RTCA SBAS DO-229 Today and in the Future with GNSS Evolutions

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Part A: RTCA MOPS Today

- DO-229 Background
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- EGNOS design and performance
- SBAS performance worldwide

DO-229 Background

- **Objective:**
  - Minimal Operational Performance Standard (MOPS) for the provision of navigation augmentation signals and messages for aviation lateral and vertical approach procedures using satellite navigation means.
- **Means:**
  - Geostationary satellite broadcasting GPS like signals.
- **Authors:**
  - RTCA Special Committee 159 consisting of aviation authorities, manufacturers and space institutes.
- **History:**
  - Several versions released since first version in early 90's, latest version is DO-229D

DO-229 Signal specifications

- **Signal similar to GPS:**
  - Carrier frequency 1575.42 MHz RHCP
  - Modulation BPSK C/A code on 1.023 Mchip/s carrier
  - 500 symbols/s using 1/2 convolutional encoding -> **250 bps**
  - Spreading codes 1023 Gold codes using PRN numbers 120-138

- **Performance:**
  - Power > -161dBW at elevation > 5°
  - Frequency stability < 5×10^{-11} over 1 - 10 seconds
  - Code Carrier Coherency < 5×10^{-11} for fractional frequency
  - Phase noise < 0.1 rad for PLL 10Hz Bandwidth.
  - Doppler shift < 40m/s (GEO satellites)
  - Polarisation ellipticity < 2 dB at ±9.1°
  - WAAS network time < 50ns to GPS Time

DO-229 Message format

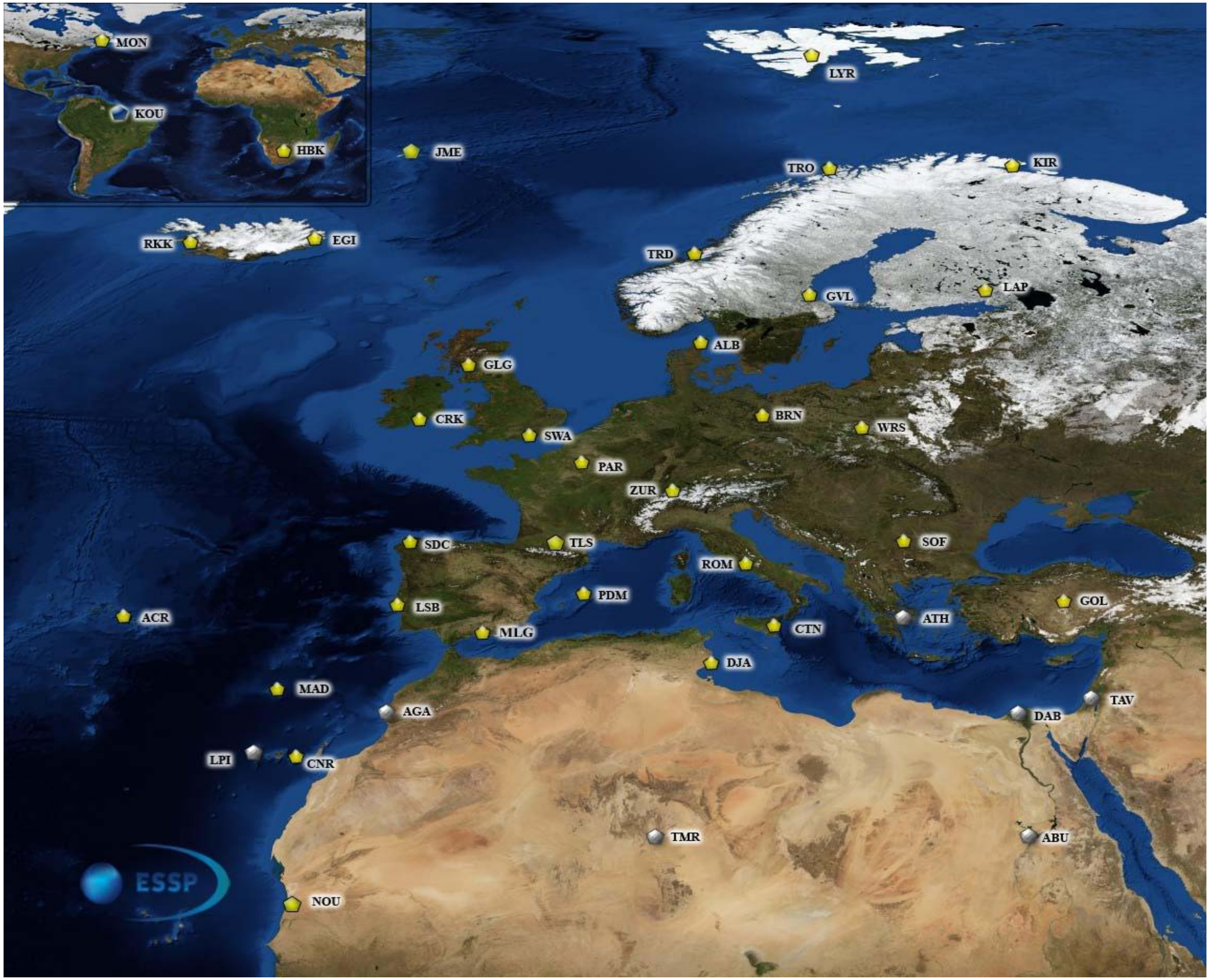
- **Each message of 250 bits contains:**
  - Preamble (8 bits)
  - Message type ID (6 bits)
  - Data field (212 bits)
  - Parity (24 bits)

- **Main message content:**
  - GPS/Glonass Satellite fast and slow orbit and clock corrections
  - GPS/Glonass Satellite orbit and clock covariance (integrity)
  - Ionospheric delay values
  - Ionospheric covariance (integrity)
  - GEO Ephemeris and almanac information
  - SBAS to UTC time offset

DO-229 Message types

Message ID	Contents
0	Test mode indicator
1	PRN Mask to map corrections
2-5	Fast orbit and clock corrections
6	Orbit and clock integrity information
7	Fast corrections degradation factors
9	GEO Ephemeris
10	General degradation parameters
12	SBAS to UTC network time offset
17	GEO Almanacs
18	Ionospheric grid mask
24	Mixed fast and slow orbit and clock corrections
25	Slow corrections
26	Ionospheric delay and covariance
27	Integrity degradation outside coverage zone
28	Orbit and clock covariance matrix

