Introduction to INSPIRe

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Content

- Background:
    - Required Navigation Performance
    - Need for Integrity
    - Types of Integrity Monitoring
    - Remaining Integrity Monitoring Issues

- Integrated Navigation System-of-Systems PNT for Resilience (INSPIRe)
    - Context
    - Focus

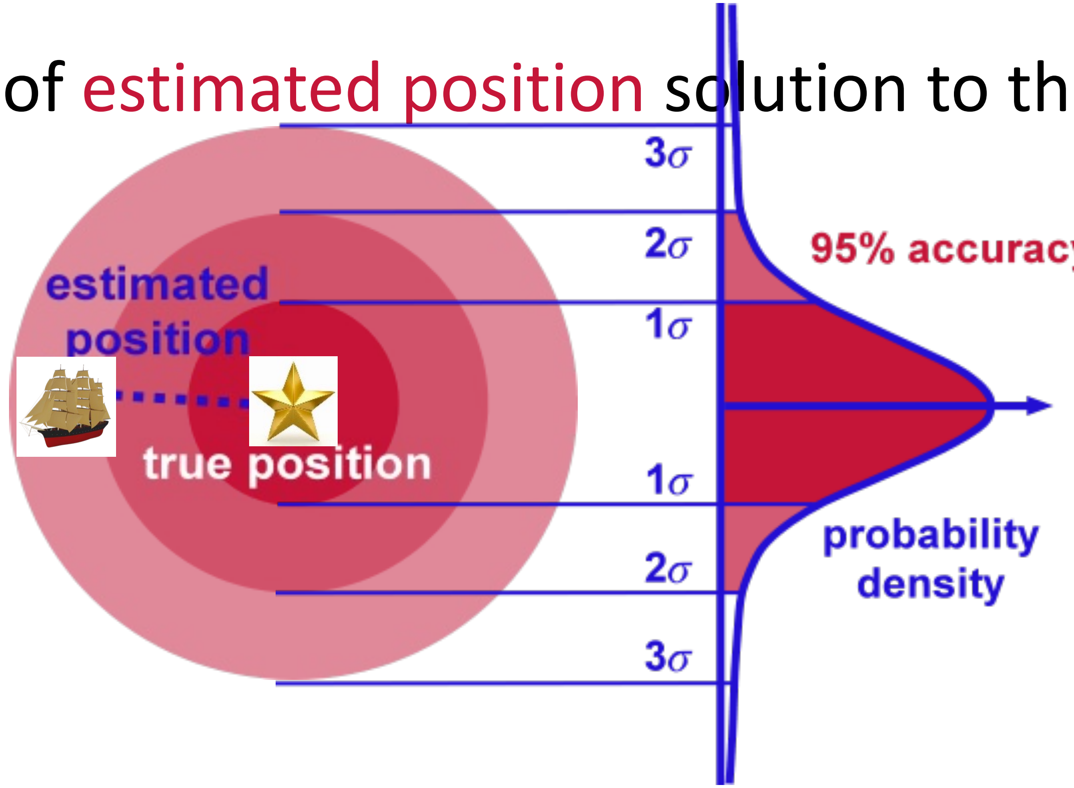
Required Navigation Performance (RNP)

- Measures/Metrics to measure performance consider:
  - performance in the absence of failure
  - performance in the presence of failure
  - operational economy
  - Standardisation

- Quantification of metrics for a given application
  - $RP_{model} = f$ *(operational factors, safety/security/liability… & efficiency)*

