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GPS/Galileo Performance Assessment for Aircraft Navigation and Approach

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Air Systems Division

Contents

- Air Traffic Evolution
- Role of Satellite Navigation in CNS/ATM
- Galileo
- SBAS/EGNOS
- GBAS
- Benefits of GPS/Galileo Interoperability
- Conclusions

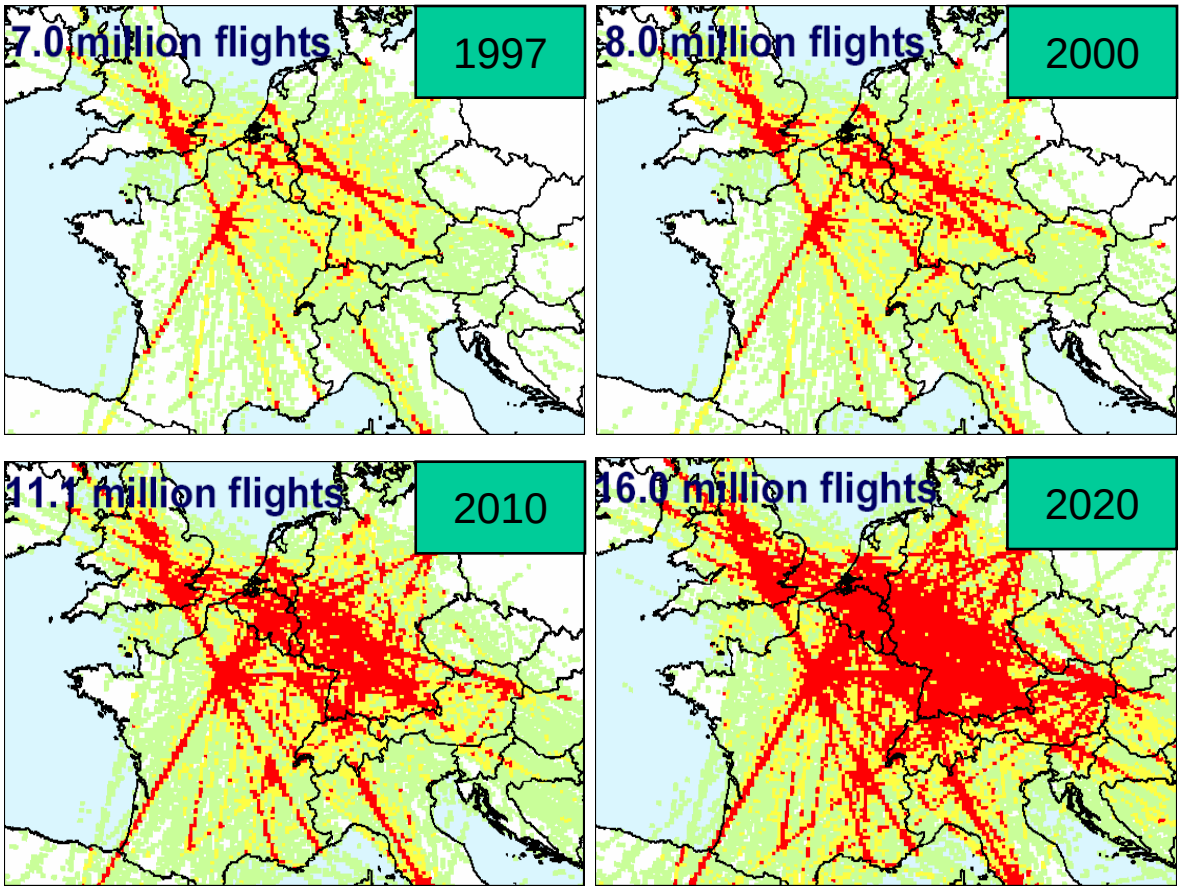
Air Traffic Evolution

Tremendous Challenges for Aviation

- Air Traffic Growth
- Safety and security improvements
- Economic pressure
- Environmental compatibility

Necessary Changes to Air Transport System

- Roles and Responsibilities of various Stakeholders
- Operational Concept
- Standards and Legal Regulations
- CNS/ATM Infrastructure



Source: Eurocontrol

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Added Value of Satellite Navigation

Advantages

- Time and Fuel Savings by direct routing
- Homogenous and Continuous Global Service
- Low altitude continuous coverage (VOR/DME limited to line of sight)
- All Weather Landing Capability
- Landing Guidance at Regional Airports without ILS or MLS
- Interoperable, Global Coverage, High Precision
- Single Navigation System for All Phases of Flight (“Gate - to- Gate”)
- Noise Abatement, Parallel and Curved Approaches will become possible

