Next Generation Global Navigation Satellite Systems

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GPS (1973)

GLONASS (1976)

GALILEO (1999)

Global Navigation Satellite Systems (GNSS) are seeing many new developments…

- *USA's GPS Modernisation and ultimately GPS-III*
- *Russia's GLONASS Re-vitalisation*
- *Japan's MSAS and QZSS*
- *India's GAGAN*
- *China's Beidou*
- ***A very significant new development is the EU's Galileo…***

Outline of the Presentation

- Next Generation GNSS
  - GPS Modernization and GPS-III
  - GLONASS
  - Galileo
- Growing Number of Centimetre Accuracy Applications of GNSS;
- Multi-GNSS Receiver Options/Implications;
- Some Issues for Surveyors and Reference Station Service Providers;
- Some Institutional Arrangements;
- Concluding Remarks.

Benefits of Next Generation GNSS

- **GPS and GLONASS combined have already demonstrated the benefits of extra satellites;**
- **Galileo brings all that and more;**
- **The benefits of the extra satellites and their signals:**
  - **Continuity (3 sub-systems are better than 1);**
  - **Accuracy (eg Galileo Commercial Service 0.1m in handset);**
  - **Efficiency (centimetre accuracy with shorter initialisation times);**
  - **Availability (60+ Satellites by 2010, 10 available will be common place, working in Urban Canyons, under Tree Canopies, in Open Cut Mines) and;**
  - **Reliability (more reliable signal tracking, also designed for Safety-of-Life).**
- **Coded signals brings cheaper receivers for centimetre applications.**

GPS Modernisation and GPS-III

GPS Satellite Status

(as at October 2005)

SVN	PRN	Launch Date	Orbit Plane	Useable
Block I				
1	4	22-02-78		no
2	7	13-05-78		no
3	6	6-10-78		no
4	8	10-12-78		no
5	5	9-02-80		no
6	9	26-04-80		no
7		launch failure		
8	11	14-07-83		no
9	13	13-06-84		no
10	12	8-09-84		no
11	3	9-10-85		no
Block II				
14	14	14-02-89		no
13	2	10-06-89		no
16	16	18-08-89		no
19	19	21-10-89		no
17	17	11-12-89		no
18	18	24-01-90		no
20	20	26-03-90		no
21	21	2-08-90		no
15	15	1-10-90	D5	15-10-90
Block IIA				
23	23	26-11-90		no
24	24	4-07-91	D1	30-08-91
25	25	23-02-92	A2	24-03-92
28	28	10-04-92		no
26	26	7-07-92	F2	23-07-92
27	27	9-09-92	A4	30-09-92
32	1	22-11-92	F6	11-12-92
29	29	18-12-92	F5	5-01-93
22	22	3-02-93		no
31	31	30-03-93		no
37	7	13-05-93	C4	12-06-93
39	9	26-06-93	A1	20-07-93
35	5	30-08-93	B4	28-09-93
34	4	26-10-93	D4	22-11-93
36	6	10-03-94	C1	28-03-94
33	3	28-03-96	C2	9-04-96
40	10	16-07-96	E3	15-08-96
30	30	12-09-96	B2	1-10-96
38	8	6-11-97	A3	18-12-97
Block IIR				
42		launch failure		
43	13	23-07-97	F3	31-01-98
46	11	6-10-99	D2	3-01-00
51	20	11-05-00	E1	1-06-00
44	28	16-07-00	B3	17-08-00
41	14	10-11-00	F1	10-12-00
54	18	30-01-01	E4	15-02-01
56	16	29-01-03	B1	18-02-03
45	21	31-03-03	D3	12-04-03
47	22	21-12-03	E2	12-01-04
59	19	4-03-04	C3	5-04-04
60	23	23-06-04	F4	9-07-04
61	2	6-11-04	D7	30-11-04

12 satellites currently older than 10yrs! (Design life is 7.5yrs).

