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GNSS performance standards in the maritime domain

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Introduction - regulatory framework

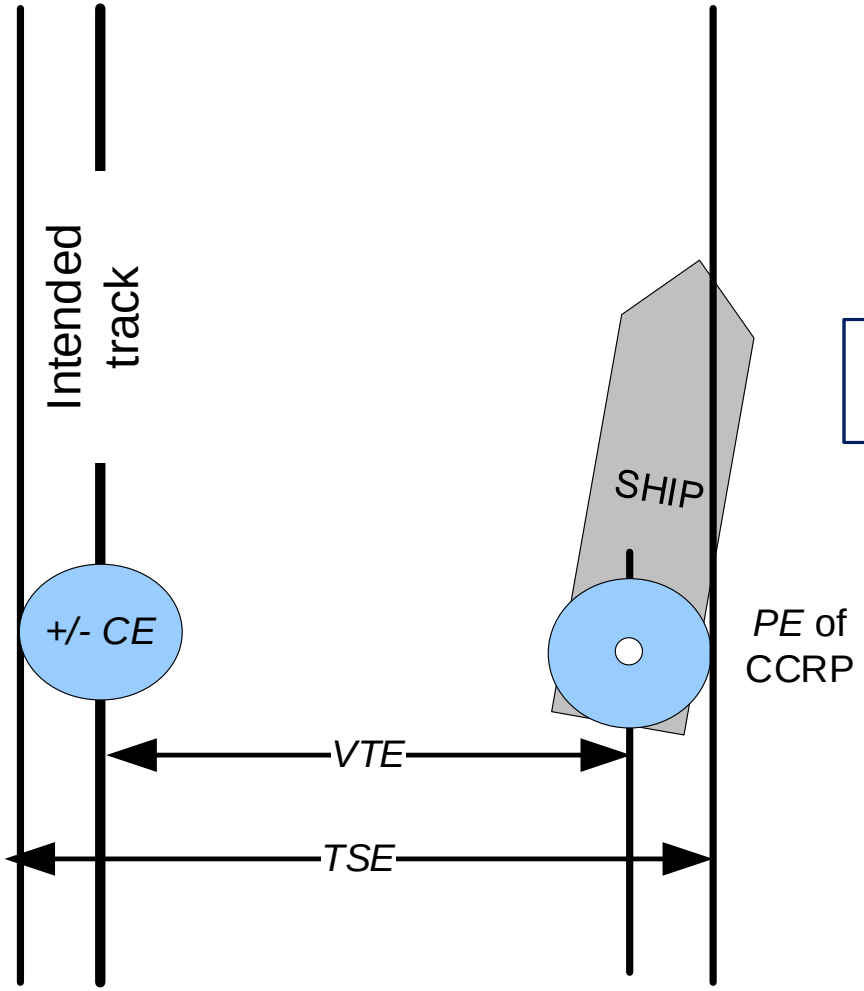
- IMO instruments set the boundary performance parameters of shipborne derived GNSS data to be expected
- Performance standards for shipborne GNSS and RNSS receivers are set by the resolutions MSC.112(73) on GPS, MSC.113(73) on Glonass, MSC.114(73) on DGPS and DGlonass, MSC.115(73) on Combined GPS & Glonass (2000), MSC.233(82) on Galileo (2006), MSC.379(93) on Beidou (2014), MSC.401(95) on Multi System Shipborne Radionavigation Receivers (2015), MSC.449(99) on IRNSS (2018), MSC.480(102) on QZSS (2020), and the resolution A.1046(27) on World Wide Radionavigation System (2011)