Role of Navigation Satellites in CNS/ATM

- Current Use: GPS for En-route to Non-Precision Approach Navigation
- Starting-up: Satellite Based Augmentation Systems (US WAAS, Japanese MSAS and EGNOS) for Approach with Vertical Guidance
- Near Future: Galileo will further improve Satellite Navigation Performance

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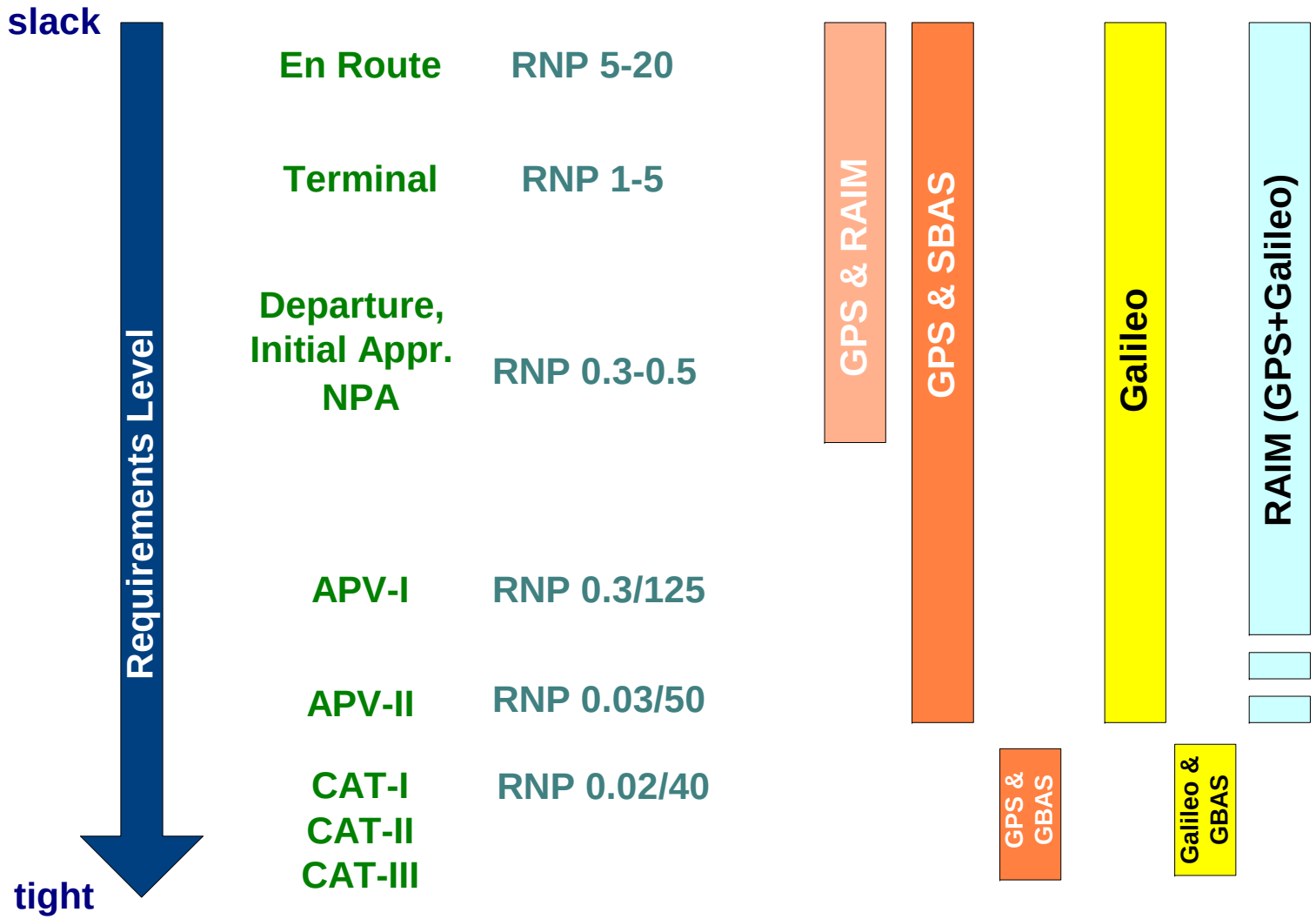
Air Navigation Requirements and GNSS Systems