GPS Signal Modernization

http://www.navcen.uscg.gov/

Block IIA/IIR
Present Signals
29 sats

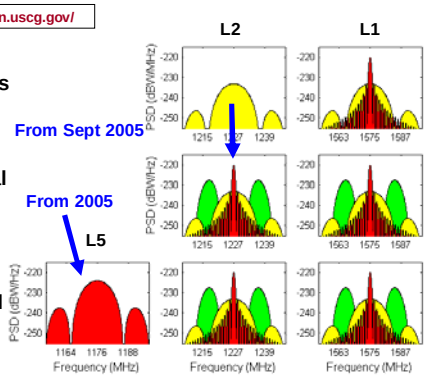
Block IIR-M
2nd Civil Signal and M-code
8 sats

Block IIF + Block III
3rd Civil Signal
16 sats
+ 30 sats

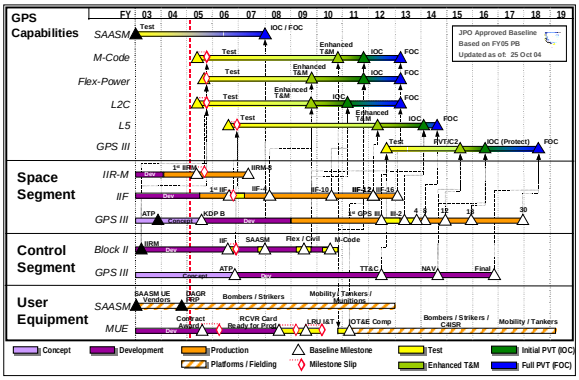
From Sept 2005

From 2005

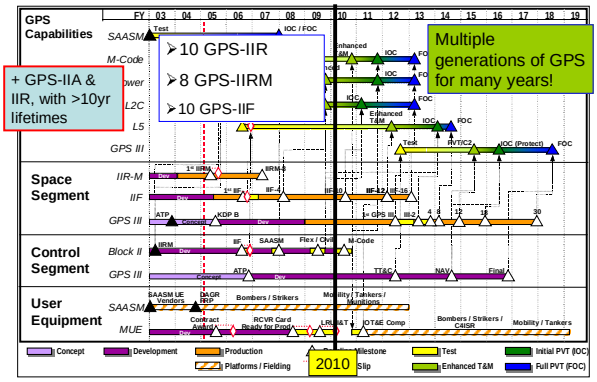
L5



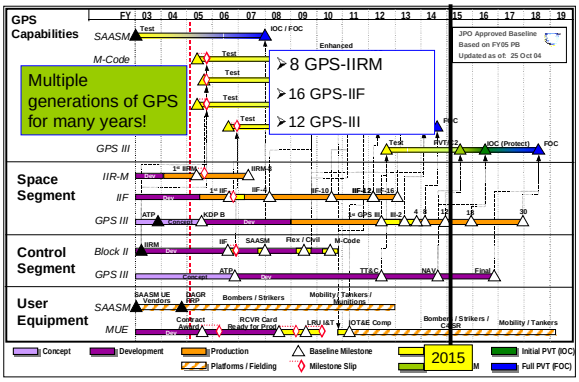
GPS Modernization Schedule (1)



GPS Modernization Schedule (2)



GPS Modernization Schedule (3)



GPS … the old & the new

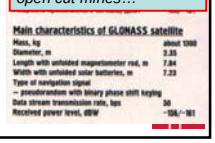
- True Next (2nd) Generation GPS is *GPS-III*.
- **For the next decade there will be 3 generations of GPS signals …**
  - ***GPS-IIR: L1 C/A code, L2 codeless***
  - ***GPS-IIRM: L1 C/A code, L2C code***
  - ***GPS-IIF: L1 C/A code, L2C code, L5 code/codeless***
  - ***GPS-III: L1C code, L2C code, L5 code/codeless***
- **Receiver costs *should* drop for some signal combinations, but complexity will rise (in antennas, hardware, software).**
- *What will NOT change is tight U.S. military control over GPS space & ground segments.*
- *No plans for introduction of user charges.*