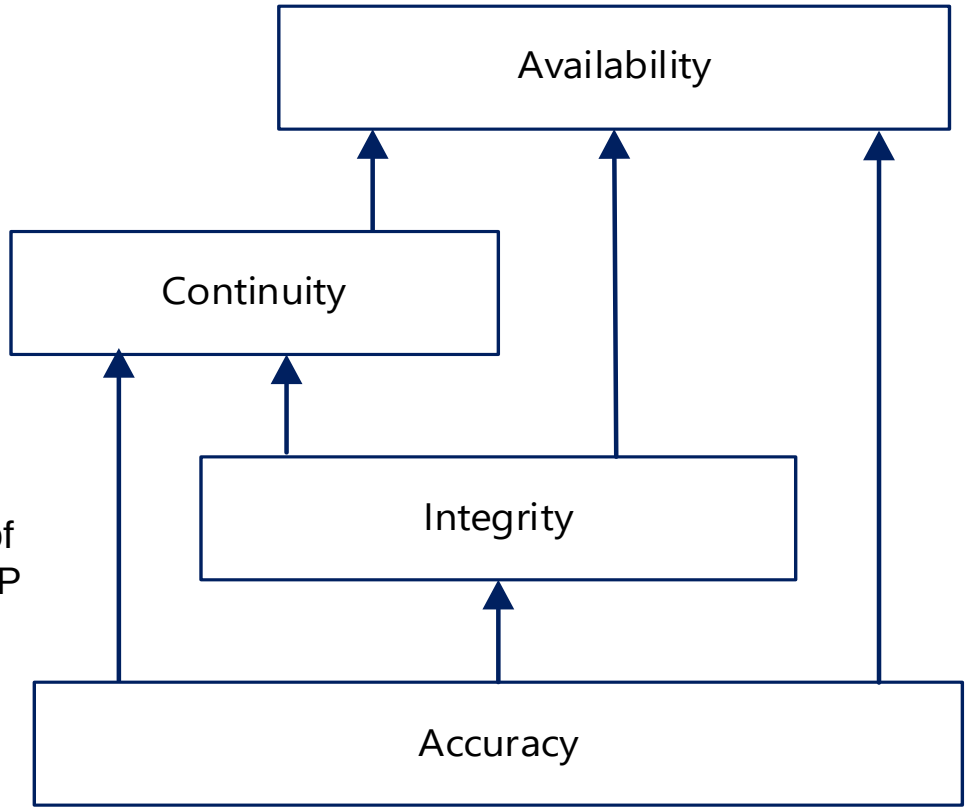
Introduction - regulatory framework

- IMO policies and guidelines are only recommendations as declared in Resolution A.915(22) on Revised maritime policy and requirements for a future GNSS (2001), and in Circular MSC.1/Circ.1575 on Guidelines for shipborne position, navigation and timing (PNT) data processing (2017)
- IHO zones of confidence (ZOC) reflecting charting standard not just a hydrographic survey standard
- Regional policies like EU regulations (European Radionavigation Plan)

IMO GNSS Policy

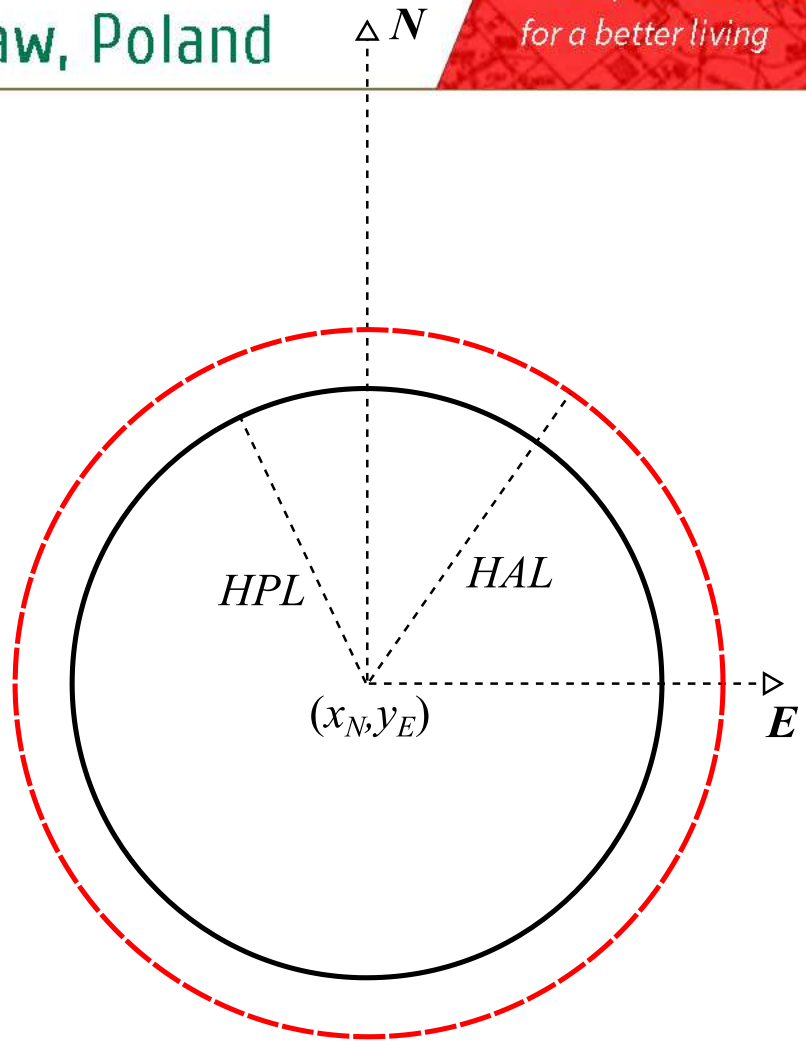
- Contribution of GNSS position error (*PE*), chart error (*CE*), and vessel technical error (*VTE*) to total system error (*TSE*)
- System and service level parameters





IMO GNSS Policy

- Integrity risk (*IR*): probability that a user will experience a position error larger than *AL* without an alarm being raised within the specified *TTA* at any instant of time at any location in the coverage area
- Horizontal protection level (*HPL*) not defined but policy implicates the necessity to determine the absolute magnitude of significant errors