EGNOS RIMS Network



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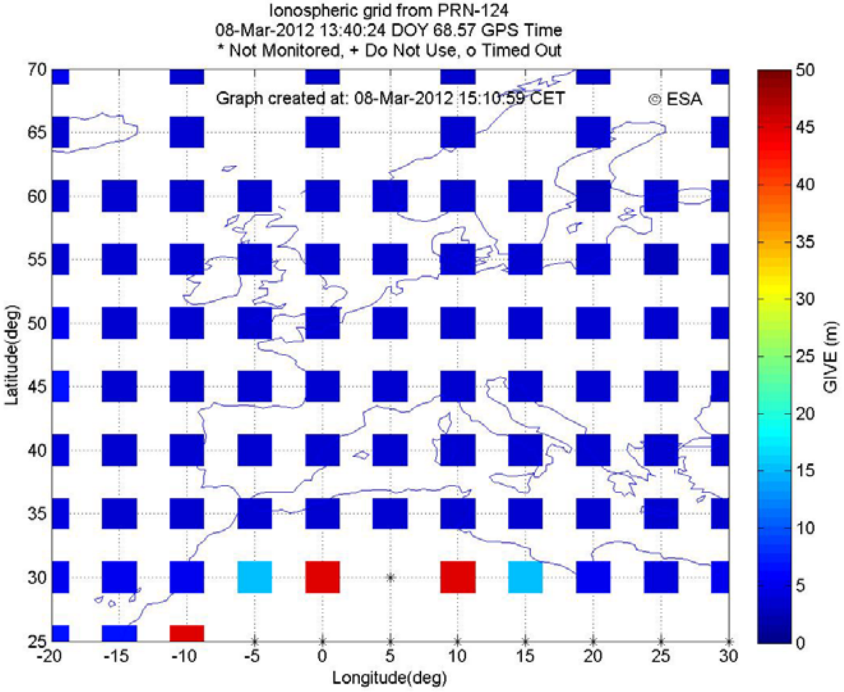
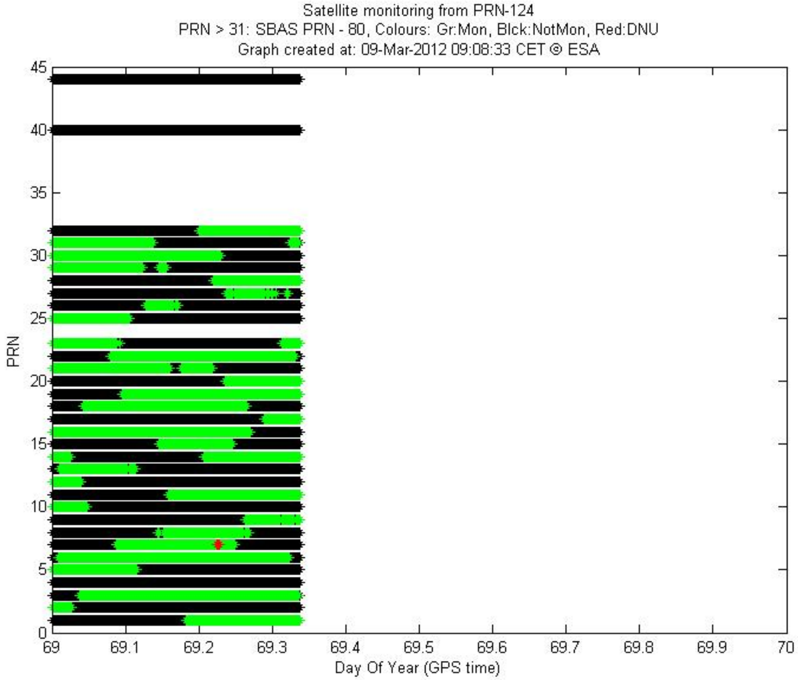
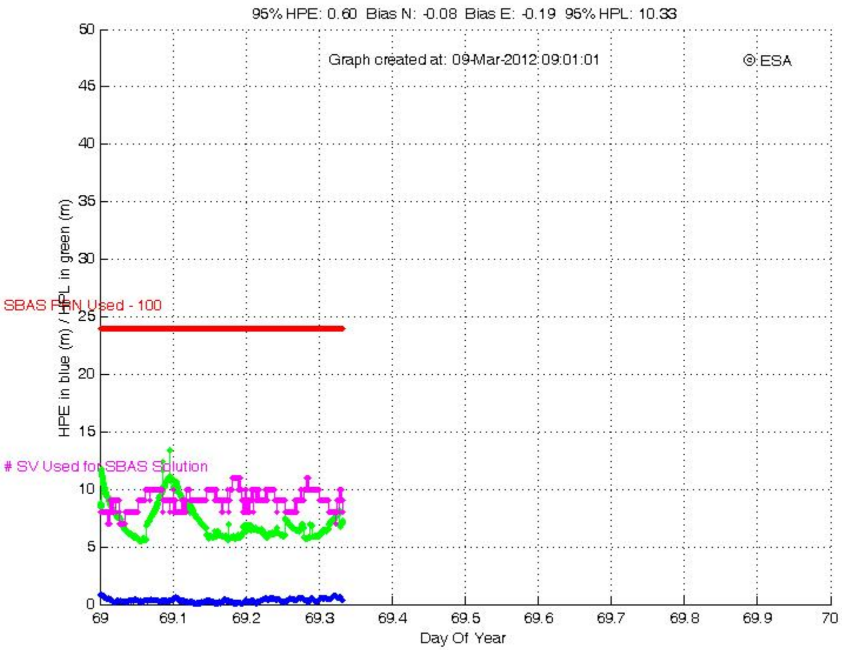
EGNOS Messages March 2012





EGNOS Performance static and dynamic urban

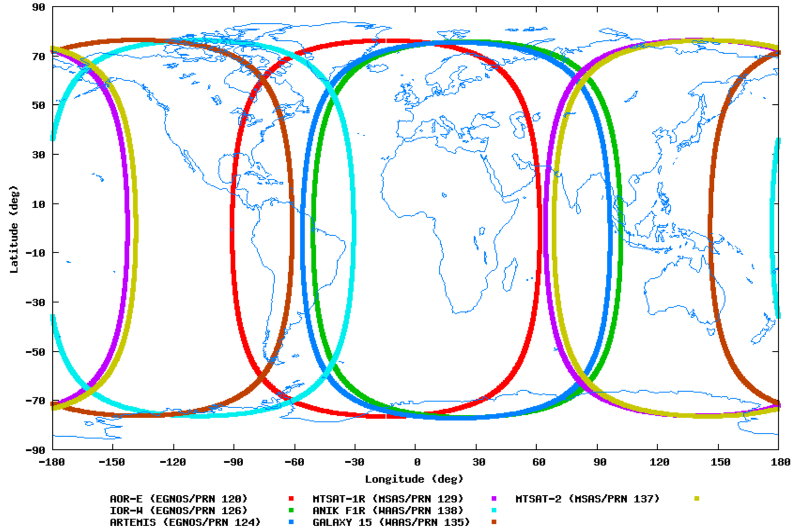


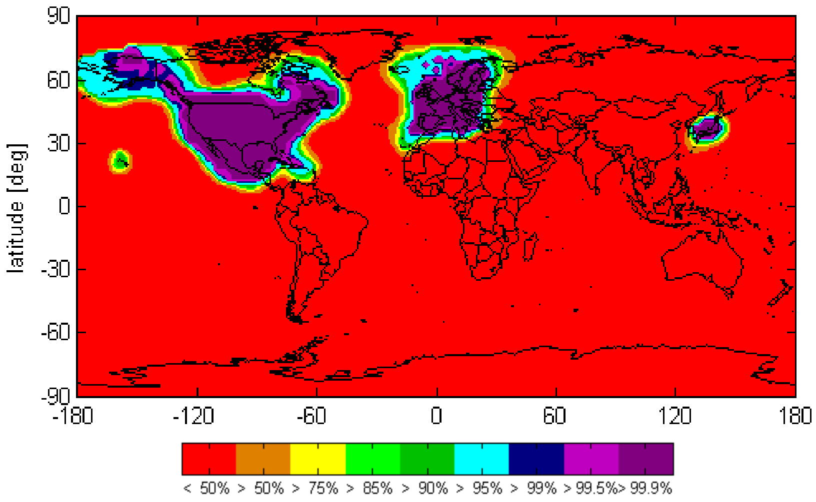
Static Measurements Prague

Urban Measurements Autumn 2011

95% Horizontal Error (m)	Nottingham	London	Helsinki
GPS Only	7.07	8.22	16.71
GPS + EGNOS	7.05	7.81	16.3s
GPS + EMS	6.48	7.87	16.50