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Galileo Overview

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The European answer to Global Satellite Navigation

GALILEO : European led Global Satellite Navigation System

- ✓ **Tailored to address User needs**
- ✓ **Worldwide coverage**
- ✓ **Under civilian control**
- ✓ **Interoperable and complementary with GPS and other systems**

Navigation Services

- ✓ **Open Service**
- ✓ **Commercial Service**
- ✓ **Safety of Life Service**
- ✓ **Public Regulated Service**
- ✓ **Search and rescue service**

Requirements on Navigation Systems

Galileo Performance Requirements for the Safety of Life Service (Lvl. A)

Source: Galileo Mission Requirements Iss 6

Accuracy (95%)	**horizontal: 4m**
	vertical: 8m
Availability	**99.8 % of service life time**
Continuity Risk	**< 8×10^{-6} / 15s**
Integrity	**HAL: 40m**
	VAL: 20m
	TTA: 6 seconds
	Integrity Risk: < 2.0×10^{-7} / 150s

ICAO APV-II Requirements

Accuracy (95%)	**horizontal: 16 m**
	vertical: 8 m
Availability	**99.0% to 99.999%**
Continuity Risk	**< 8×10^{-6} / 15s**
Integrity	**HAL: 40m**
	VAL: 20m
	TTA: 6 seconds
	Integrity Risk: < 2×10^{-7} / approach

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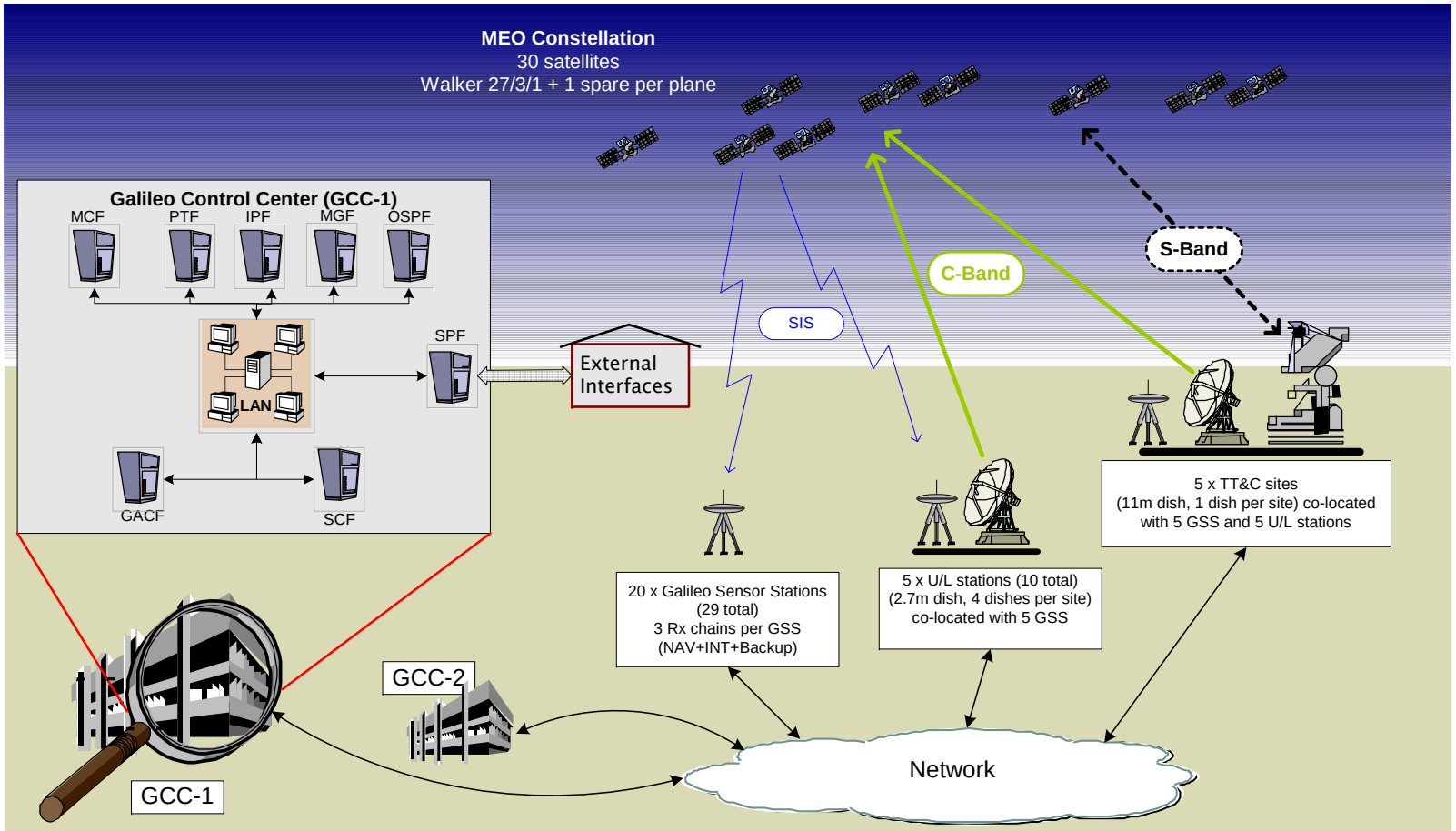
Galileo Architecture