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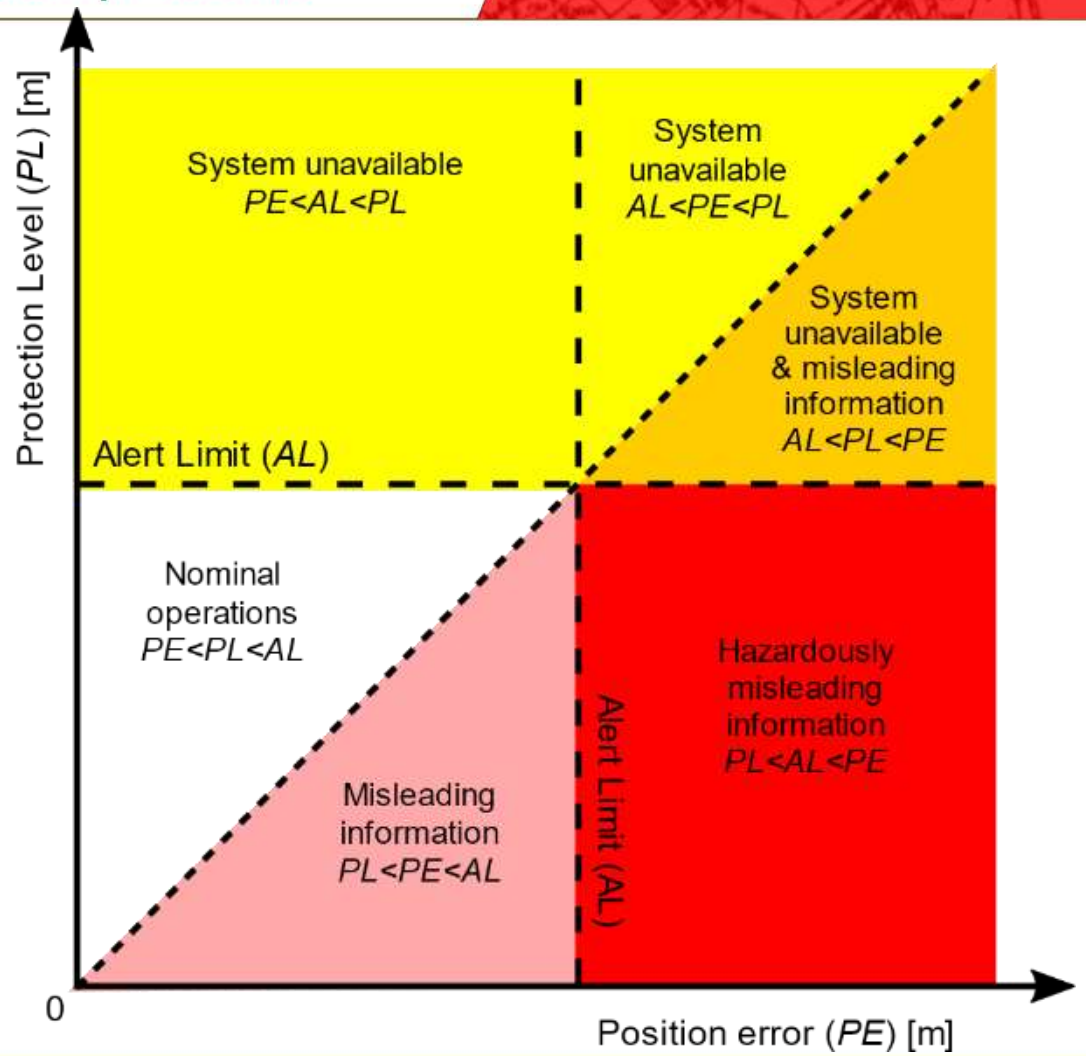


IMO GNSS Policy

Area	Minimum maritime user requirements for general navigation							
	System level parameters				Service level parameters			
	Absolute accuracy	Integrity			Availability [%] (per 30 days)	Continuity [%] (over 3 hours)	Coverage	Fix interval [s]
	Horizontal 95% [m]	AL [m]	TTA [s]	IR (per 3h)				
Ocean	10	25	10	1.00E-05	99.8	-	Global	1
Coastal	10	25	10	1.00E-05	99.8	-	Global	1
Port approach and restricted waters	10	25	10	1.00E-05	99.8	99.97	Regional	1
Port	1	2.5	10	1.00E-05	99.8	99.97	Local	1
Inland waterways	10	25	10	1.00E-05	99.8	99.97	Regional	1

IMO GNSS Standards

- **ocean waters** where a GNSS provides positional information with an error not greater than 100 m with a probability of 95%, and an integrity warning of system malfunction, non-availability or discontinuity is provided to users as soon as practicable by Maritime Safety Information (MSI) systems
- **harbour entrances, harbour approaches and coastal waters** where a GNSS provides positional information with an error not greater than 10 m with a probability of 95%, and when the system is available, the service continuity should be ≥99.97% over a period of 15 min. and an integrity warning of system malfunction, non-availability or discontinuity should be provided to users within 10 s