Current SBAS world wide Status





SBAS Systems LPV-200 coverage today

Operating

- EGNOS v2.3 certified for APV-I, 3 GEO, 41 RIMS, 4 MCC, 4 NLES.
- WAAS operational LPV (250 ft),

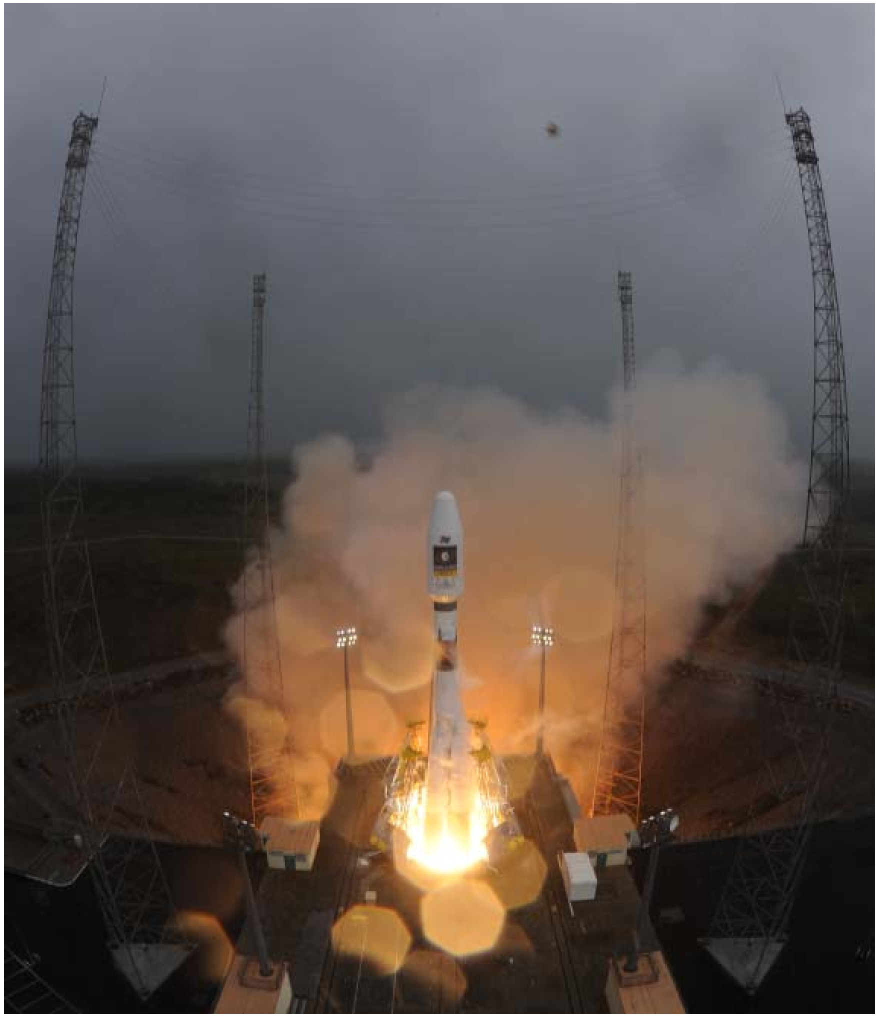
  3 GEO, 38 RIMS, 2 MCC, 4 NLES.
- MSAS operational RNAV,

  2 GEO, 4 RIMS, 2 MCC, 4 NLES.

Planned for 2014

- GAGAN under test
- SDCM under test (Launch Luch-5A 2011)
- Chinese SBAS system in development

SBAS looking ahead to LPV-200.



Part B: RTCA MOPS Future

- New requirements for L1/L5
- IWG process and status
- Expected performance

Background & Requirements for new standard

1. **Evolutions induced by a new GNSS environment**
    a. Evolutions induced by GPS: L2P(Y) -> Codeless tracking not guaranteed after 2020
    b. Used in EGNOS v2 for ionosphere -> To be replaced by L5 (SoL)
2. **Evolutions induced by WAAS**
    a. FAA prepares WAAS dual frequency L1/L5 services by 2018
3. **Enhanced robustness**
    a. Robustness to loss of one frequency or constellation
4. **Service extension**
    a. Africa and Middle-East
5. **Additional services**
    a. ADS-B, Maritime, railway, etc.
6. **Enhanced performance**
    a. Cat-I Autoland (VAL = 10m TBC)

SBAS IWG prepares next RTCA standard

1. **SBAS International Working Group objectives:**
   - Harmonise world wide SBAS operations
   - Exchange technical data and expertise
   - Prepare future new standards on SBAS to propose at RTCA
2. **IWG members:**
   - United States, Europe, Japan, Russia, India, China, etc.
3. **IWG agreements on new L1/L5 standard:**
   - New ICD to be ready end 2014, new RTCA DO-229 standard to be ready by mid 2018.
   - Shall enable the augmentation of at least 3 constellations, flexible to choose for each SBAS operator.
   - Shall provide new ranging & messages on L5 signal, using the I-component of the L5 signal (at 250bps).
   - Shall be backward compatible for L1 users, L1 signal standard changes will be minor and can be handled with new DO-229 version.

IWG L1/L5 standard main open points

1. **Frequency robustness needed?**
   - Today full loss of L1 is not considered in SBAS.
   - Are L5 only LPV-200 operations needed?

2. **Number of constellations?**
   - Depending on answer to point 1. above 3 or 4 constellations can be augmented realistically with a correction update rate of about 1-2 minutes.