GLONASS

- **GNSS similar to GPS, originally developed by the USSR (now Russian Federation). *Also military controlled*.**
- **GPS is CDMA-based, GLONASS is FDMA.**
- **No direct user charges, *as in the case of GPS*.**
- **Fully operational in 1996, but now only 14 functioning satellites.**
- **Several new (multiple satellite) launches in the last few years.**
- **Russian president has made commitment to be operational by 2007 (18 sats?).**
- **Open, dual-use system, with civil L2 signal and new L5 signal (2007+), *compatible with GPS*.**
- **India has signed a MoU with Russia in January 2004.**
- **India's SBAS ('GAGAN') is based on both GPS and GLONASS.**

http://www.glonass-center.ru/

Combined GPS/GLONASS receivers already have market advantage where signal availability difficult, *e.g. open cut mines…*



Comparison GPS & GLONASS

	GLONASS	GPS
No of satellites	24	24
No of orbital planes	3	6
Orbital inclination	64.8°	55°
Orbit altitude	19,130 km	20,160 km
Period of revolution	11h15m40s	11h58m00s
Geodetic datum	PZ-90	WGS-84
Geodetic time reference	UTC(Russia)	UTC(USNO)
Signalling	FDMA	CDMA
L1 carrier frequency	1602 - 1609 MHz	1575 MHz
L2 carrier frequency	1246 - 1251 MHz	1227 MHz
# of code elements (C/A)	511	1023
# of code elements (P)	5.11×10^6	2.35×10^{14}
Code rate (C/A)	511 kbps	1023 kbps
Code rate (P)	5.11 Mbps	10.23 Mbps
Crosscorr. Interference	-48 dB	-21.6 dB

GALILEO

- Initiative of the EU, supported by ESA.
- Tension between EU & USA over issues of "interoperability" & "compatibility".
- 'Development & Validation' phase has commenced (naming of Concessionaire).
- First test satellite launches in *2005-2006*.
- 30 MEO satellite constellation, *operational by 2008-2010*.
- **Four levels of service:** 2 fee-based to guarantee certain level of performance (e.g. *integrity* for **SoL** users, *accuracy* for **CS**), plus free **OS** to match GPS's, & restricted **PRS**.
- **'Private-Public Partnership'**, *in contrast to U.S. military control/funding of GPS*.
- Current Business Models will be challenged.
- Galileo is a '2G' system, *compared with GPS's '1G' system*.

http://www.galileo-pgm.org/index.htm
http://www.genesis-office.org/
http://www.galileoju.com/
http://www.esa.int/navigation/

The GALILEO Arguments …

- Independence and sovereignty
- Industrial politics

Political

Social

- Better and new services for the citizens
- Improved safety of transport systems
- Environmental benefits

Technological

- Technological lead
- Explore synergy of a number of technologies

Economic

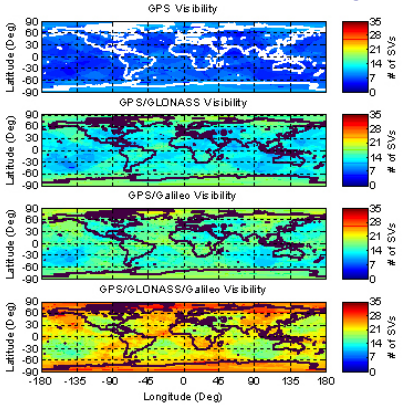
- Global market shares
- Global competitiveness of all segments of the Value Chain
- Employment
- Efficiency of transport industry