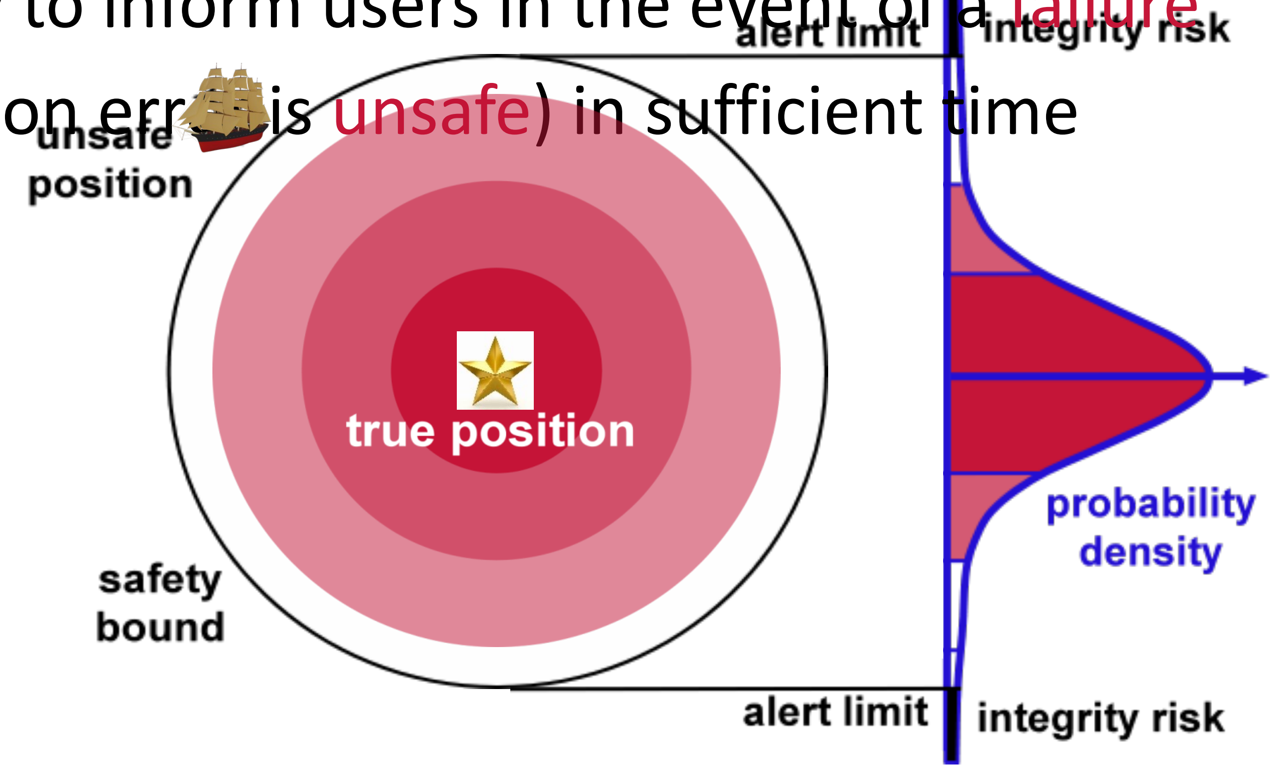
Performance in the absence of failure (2/2)

- *Accuracy*
- Conformance of estimated position solution to the true position (95%)



Performance in the presence of failure (1/2)

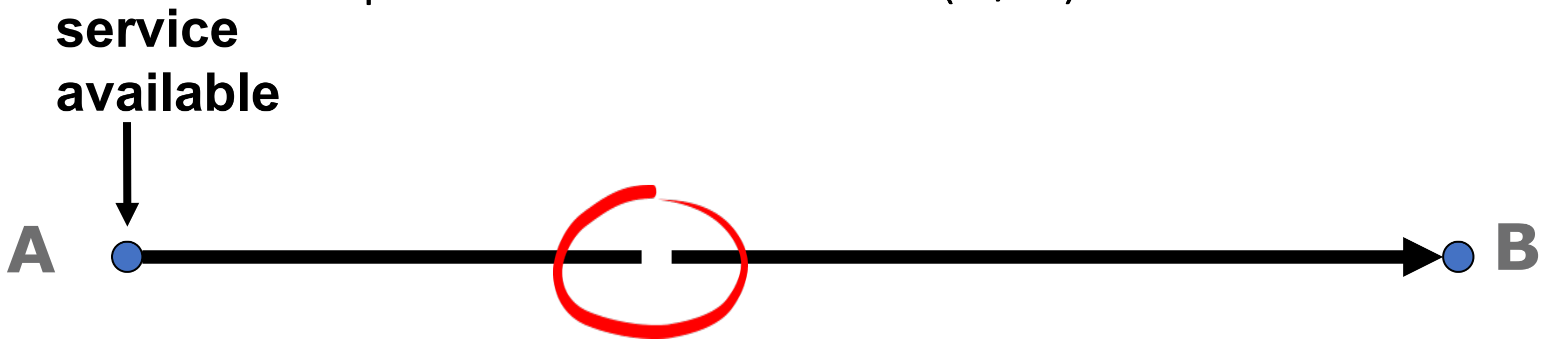
- Providing mission criticality e.g. safety – *integrity*
- Ability to inform users in the event of a failure (position error is unsafe) in sufficient time