IMO GNSS Standards

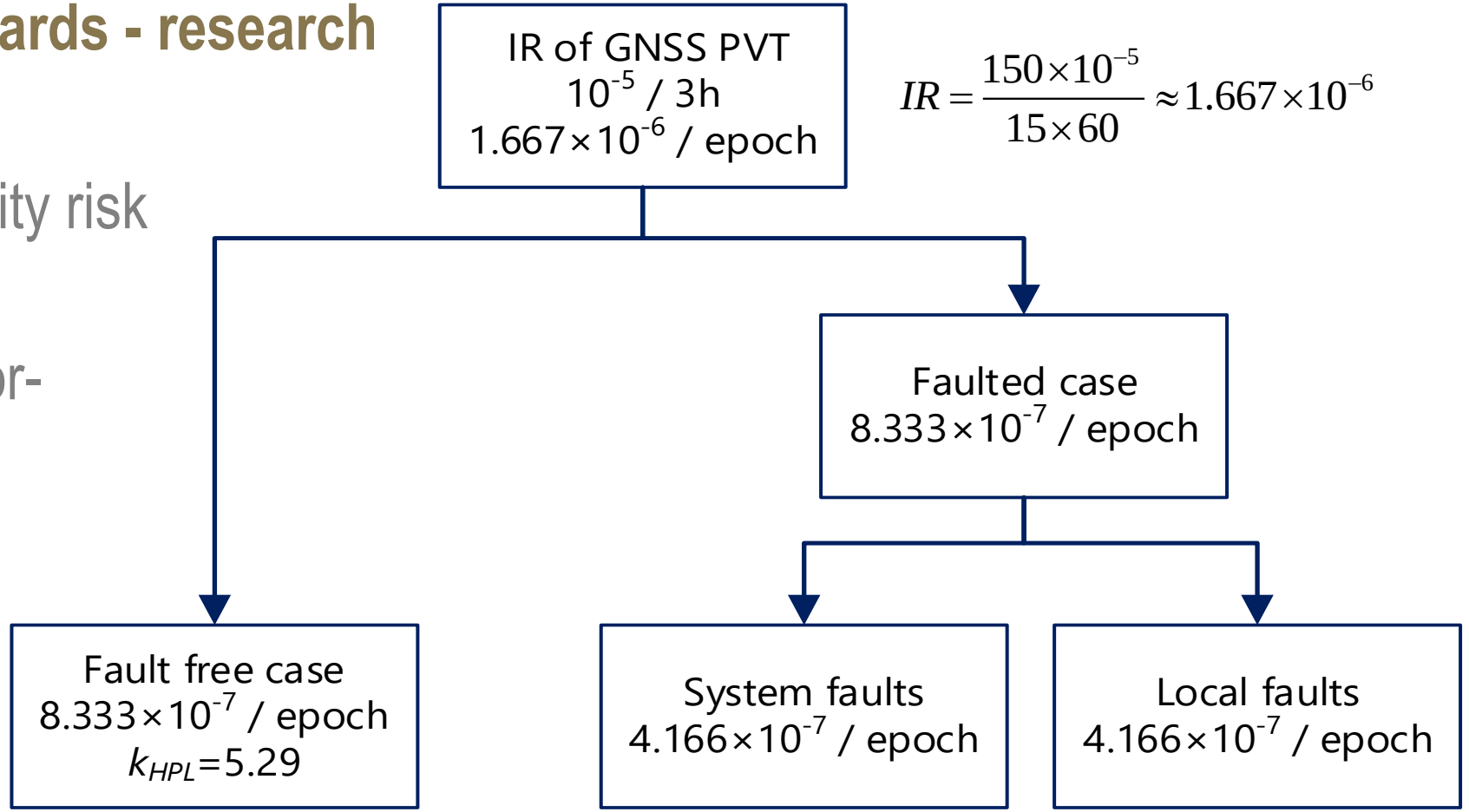
- in both zones signal availability should exceed 99.8% and the system shall be considered available when it provides the required integrity for the given accuracy level

- continuity over 15 min. $MTBF = \frac{0.25\text{h} \times 100}{100 - 99.97} = 833\frac{1}{3}\text{h} \approx 34\frac{3}{4}\text{days}$

- availability per 30 days $DT = \frac{(100 - 99.8) \times 30 \times 24\text{h}}{100} = 1.44\text{h}$