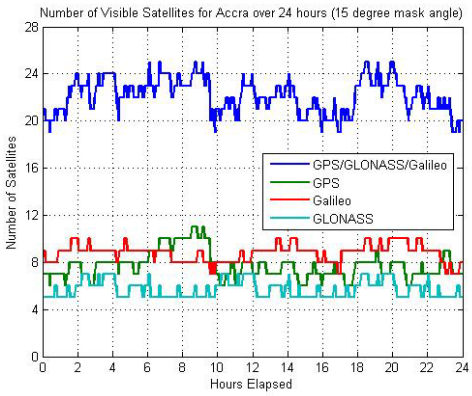
US-EU Dromoland Castle Agreement

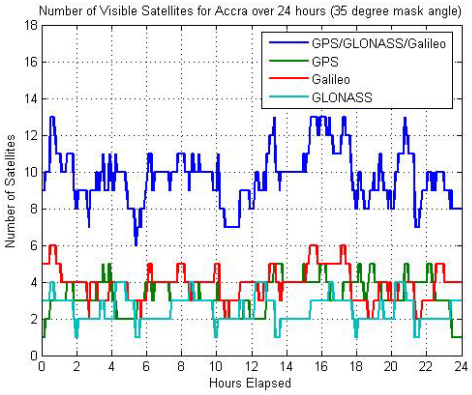
26 June 2004

- **Paves way for eventual** doubling **of satellites that will broadcast a common civil signal worldwide (GPS+GALILEO),** *tripling* ***if include GLONASS.***
- **Requires non-discrimination and open markets in trade in civil GNSS-related goods and services.**
- **Ensures GALILEO's signals will not harm NAVWAR capabilities of U.S. and NATO.**
- **Establishes process for U.S. and EU to address individual and mutual security concerns.**
- **GPS-III new L1 signal should be compatible with GALILEO's.**

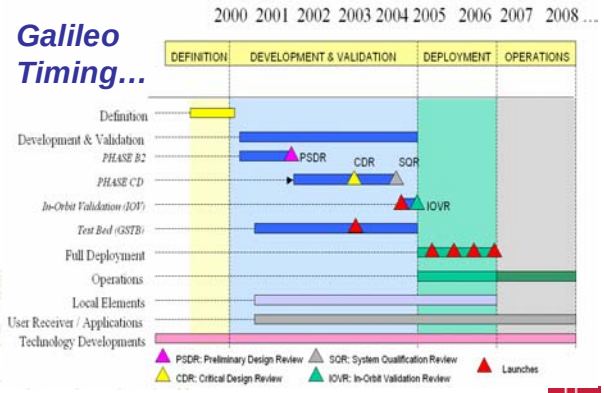
Multi-GNSS Availability







Galileo Timing…

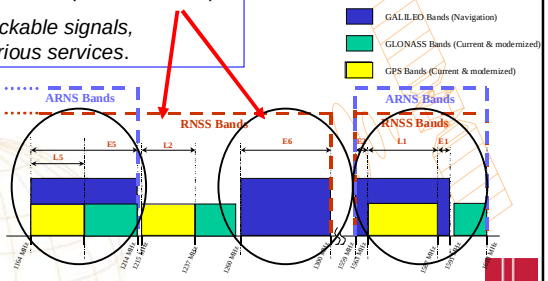


There have been delays since this plan was made –first experimental GALILEO satellite launched in Dec 2005! *Two years behind schedule.*

GALILEO Frequencies…GPS & GLONASS

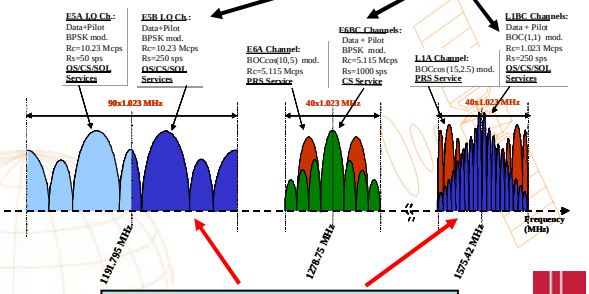
3 frequency bands
(but no overlap of E6 with L2)…

10 trackable signals, for various services.