3. **What shall be the target operation and associated alert limits?**

	VAL (m)	TTA (s)	Integrity risk
LPV -200	35	6	$1x10^{-7}$/150s
CAT-I	10	6	$1x10^{-7}$/150s
CAT II/III	5	2	$1x10^{-9}$/150s

IWG L5 messages - current study cases

- **With L1/L5 frequency robustness (up to 51 satellites):**
  - In principle a copy of L1 messages with iono information
  - Relaxation of fast corrections update intervals from 6-60s
  - Dynamic PRN Masking for up to 3 constellations (not all satellites)
  - Robustness upon alerts and message loss

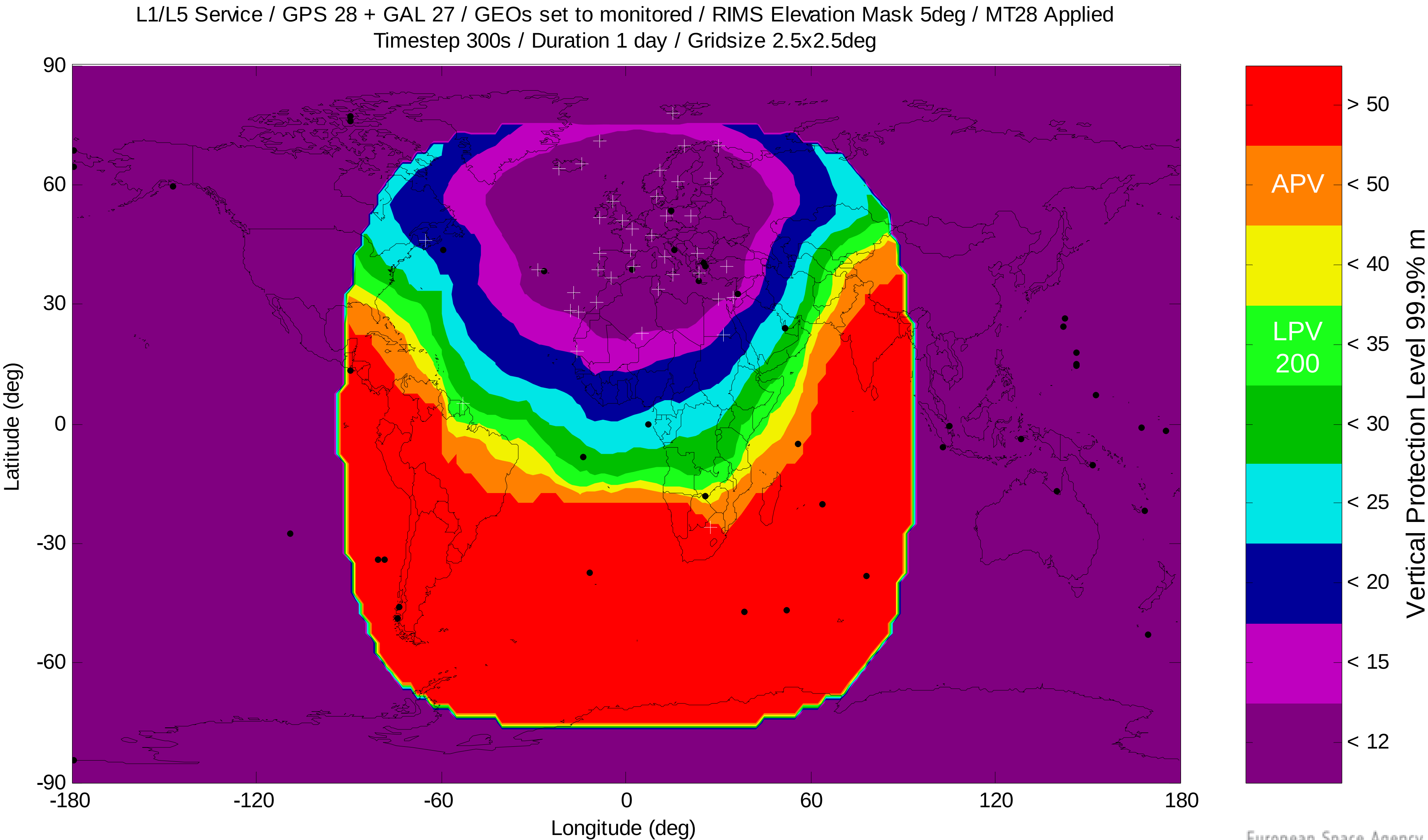
  -> Implies small changes to current L1 standard

- **Without L1/L5 frequency robustness (up to 4x37=148 satellites):**

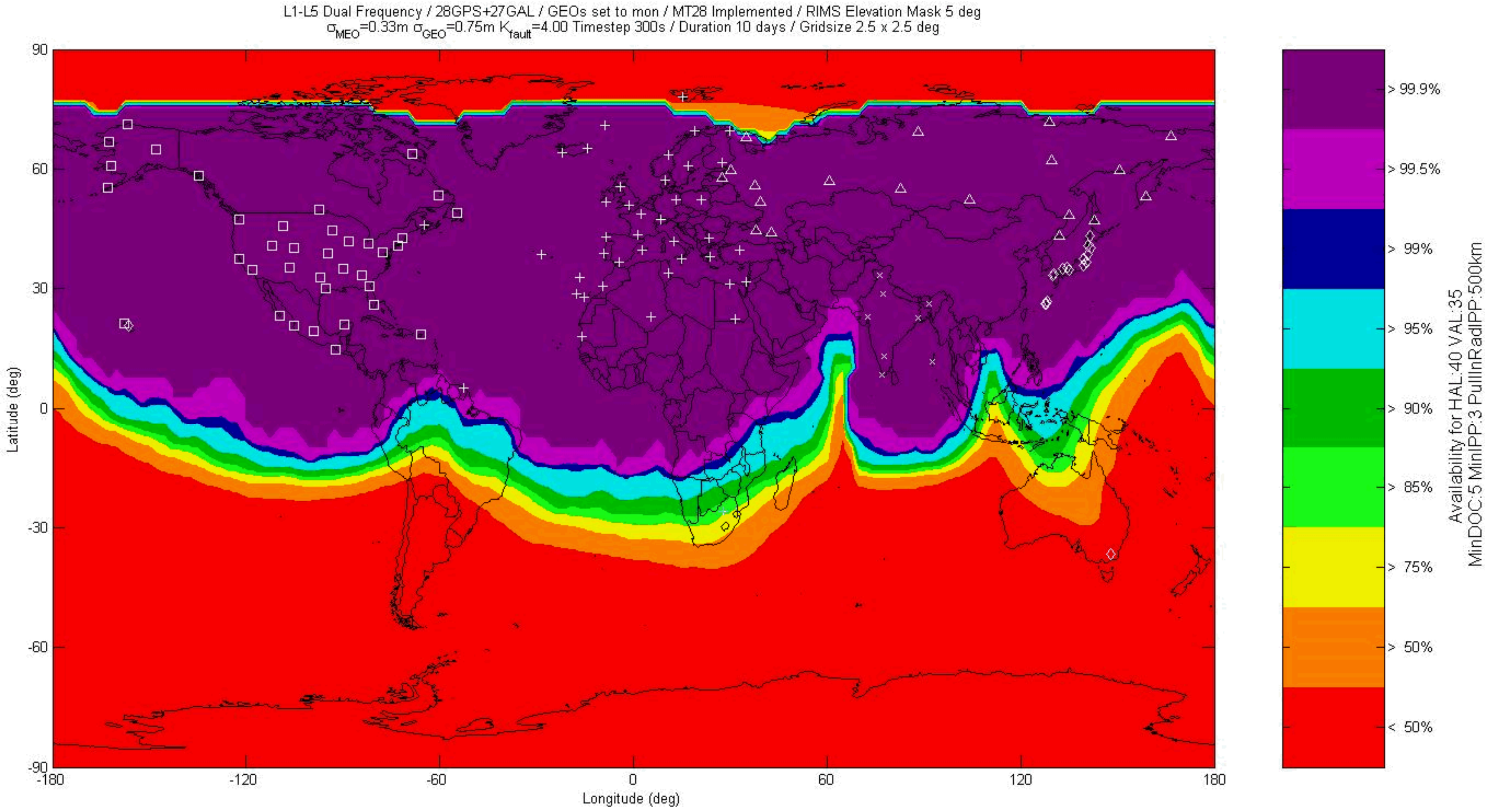
  Only satellite information (no iono information on L5)
  - New PRN Mask definition for:
    - GPS, Glonass, Galileo, Compass
    - QZSS and IRNSS
    - SBAS GEO satellites
  - Single satellite orbit, clock and covariance message per SV every 120s
  - Broadcast covariance status in 2 bits (old MT6) info every 6 seconds