Galileo Sensor Stations (GSS)

Mission Control Facility (MCF)

Mission Support Facility (MSF)

Ground Assets Control Facility (GACF)

Satellite Control Facility (SCF)

Orbit & Synchronisation Processing Facility (OSPF)

Integrity Processing Facility (IPF)

Message Generation Facility (MGF)

Precision Time Facility (PTF)

Service Products Facility (SPF)

Up-link Station (ULS)

Uplink Scheduling Facility (USF)

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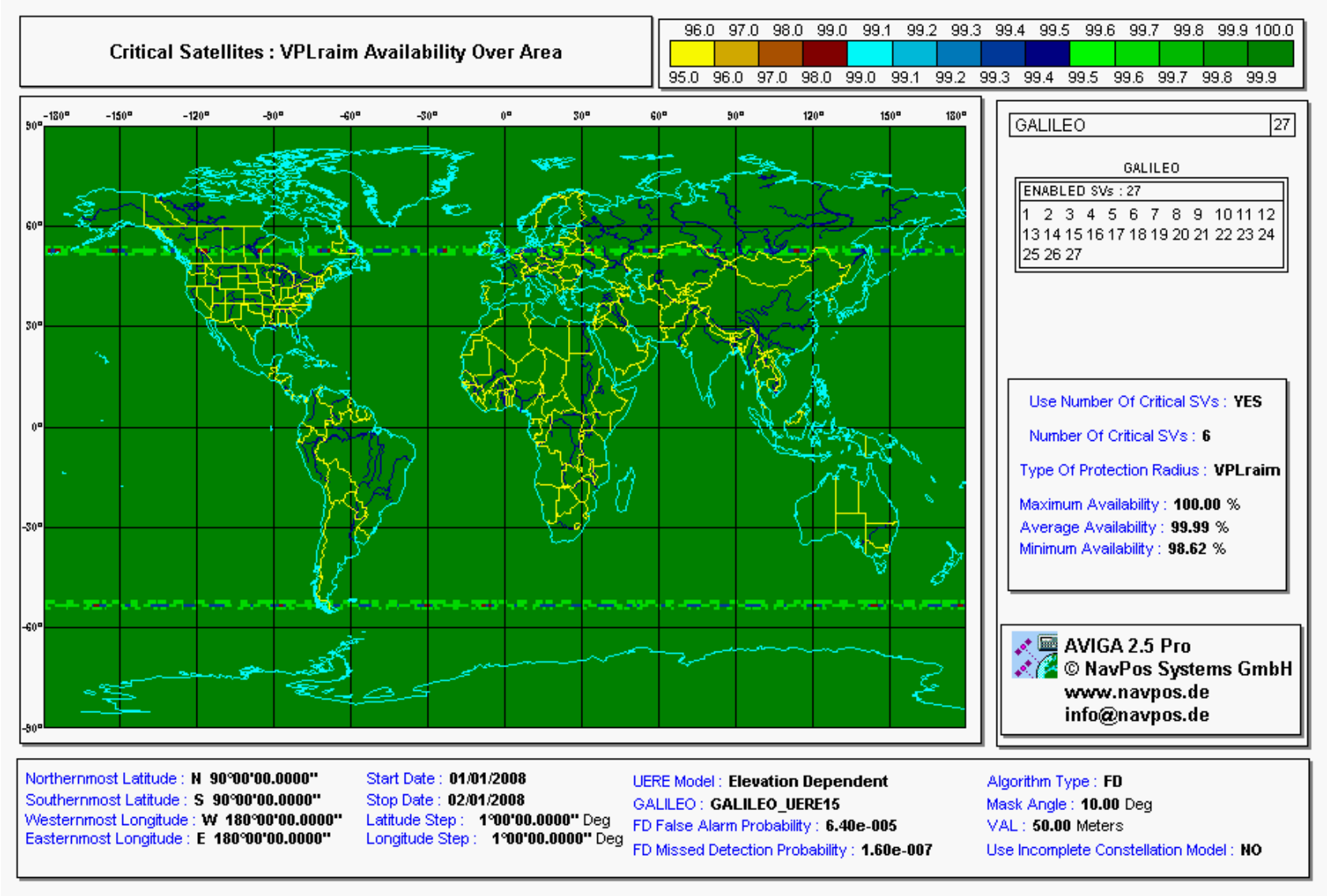
Comparison of GNSS Integrity Concepts