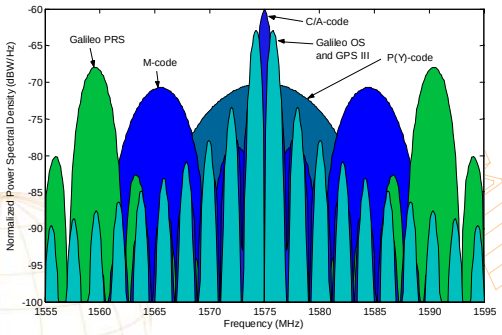
GALILEO Signals

Commercial Service – Differential Corrections in the downlink message…

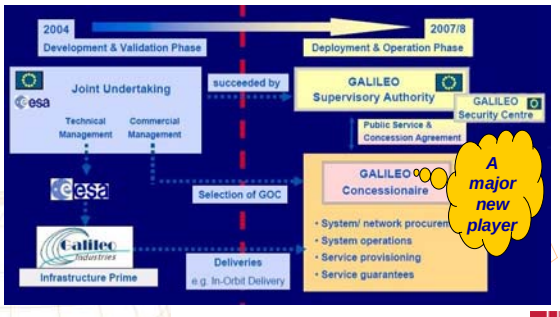


"Open Service" signals are L1 & E5

GPS & GALILEO L1 Signal Spectra



Galileo Management Structure – A PPP

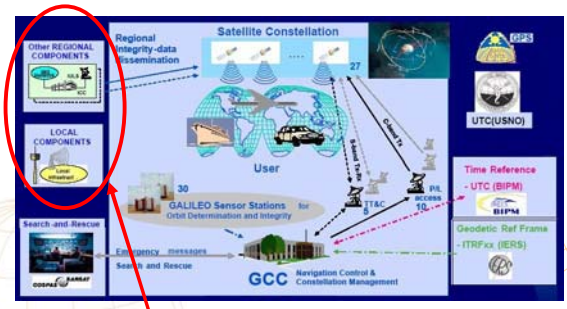


GALILEO Concessionaire: consortium of

- EADS - *setup to be Europe's Boeing* - owns Airbus, Ariane, Eurofighter and Eurocopter. In 2004 had revenues of €31.8 billion & employed more than 110,000 people!
- Alcatel – 2004 sales of €12.3 billion, in more than 130 countries
- Thales – 2004 revenue of €10.3 billion, employs 60,000 people worldwide
- Finmeccanica – 2003 turnover €8.6 billion, €1.2 billion on R&D, 51,000 staff
- Inmarsat - 2004 revenue was $US480.7 million
- Also involves Spain's AENA and Hispasat

- So parent companies of the Concessionaire had 2004 revenues of more than **€60 billion!**

GALILEO's System Architecture



Concessionaire wants to partner with Service Providers (eg. RTK services)…

From GPS to GNSS *for High Accuracy Users…*

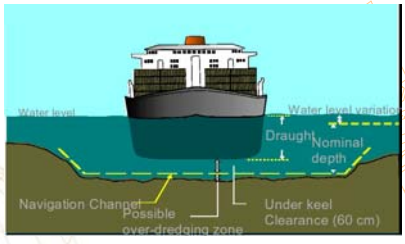
- ***Assumption: Surveyors and other centimetre accuracy users seek best performance…***
- Use multi-GNSS receivers, *to improve availability.*
- Use multiple-frequency receivers, *to improve accuracy & Time-to-Ambiguity Resolution for Carrier Phase based techniques.*
- Will still need CORS networks for DGNSS.
- Variety of CORS &/or Service Providers, *different scales/coverage/markets & business models.*

GNSS Applications in Queensland Government

eg Queensland Rail…

Port of Brisbane: New Port Road and Seawall built using GPS Machine Guidance

Improved Shipping Guidance and Clearance



Some ports – dredging an extra 0.1m costs over $3 Million

Mine Safety

Dragline Automation

My Dept's SunPOZ RTK Network Service

- Centimetre accuracy in real-time using survey quality GPS receiver and mobile phone communications;
- Pilot Network since 2001;
- Operational Network during 2006;
- Coverage for cm accuracy includes 15km buffer around outside of network;
- Coverage much larger for sub-meter corrections;
- Ideally suited to become a *Galileo Local Element*