IMO GNSS Policy & Standards - research

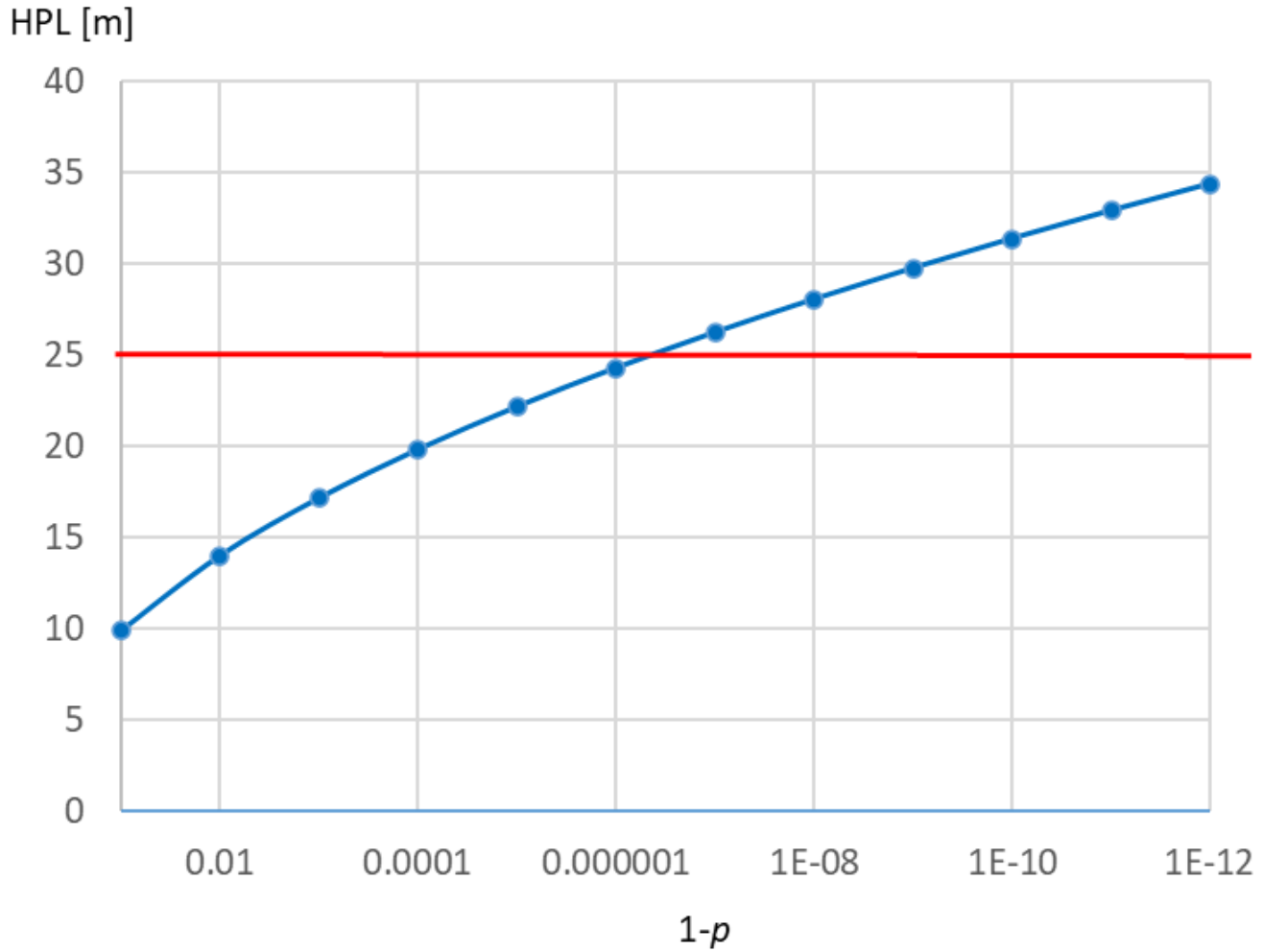
- Integrity fault-tree branch allocating maritime integrity risk
- *IR* calculated for 15min. operation and GNSS error-correlation time of 150s



IMO GNSS Policy & Standards - research

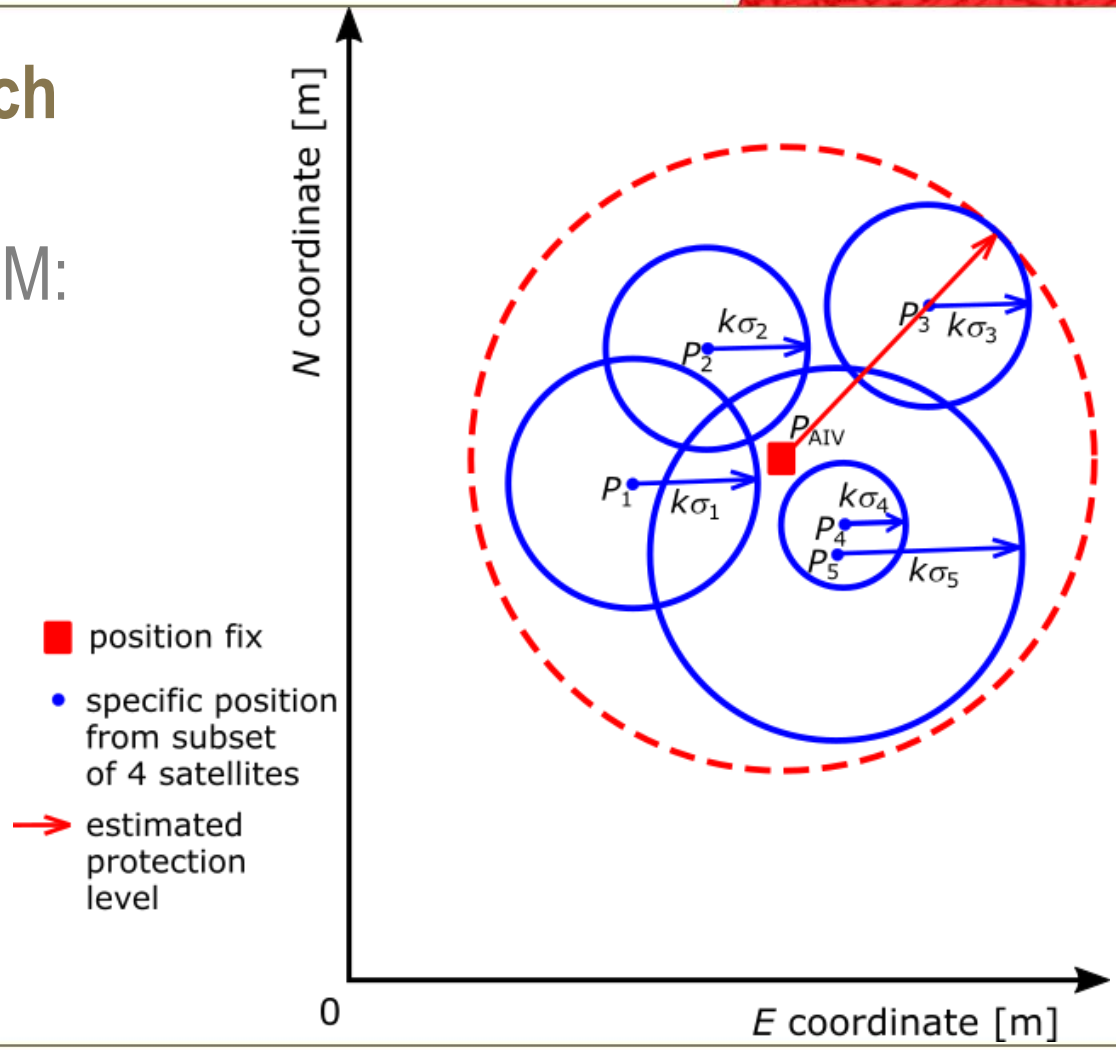
- Dependence of HPL specified for 8m 95% accuracy on its probability level *p* (logarithmic scale)