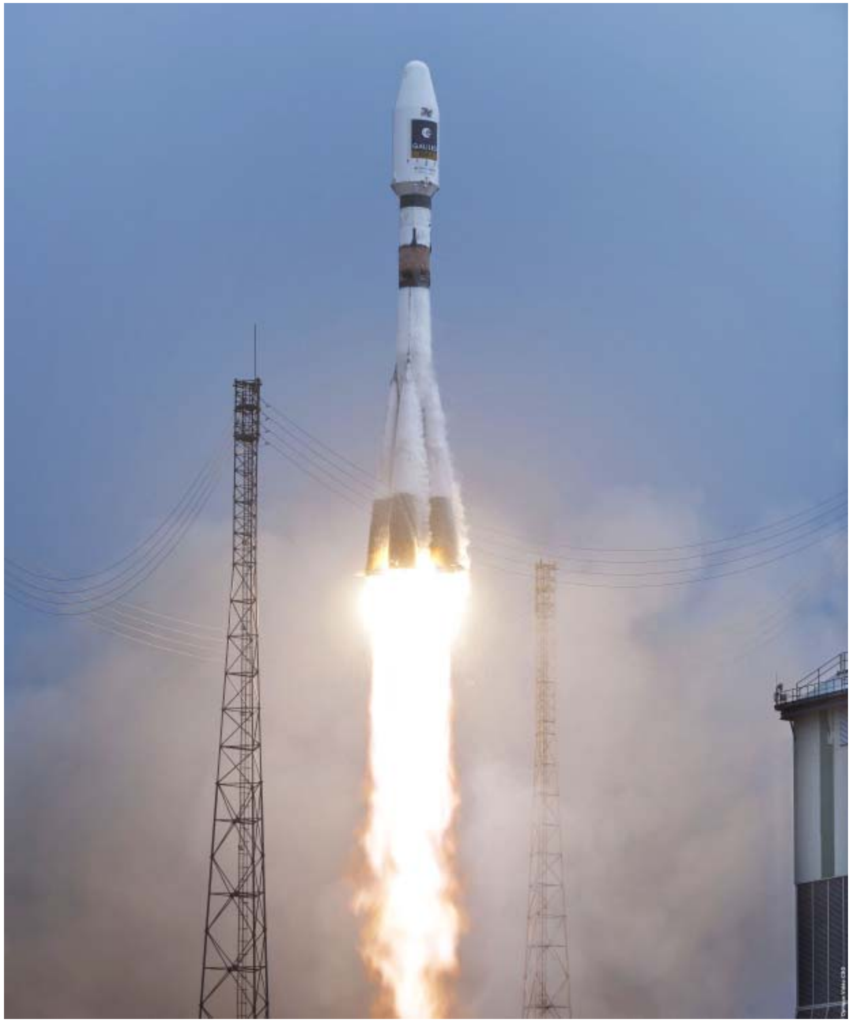
  -> No changes to current L1 standard

EGNOS L1 / L5 Simulated performance



SBAS L1 / L5 Simulated world wide performance





Part C: Galileo future studies

– Mission evolution objectives

– Main design options

– Schedule

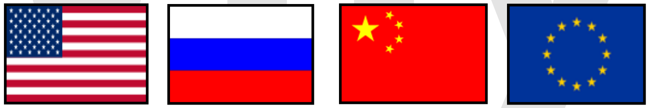
Why Galileo Evolution?

1. **Need to improve compliance of the system and to take evolving needs into account**

   Aligned and according to programme objectives

2. **Competitiveness**

   Galileo is the last of four worldwide GNSS



3. **Opportunities offered by evolving technologies**

   New technologies like e. g. Electrical Propulsion or Inter-Satellite Links offer new functionalities and solve shortcomings

4. **Need to improve cost effectiveness**

   Optimize exploitation efficiency w/r to cost and operability

   Safety-of-Life (SoL) removal

   Launch cost, number of ground stations, synergies with EGNOS

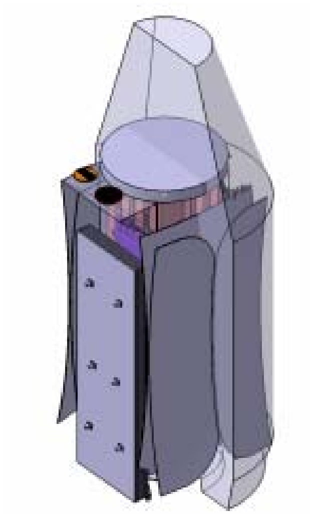
Increase space segment flexibility

Satellite class	Family	Launcher		
		Vega	Soyuz	Ariane 5
Current (750kg)	2A		2 sat	4 sat
	2B	1 or 2 sat	3 or 4 sat	6, 7 or 8 sat
Larger (1500kg)	3A		1 sat	2 sat
	3B	1 sat	2 sat	4 sat