Key factors:

1. **Alert limit**
2. **Integrity risk**
3. **Time-to-alert**

Performance in the presence of failure (2/2)



Continuity risk = Pr(interruption of service)

f (true alerts, false alerts, period of operation)

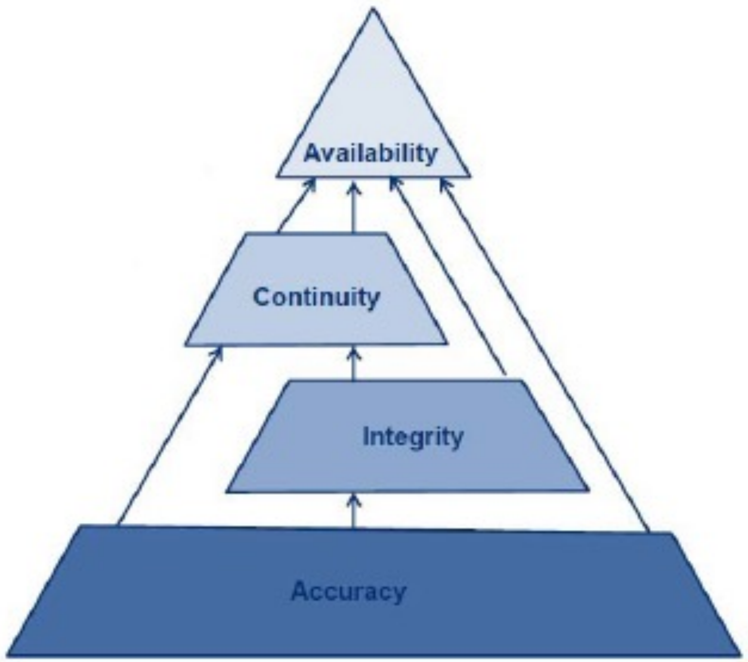
Mission Criticality

confidence/efficiency

- **Measure of reliability**

Performance – Operational economy & standardisation

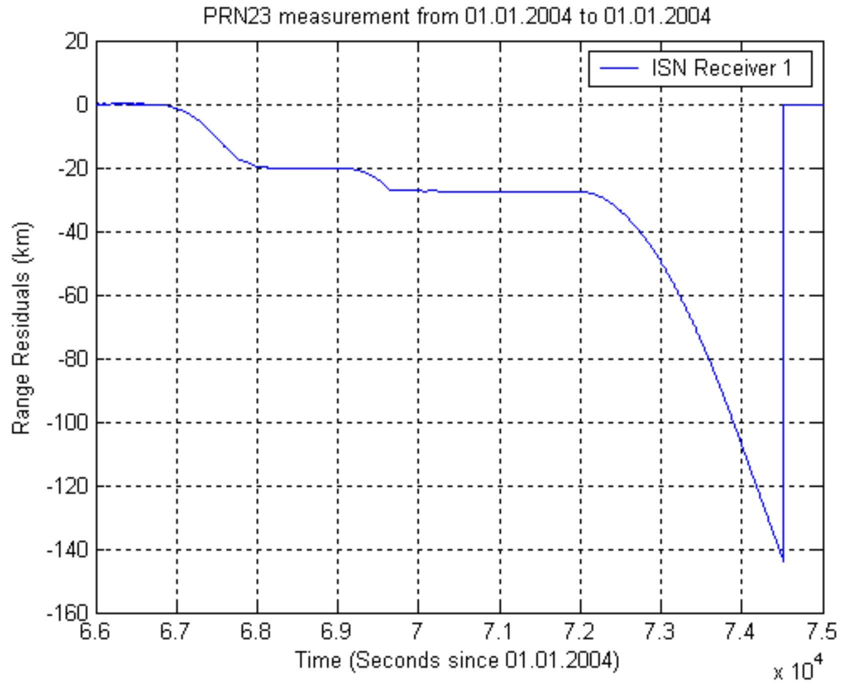
- Providing system access – *availability*
  - accuracy, integrity & continuity requirements satisfied
  - proportion of time of positioning at required levels



