentication.
- Still work to do on service definition, development and exploitation toward an Early CS by 2016/2017.

CS Response to High Level Objectives

- **Public benefits**: Increased civil security (free NMA, controlled NMA/SCE), robust authentication service for EU Institutional Users
- **Revenue Source & Economic Value :** HA-CS, AUTH-CS commercial exploitation.
- **Navigation Performance**: HA-CS: most accurate (cm-level) **global** service ever (e.g. above 60º latitude GEO signals are not well received)
- **Innovation:** Downstream markets & applications, NMA/SCE + receiver-based authentication, etc.



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Thank you for your attention!

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