$$HPL = k\sqrt{\frac{\sigma_E^2+\sigma_N^2}{2}+\sqrt{\left(\frac{\sigma_E^2-\sigma_N^2}{2}\right)^2+\sigma_{EN}^2}}$$



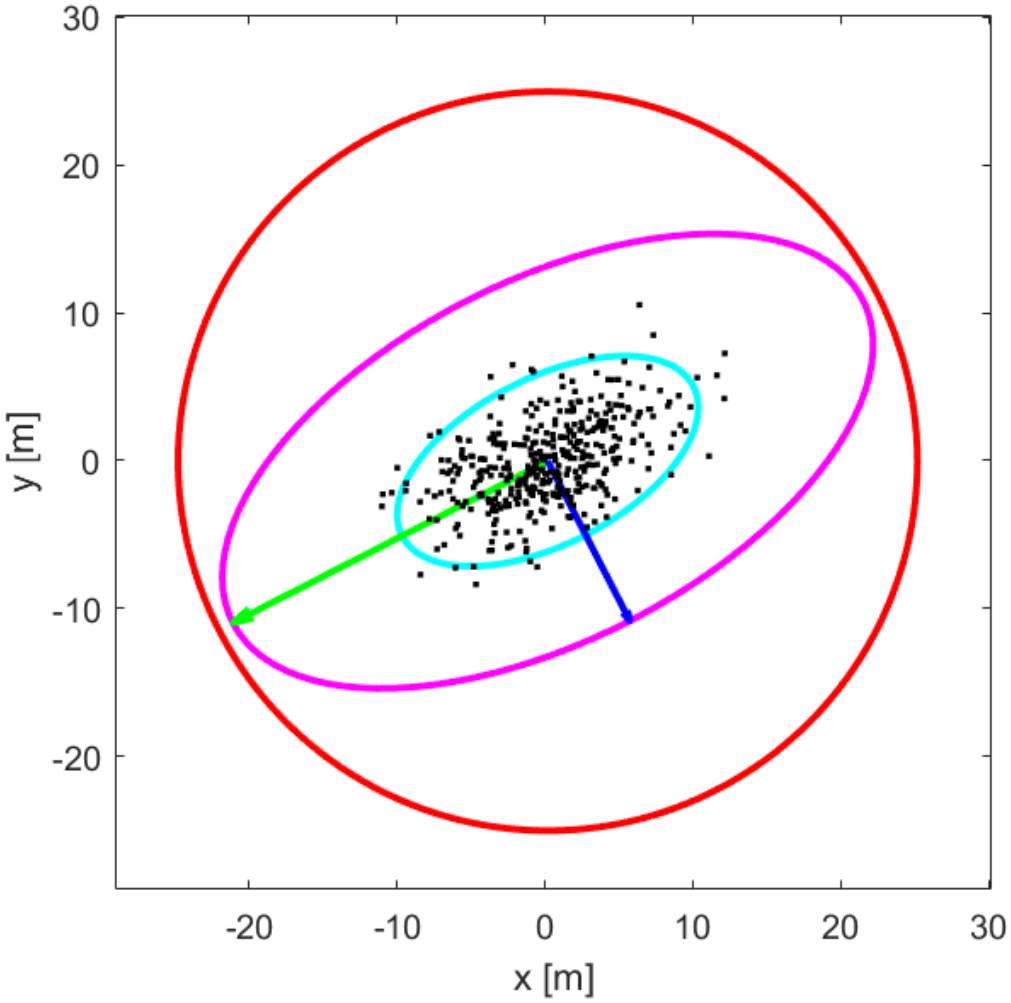
IMO GNSS Policy & Standards - research

- Determination of HPL by high level RAIM: 6 position solutions from 5 measured pseudoranges if only 5 satellite signals passed consistency tests