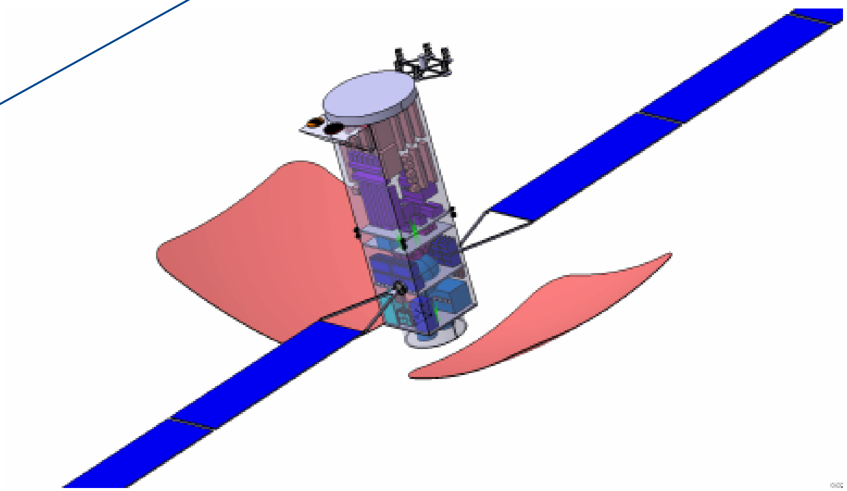
Save Launch Cost

Cost Neutral

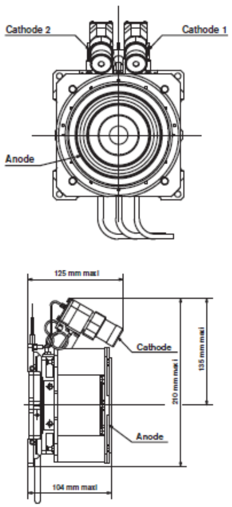
Increase Launch Cost



Satellite stow configuration in VEGA



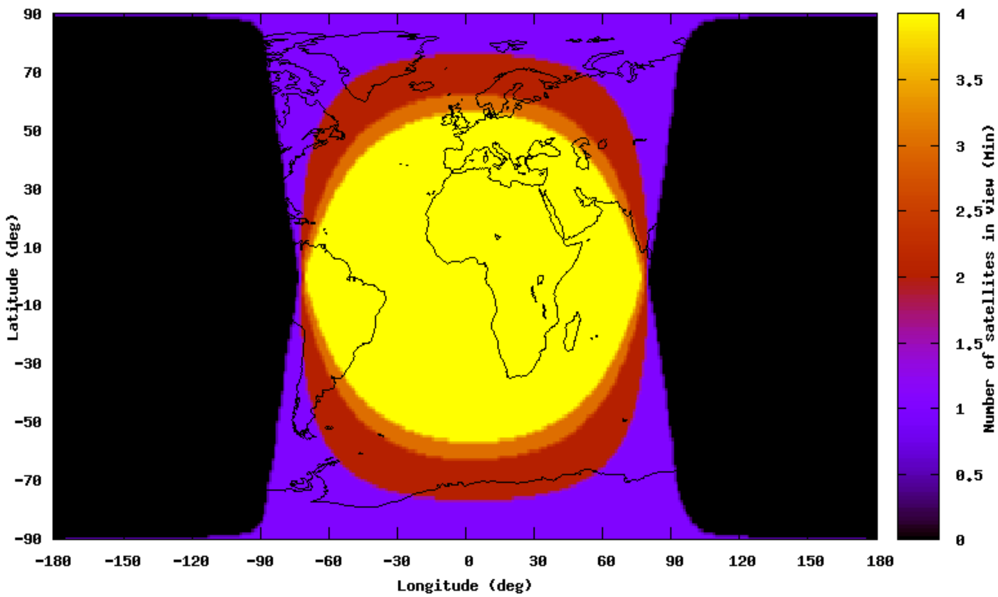
Satellite deployed



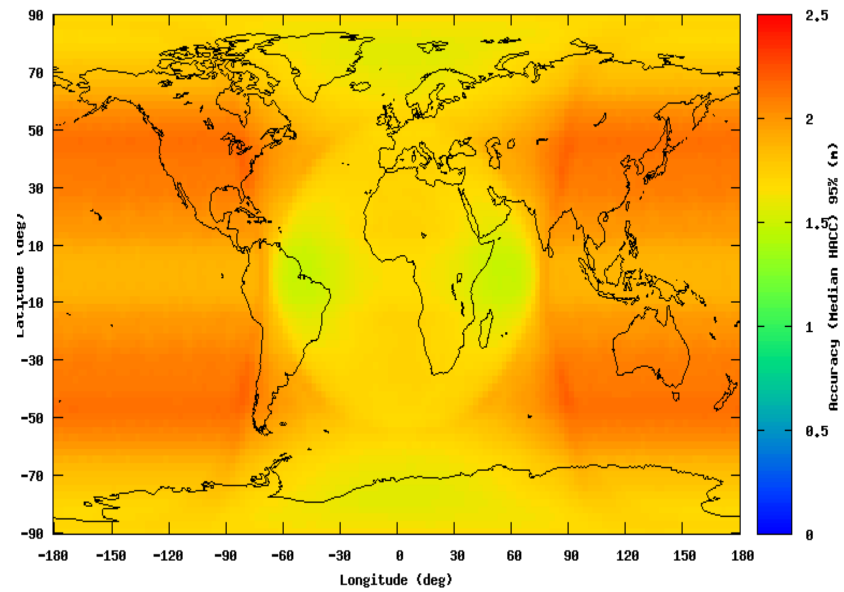
PPS-1350 EPS engine

Improve regional capabilities

Preferred solution:
Complement MEO constellation with few inclined GEO satellites



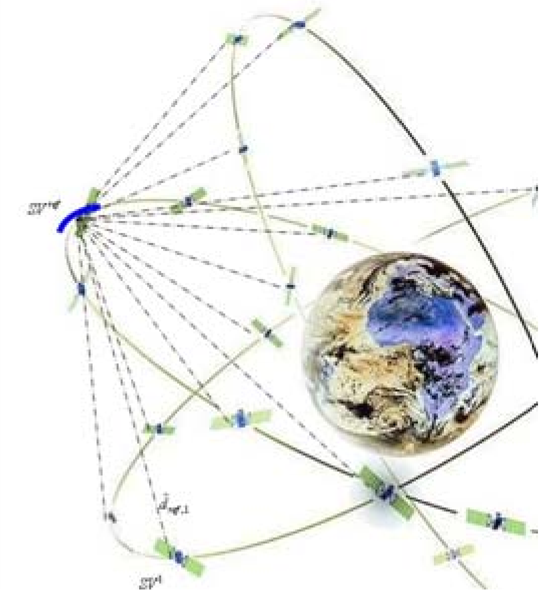
4 IGSO (20deg inclination)
Min. # satellites in view