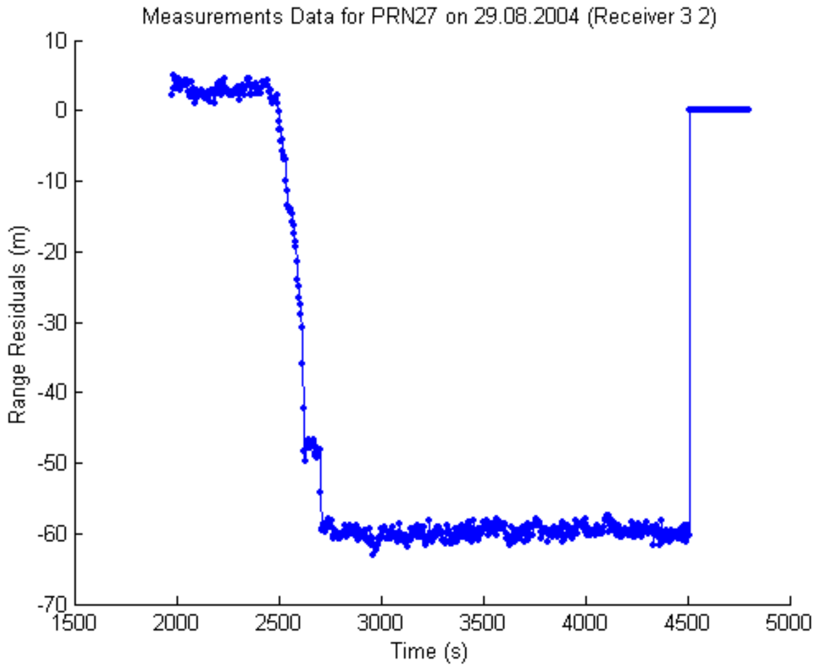
- Standardisation
  - transferability to other domains
  - education of manufactures, service providers & users
  - support to relevant policy and regulatory authorities

Why Monitor Integrity ? – Example of GPS

- Well documented GPS failures
  - SVN23; SVN27 – atomic frequency standard failure (1, 2004; 8,2004)
  - … 2007)
  - …

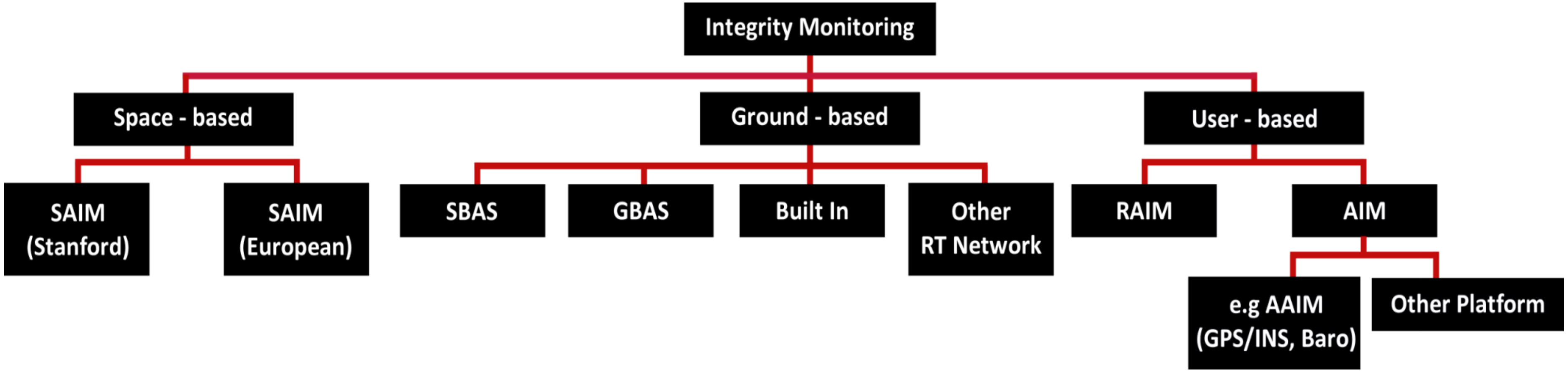


SVN23 failure – 1.1.04



SVN27 failure – 29.8.04

Integrity Monitoring Methods



- GNSS stand-alone integrity insufficient for many mission critical applications
  - e.g. GPS SPS PS integrity risk of 10-5 /hr with a 10-second TTA