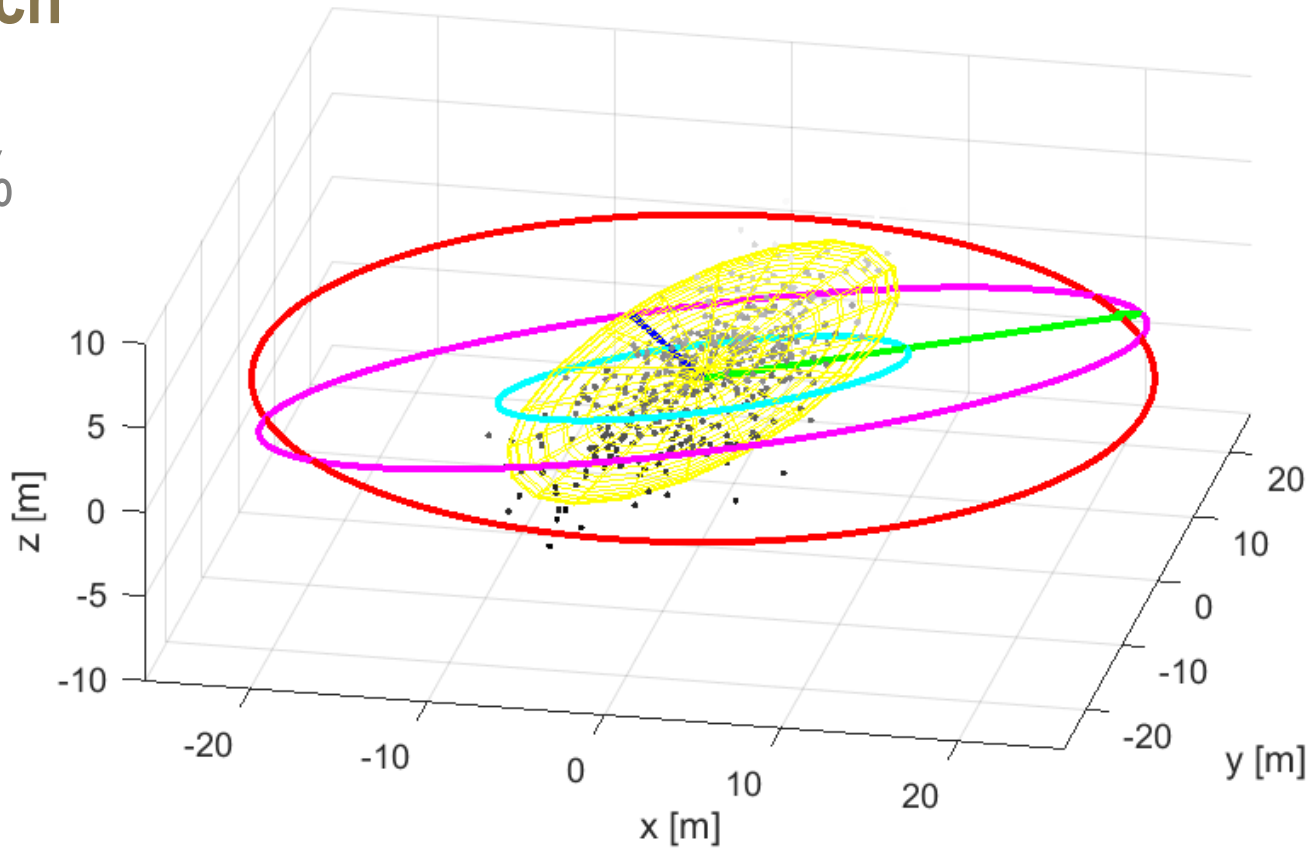
IMO GNSS Policy & Standards - research

- Example of 2D 95% and 99.99992% (corresponding to IR) confidence ellipses, and AL circle for GNSS recorded data