Galileo Sensor Station Proposal to European Space Agency

GPS Surveying Receivers… *cm accuracy RT or PP*

Decreasing cost ↓

L1	L2 codeless	L2C	L5	# sats 2010 *# sats 2015*	Comments
28 *36*	10 *0*	18 *36*	10 *28*	28/10-DF, 10-TF *36-DF, 28-TF*	**A** Can old Rx track L2C in codeless mode?
28 *36*	- -	18 *36*	10 *28*	18/10-DF, 10-TF *36-DF, 28-TF*	**B**
18 *36*	- -	18 *36*	- -	18-DF *36-DF*	**C**

A: Rx tracks all sats, *highest* availability, *highest cost*, *improvement* in DF-only performance over current system, *no* TF-only positioning until 2015, *best hybrid*.

B: *Moderate cost* Rx, DF-only performance *improved* in 2015, *no* TF-only positioning until 2015, *good hybrid positioning*.

C: *Lowest cost* Rx, DF-only performance (*decreased* performance in 2010, but *improved* in 2015), *no TF positioning possible*.

GALILEO[1]/GPS[2] Surveying Receivers…

Decreasing cost ↓

L1[1,2]	E6[1]	L2C[2]	E5[1]/L5[2]	# sats 2010; *# sats 2015*	Comment
30/28 *30/36*	30 *30*	18 *36*	30/10 *30/28*	60-DF[1],28-DF[2]; 30-TF[1],10-TF[2] *60-DF[1],64-DF[2]; 30-TF[1],28-TF[2]*	**A** GPS+GALILEO
30/28 *30/36*	- -	18 *36*	30/10 *30/28*	30-DF[1],28-DF[2]; 10-TF[2] *30-DF[1],64-DF[2]; 30-TF[1]*	**B** GPS+GALILEO
30 *30*	30 *30*	- -	30 *30*	60-DF[1]; 30-TF[1] *60-DF[1]; 30-TF[1]*	**C** GALILEO
30 *30*	- -	- -	30 *30*	30-DF[1] *30-DF[1]*	**D** GALILEO

A: Top-of-line GNSS Rx tracks all sats, *highest* availability, *highest cost*, *highest* in DF-only & TF-only performance, *best hybrid*.

B: *Moderate cost* GNSS Rx tracks all sats, but does not track E6, GPS TF-only positioning available 2015, *good price/performance compromise*.

C: *Moderate cost* GALILEO-only surveying Rx, TF-only positioning available 2010, *unclear if tracking of E6 requires user charges for CS*.

D: *Lowest cost* GALILEO-only surveying Rx, DF-only performance (*similar* to current GPS-only performance in 2010), *uses OS signals only*.

Multiple GNSS Sub-Systems needs improved Institutional Arrangements for GNSS

International Committee on GNSS

- **In 2004 UN General Assembly Resolution 59/2 (paragraph 11) invited GNSS and augmentation providers to consider establishing an international committee on GNSS in order to maximize the benefits of the use and applications of GNSS to support sustainable development.**
- **In December 2005 at a meeting convened by the UN Office for Outer Space Affairs in Vienna, interested Governments, intergovernmental and nongovernmental organizations present at the meeting agreed to establish the ICG.**

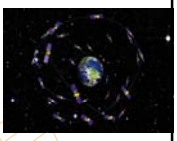
International Committee on GNSS

- *UN Office for Outer Space Affairs in Vienna will continue to act as the focal point for the ICG.*
- *I will represent FIG on ICG.*