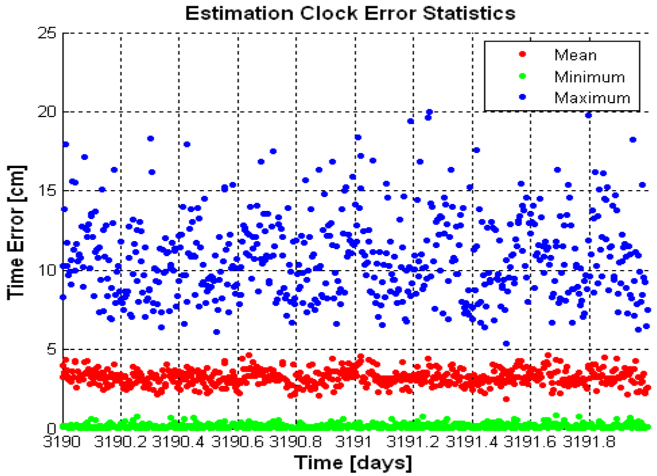
24 MEO + 4 IGSO
HACC 95%

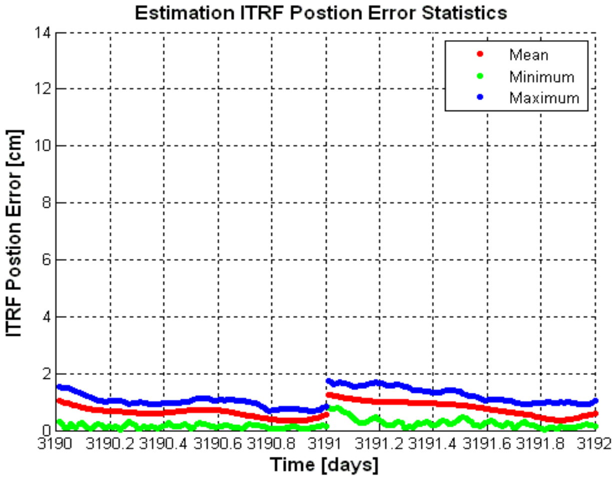
Potential synergy with EGNOS possible

Benefits of Inter Satellite Links

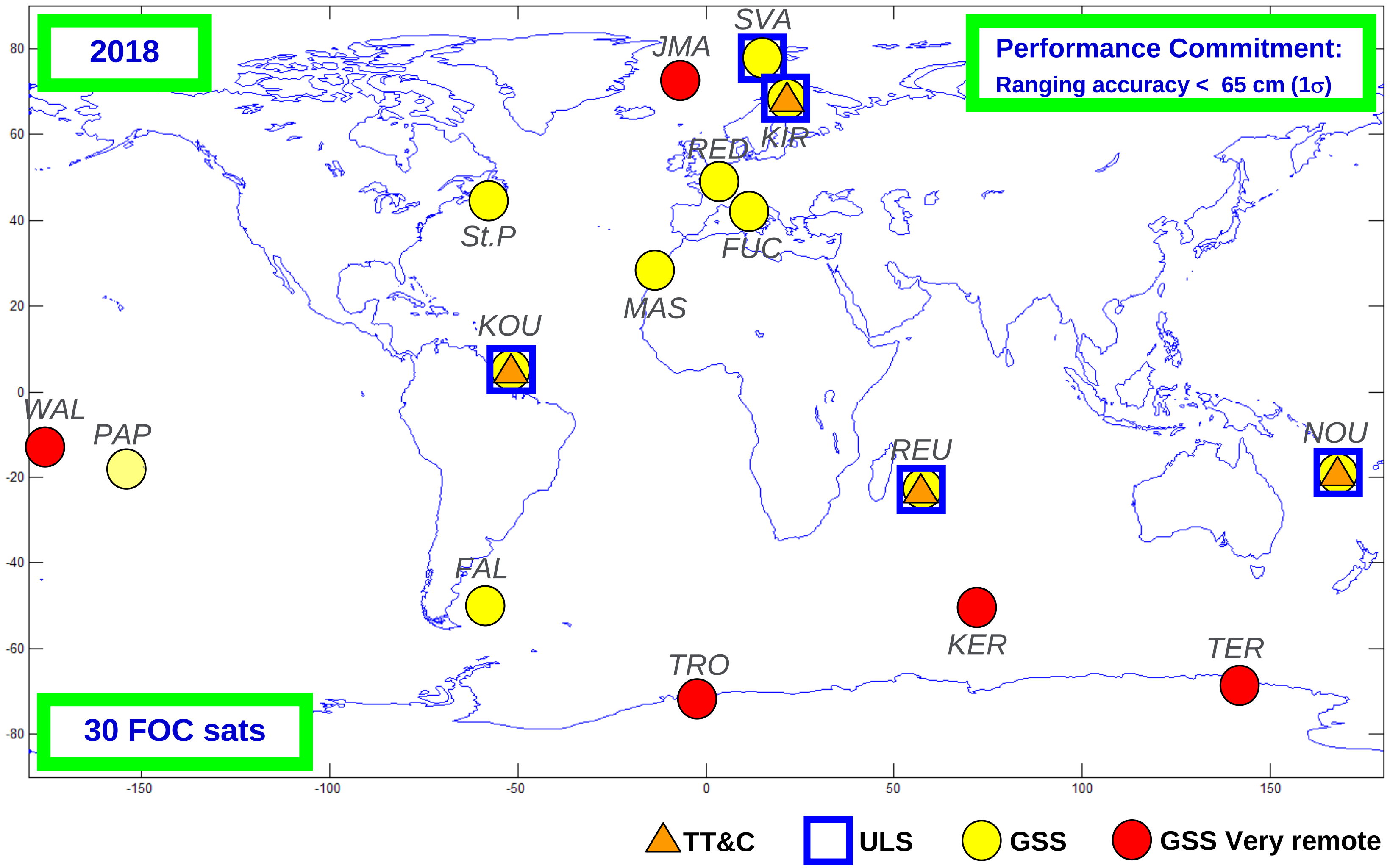


1. **Improved performance OS/PRS**
   a. Only way to reduce UERE by order of magnitude
   b. For same reason substantially improves integrity
2. **Improved cost benefit (Long Term)**
   a. Reduced number of TT&C, ULS and GSS
   b. Reduced number of network connections
   c. Reduced number of on board clocks
3. **Improved security**
   a. Faster commanding
4. **Additional benefits**
   a. Could be used for atmospheric sounding troposphere and atmosphere





Gradual ISL implementation
Limiting number of ground assets



Gradual ISL implementation
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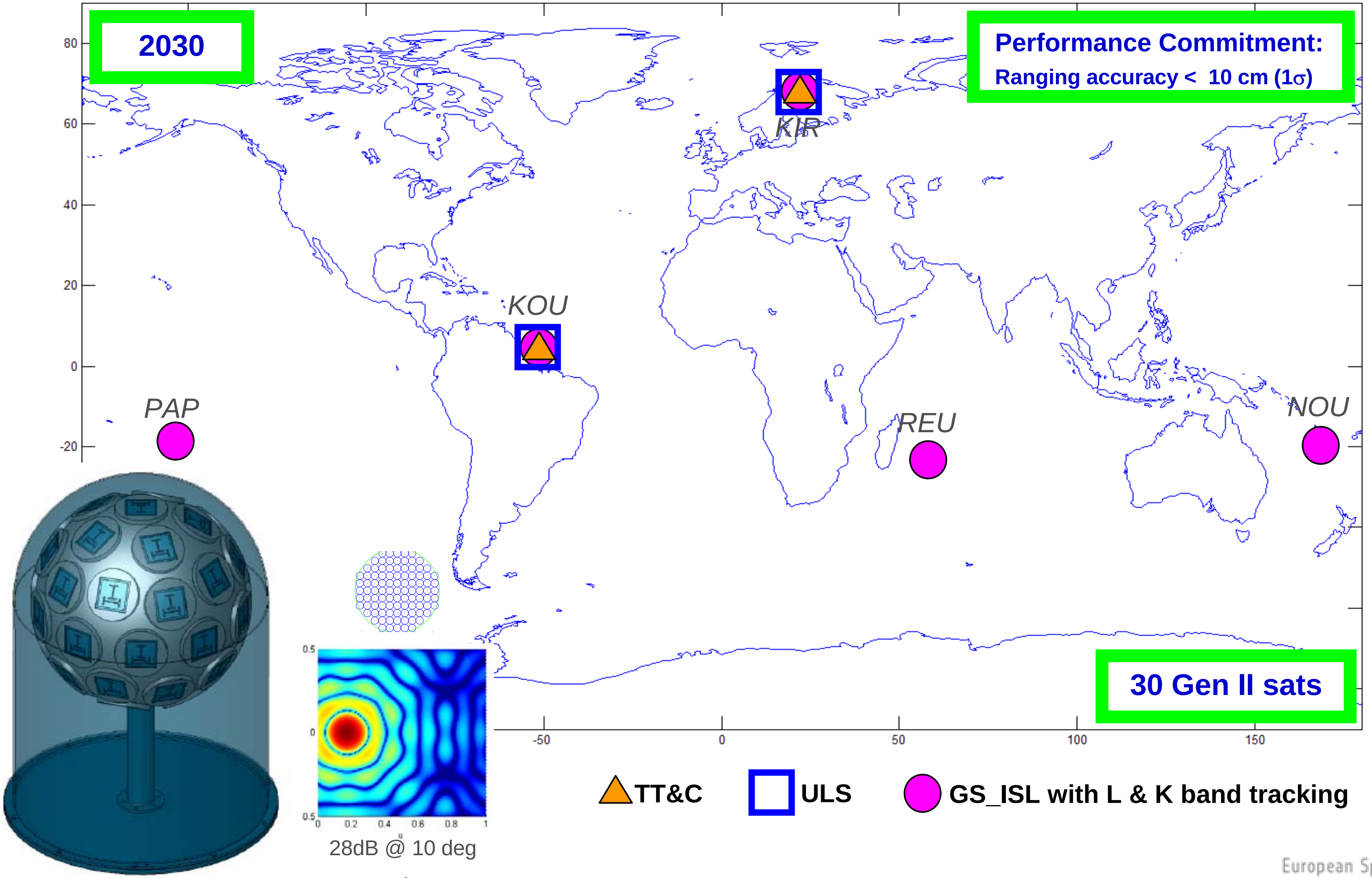