- Currently two main approaches
  - system/ground level (GIC/SBAS/GBAS)
  - sensor/user – (R)AIM

Ground / System Level: SBAS/GBAS

- SBAS/GBAS designed for:
  - improved accuracy through differential corrections
  - improved integrity (dedicated infrastructure)
  - improved availability by additional ranging (SBAS)
- Integrity
  - failures detected using reference station location(s) – alerts for 'major' failures
  - quality data sent to users for computation of Protection Level (PL)
  - PL is compared to Alert Limit (AL) to determine compliance

$$\sigma^2 = \sigma^2_{diff(SIS)} + \sigma^2_{iono} + \sigma^2_{RX} + \sigma^2_{tropo}$$

$$VPL = k_V \sqrt{\sum_{sats} s_V^2 \sigma^2}$$

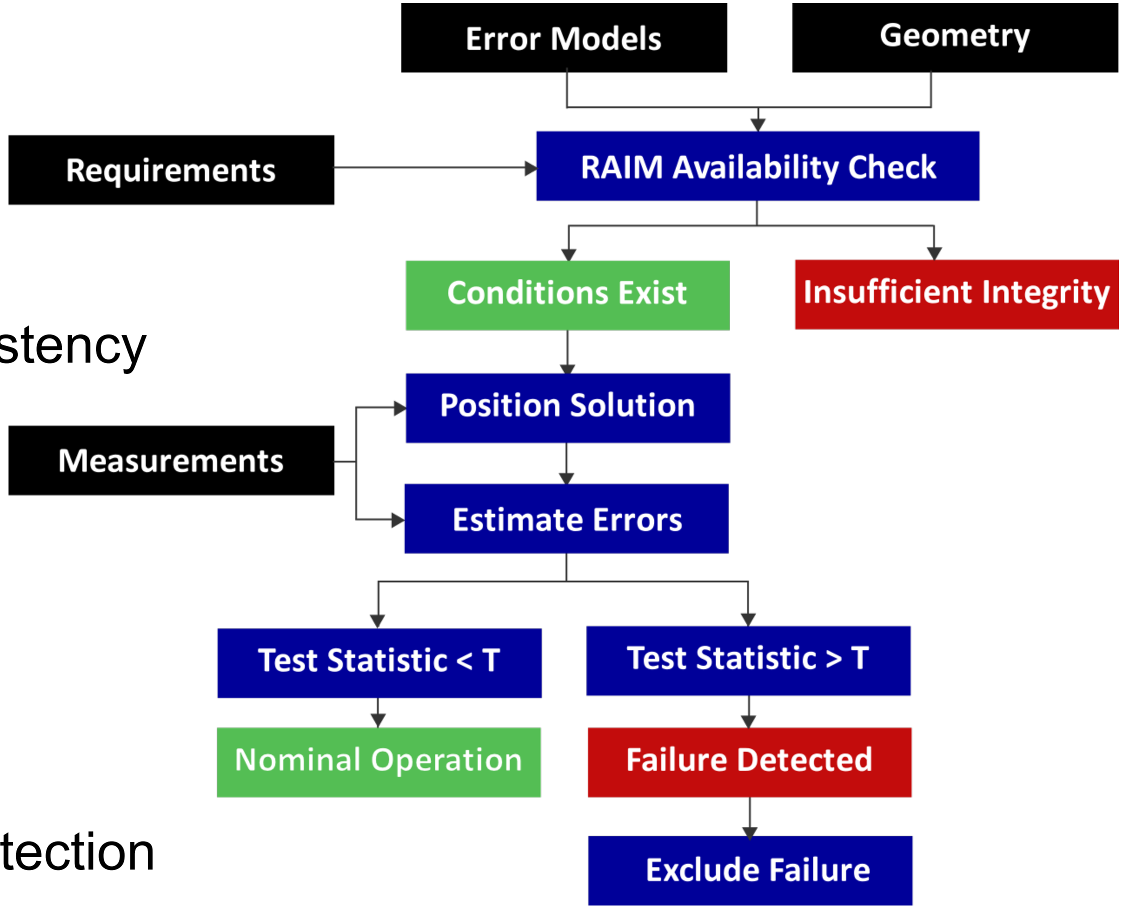
(ICAO SBAS model)