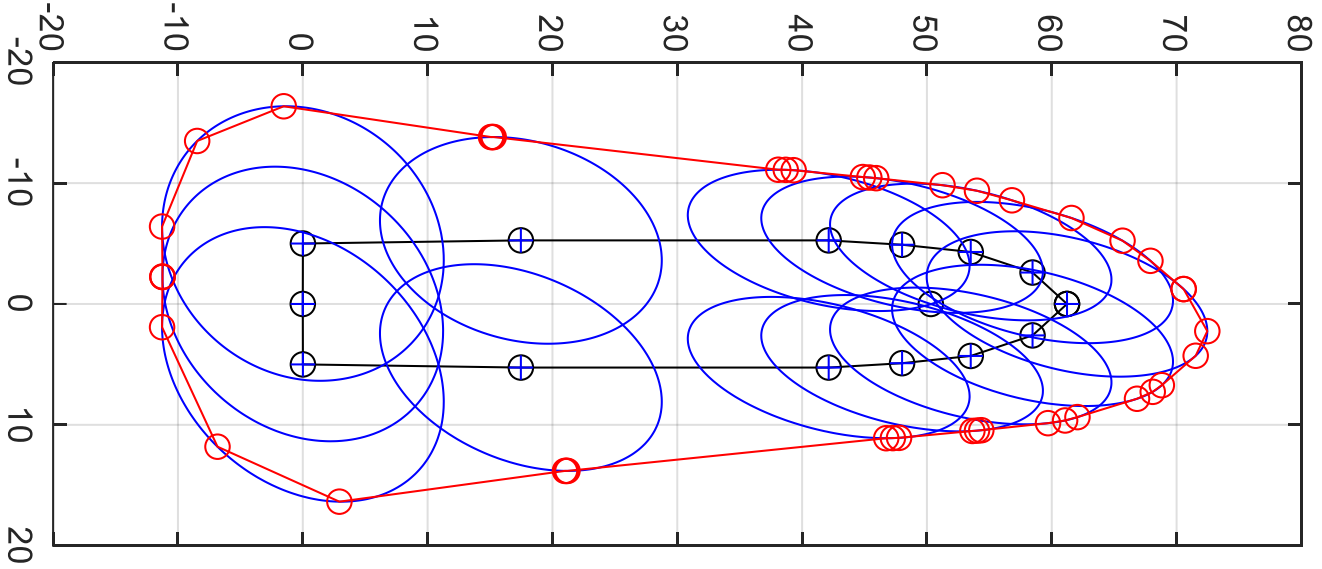
IMO GNSS Policy & Standards - research

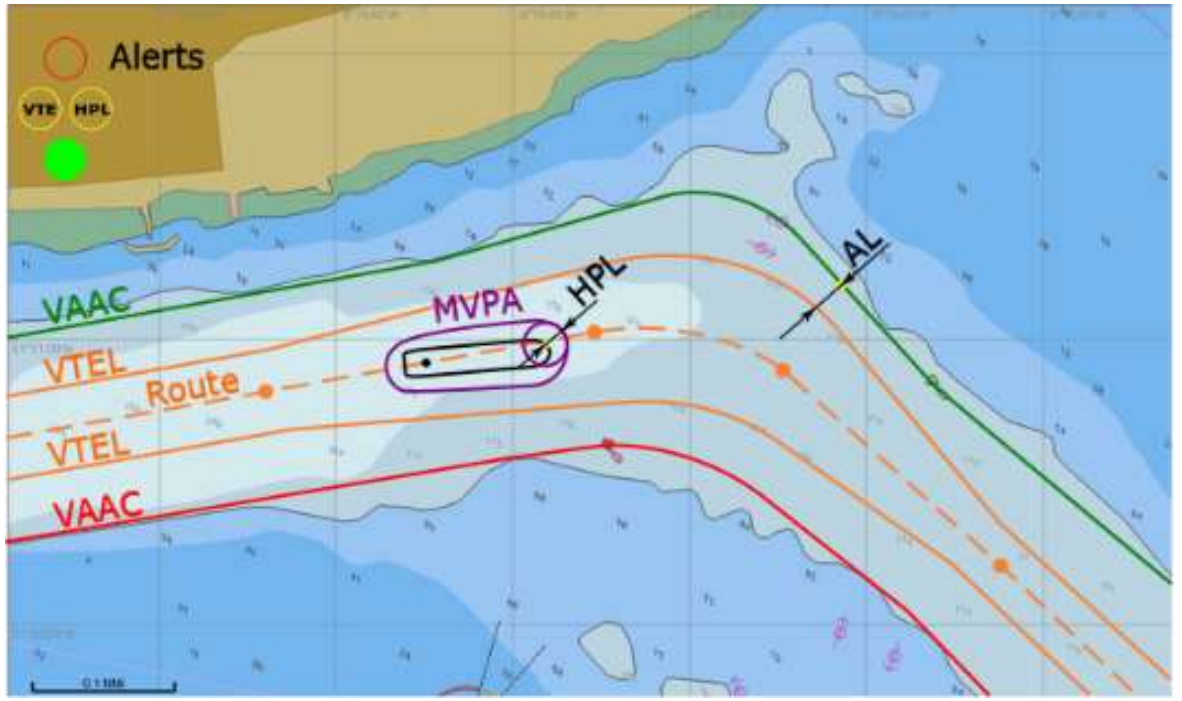
- Example of horizontal 95%, 99.99992% confidence ellipses, AL circle and 3D 95% confidence ellipsoid for GNSS recorded data



IMO GNSS Policy & Standards - research

- Maritime Vessel Protection Area (MVPA) concept





Conclusions

- No standard algorithm of HPL calculation (DOP, DRMS, elliptical, k-factor of IR)
- Disagreement over practical value of time scope for continuity, availability and integrity
- High level RAIM parameters are producer proprietary (no data in user manuals of system and service data settings, assumed to meet IMO GNSS policy resolution)
- Very basic user knowledge of RAIM algorithms used in GNSS receivers and their interpretations
- Limited uptake of SBAS-enabled shipborne receivers