28dB @ 10 deg

L-Band Array

K-Band Array

Increase competitive performance

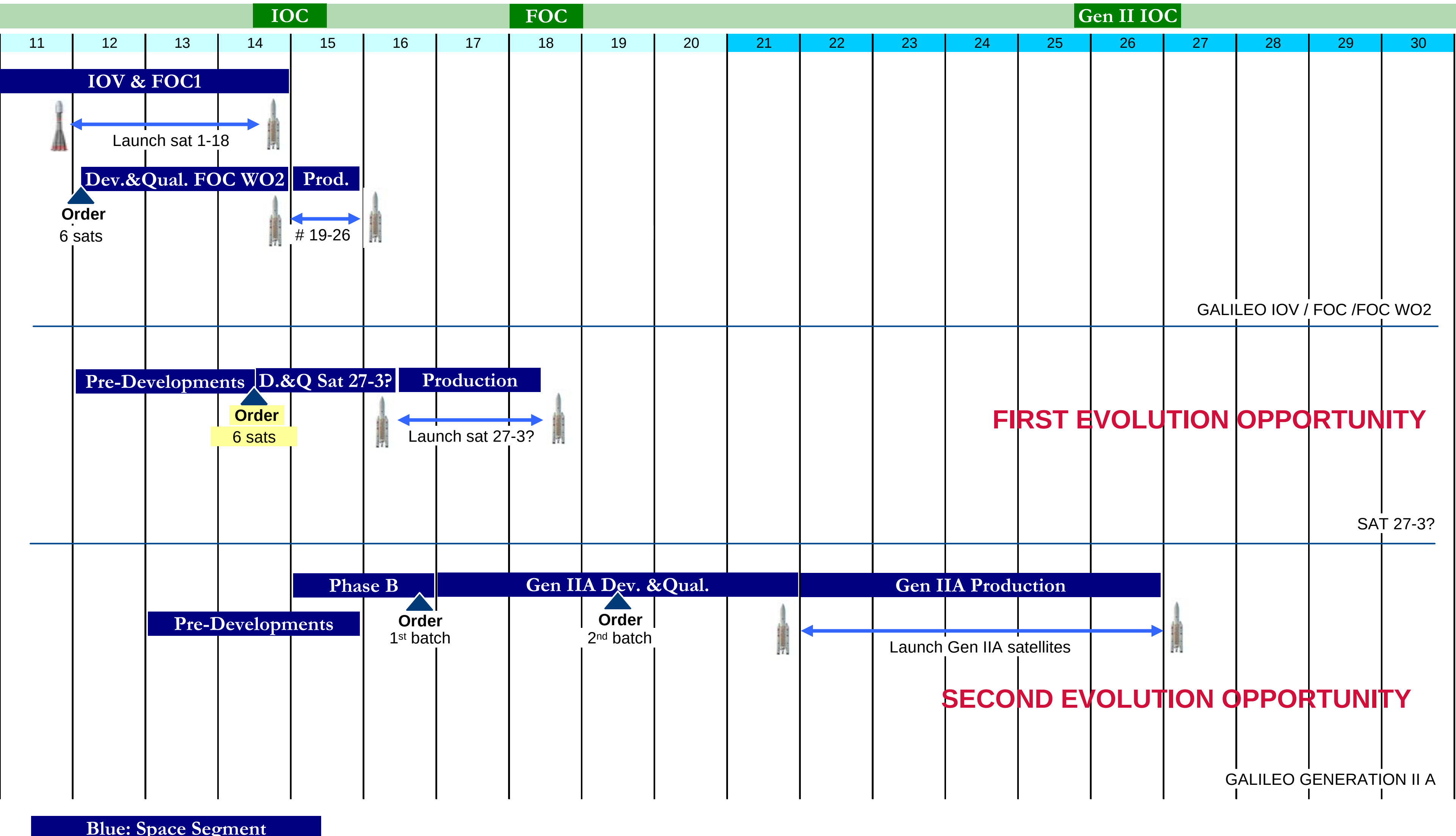
1. **Acquisition sensitivity:**
    a. GPS is better than Galileo due to lower data rate.
    b. Data rate in Galileo higher than GPS (former SoL service concept).
    c. SOL service no requirement anymore.

2. **Time To First Fix (TTFF):**
    a. Open Service shall facilitate a TTFF performance in cold start faster than currently (e.g. in less than a minute).
    b. Current solution is Assisted GPS, but requires terrestrial communications.

3. **Navigation message**
    a. Channel coding is applied after multiplexing of all messages: Extra delays for long message, no possibility to apply coding scheme adapted to different user schemes.

4. **Point Positioning Accuracy**
    a. The current specification is not competitive w/r to other systems. Need to improve from 4 meters to below one meter.

Evolution opportunities



Conclusion

1. MOPS Today
    a. Supports GPS/Glonass corrections on L1 at 6s update rate
    b. WAAS, EGNOS and MSAS support GPS only
    c. SDCM, GAGAN and Chinese SBAS planned for 2014

2. MOPS Future
    a. New frequency L5
    b. More constellations: at least 3
    c. Studies:
        – Frequency robustness
        – Relaxed update rate: 1-2 min

3. Galileo Future studies
    a. Increased launcher / platform / payload flexibility
    b. Allows different orbit types in same constellation -> SBAS synergy
    c. Inter satellite links can bring orbit&clock error to < 10cm
    d. Opportunities: 1st 2016, 2nd 2021