Ground / System Level: SBAS/GBAS Issues

- Network installed, tested, operated and maintained at a cost
- Currently regional (complexities associated with global coverage)
- Additional geostationary satellites
- Increasingly challenging Time-To-Alert (TTA) requirements
- Performance improvements may require a system-wide overhaul
- Localised failures may not be detected by the ground segment
- Gaussian assumption

User Level: RAIM

- Baseline FDE RAIM steps
  - PL computation
  - failure detection
  - failure exclusion
- Detection function
  - measurement consistency
- Exclusion function
  - improves continuity
- Main RAIM strengths
  - autonomy
  - local failure/error detection



User Level: RAIM issues

Issues	Current attempts at resolution
Critical geometry (max slope)	Integration
RAIM availability	Integration, better PL
Multiple failures	Separation (Group/Solution)
Failure models	FMEA
Residual error characterisation	Dist. drivers, EVT / other models
Failure probability	FMEA
Failure rate (small/brief errors)	FMEA
Exclusion	Separation (Group/Solution)
Time-To-Alert	Early detection techniques (e.g. *difference test* for SGEs)

Impact of new signals

- Greater satellite visibility
  - more satellites, more signal power, longer codes
  - pilot signals, fast acquisition
  - higher penetration, better interference protection
- Higher ranging accuracy
  - less multipath, less ionospheric error
  - better tropospheric modelling due to more satellites
  - less orbit and clock errors
- Better integrity monitoring
  - greater satellite visibility, system and signal diversity
  - optimal 'mix' of data?
    - redundant or interoperable solution preferred?
    - consider differences in the spatial and temporal references
    - other potential failure modes?

Ground Based / System Level - Impact of new signals

- Relatively sparse network – multiple frequencies

- Interoperability
  - monitoring of other systems
  - liability of combined solutions for mission critical applications

- Failure database crucial for satellite upgrades

- Multi-constellation environment requires
  - spatial and temporal reference frame offsets?

User based – RAIM – Impact of new signals

Issues	Current attempts at resolution	Impact of New Signals/Systems
Critical satellite geometry	Integration	Major impact
RAIM availability	Integration, better PL	Major impact
Multiple failures	Separation (Group/Solution)	Major but trade/off with failures associated with new satellites
Failure models	FMEA	Major - better signals and error modelling Potential for new failure modes
Residual error characterisation	Dist. drivers, EVT / other models	Change in residuals due to multiple frequencies and new systems
Failure probability	FMEA	More data, changing systems
Failure rate (small/brief errors)	FMEA	Greater focus due to shift in requirements
Exclusion	Separation (Group/Solution)	Better detection for single & multiple failures, but more complexity in the latter
Time To Alert	Early detection techniques (e.g. *difference test* for SGEs)	Higher processing burden depending integrity monitoring technique