Com 5 – Working Groups

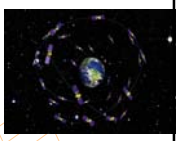
- **WG 5.1 Standards, Quality Assurance and Calibration**
- **WG 5.2 Reference Frame in Practice**
- **WG 5.3 Integrated Positioning, Navigation and Mapping Systems**
  - **Sub-Group on Next Generation Global Navigation Satellite Systems**
- **WG 5.4 Low Cost Technology and Techniques for Developing Countries (Joint with Com 3 and 7)**

By 2010…



- GPS Modernization – *3 civilian signals for 10 sats (Block IIF), all 8 Block IIR-M sats.*
- Mixed generations of GPS & GLONASS, *can old Rxs track new L2C signal in codeless mode? When will new Rxs stop tracking "old" signals?*
- Europe's GALILEO FOC by 2008-2010
- Some SBAS sats, *e.g. Japan's QZSS*
- No full triple-frequency overlap amongst all GNSSs, *have to use combined processing (as in GPS/GLONASS now)*
- Unclear situation re GALILEO tracking of all frequencies
- Getting "inside" GALILEO - *partnerships with Regional Elements?*
- CORS networks, *from "Ad-Hoc" to "Infrastructure"*
- 2010 GNSS should have 50+ satellites giving:
  - *Surveying initialisation for cm accuracy in 1 sec*
  - *Urban canyon availability 80% (up from 15%)*
  - *Premium GALILEO Commercial Service 0.1m from handheld Rx*

By 2015…



- GPS Modernization – *FOC 3 civilian signals for >24 sats.*
- *Triple-freq GPS FOC 5 yrs after GALILEO's*
- No more Block IIA/IIR sats.
- Half the GPS-III satellites launched
- New generation of GLONASS satellites launched
- GALILEO upgrade satellites launched
- More SBAS sats., *e.g. Japan's QZSS, India's GAGAN, China's?*
- *No full triple-frequency overlap amongst all GNSSs, but combined processing possible (as in GPS/GLONASS now)*
- Mature partnerships with Regional & Local Elements - *less dense CORS infrastructures?*

NextGen GNSS: Some User Issues…

- Towards more availability, efficiency and reliability:
  - L1+L2 Rxs & processing less complicated - *cheaper Rx?*
  - L1+L2+L5 will give better accuracy, efficiency & reliability.
  - GLONASS has demonstrated advantage of extra sats/signals.
  - GALILEO will add all of this again, *and more.*
- Concerns:
  - Cost of upgrade to take advantage of new developments.
  - Mixed generations of GPS/GLONASS for many years.
  - There are many DF & TF combinations possible, *but quality & reliability will be variable unless "pure" TF positioning possible.*
  - What choice of Rxs will there be? *How will I choose?*
  - Can standard RTK-DGNSS operate with multi-GNSS Rxs w/o paying for GALILEO's CS?

NextGen GNSS: Some CORS Issues…

- Concerns:
  - Cost to upgrade CORS networks to handle all GNSS signals.
  - Mixed generations of GPS/GLONASS for many years, *how to support legacy systems?*
  - CORS networks are geodetic infrastructure, *but could also support GALILEO "local/regional element".*
  - Can CORS networks supporting RTK-DGNSS operate without paying for GALILEO's CS?
  - How will current Service Providers compete with the Concessionaire & Commercial Service?... Partnering?
  - What is the appropriate mix of free & fee-based services?
  - The belief that there will be less need for CORS infrastructure for surveyors may be illusionary, *unless all users are forced to triple-frequency-only positioning, but then vulnerable to loss of tracking of one signal!*

Concluding Remarks

- GPS is already a great tool, when signal availability & measurement quality is good.
- NextGen GNSS, will have more satellites, more frequencies & more signals.
- Positioning with NextGen GNSS will be *more accurate, more efficient and more reliable*, but only if conditions are right (including CORS station spacing).
- Many unresolved issues with mixed GNSS Rxs & CORS services, *especially wrt GALILEO*.
- GALILEO's *revolutionary* commercial focus may have a greater impact than the *evolution* of NextGen GNSS.