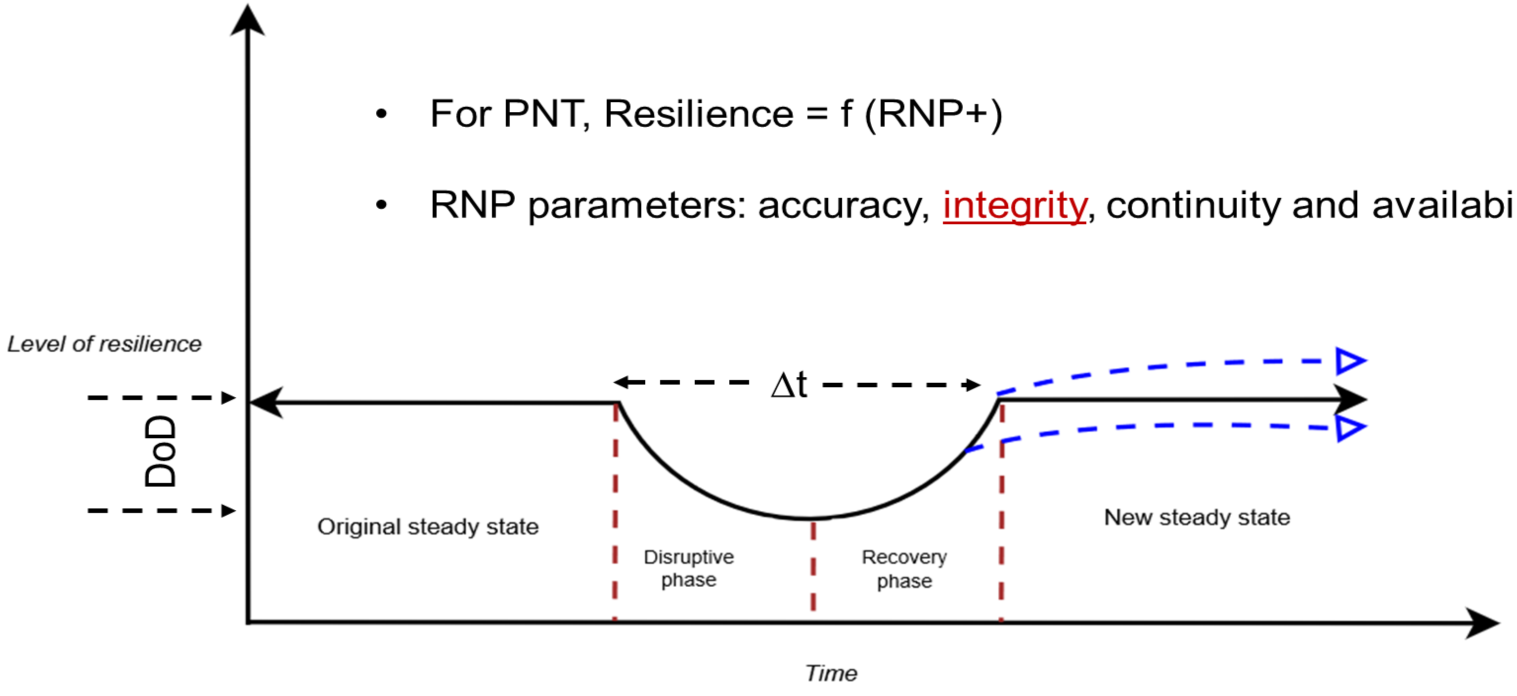
INSPIRe - Overall project description and context

- Overall goal - ensure maritime PNT information is provided to the required level of Integrity:
  - within the UK & its coastal waters, as part of an overall resilient PNT solution
  - 18 months project ESA's Navigation Innovation and Support Programme (NAVISP)

- Builds on MarRINav (Maritime Resilience and Integrity of Navigation - addressed the needs for:
  - The Blackett Report (GoS, 2018) – CNIs dependency on GNSS
  - Trustworthy PNT as sea space gets cluttered (energy production & autonomous systems)
  - Need for requirements for maritime-resilient and high integrity PNT
  - GNSS-cored system-of-systems conceptual architecture & development plan
  - Evolutionary & incremental approach for timely and cost-efficient:
    - ✓ improvements to maritime PNT integrity & resilience

Resilience and Integrity

- **MarRINav defines resilience as ability to anticipate, mitigate and recover from disruption**
- Resilience is a function of:
  - Original Steady State (OSS), Disruptive Phase (DP)
  - Recovery Phase (RP), Depth of disruption (DoD), New Steady State (NSS)
- When Δt (DP time + RP time) = 0 and NSS =/or better than OSS, then system is ROBUST
- For PNT, Resilience = f (RNP+)
- RNP parameters: accuracy, integrity, continuity and availability



INSPIRe's Focus

- **INSPIRe focuses on (facilitated by stakeholder proactive engagement)**
  - User level – (R)AIM – including dual-frequency multi-constellation GNSS
  - Role of SBAS
  - Ground-based systems for system level integrity to support user-level integrity
  - Value of crowd-sourced, user-derived integrity data
  - Flexible to design for development of system-of-systems for resilient PNT
  - Identification of value-add beyond the maritime sector