- Integrity Monitoring at User Level
  - RAIM (Receiver Autonomous Integrity Monitoring)
  - AAIM (Aircraft Autonomous Integrity Monitoring)
- Integrity Monitoring at System Level
  - The Galileo Global Integrity Concept
  - Regional Augmentation (SBAS)
  - Local Augmentation (GBAS)

Galileo APV-I Vertical RAIM Availability



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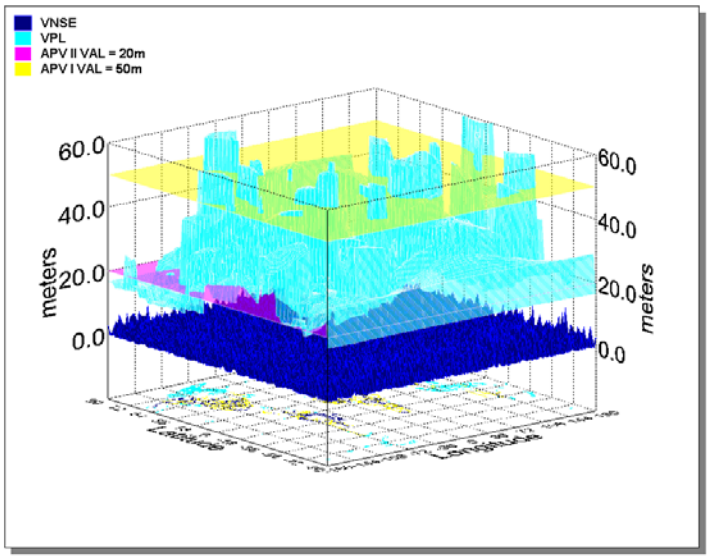
GPS & Galileo RAIM Protection Level



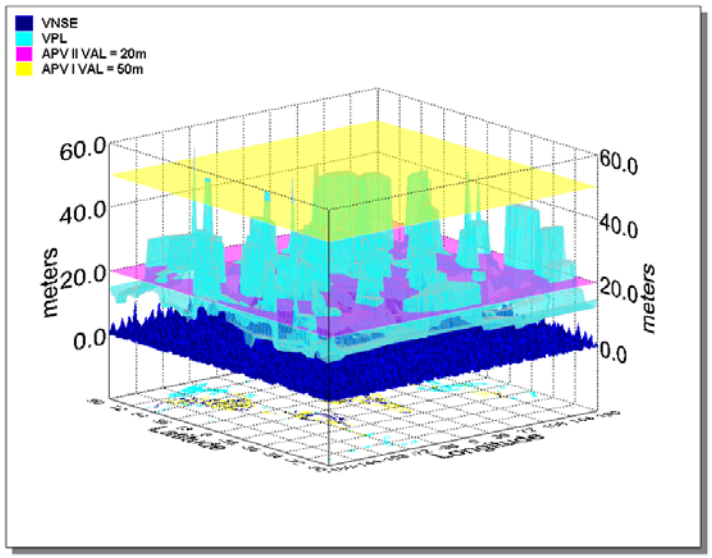
GPS

ENABLED SVs : 28

01 02 03 04 05 06 07 08 09 10 11
13 14 15 17 18 20 21 22 23 24 25
26 27 28 29 30 31

UERE Model : **UERE**
Mask Angle : **5.00**
Current Time : **02:20:00.00**
Type Of Protection Radius : **VPL**
FD False Alarm Rate : **6.67e-005**
FD Miss Rate : **1.00e-003**
Northernmost Latitude : **N 90°00'00.0000**
Southernmost Latitude : **S 90°00'00.0000**
Latitude Step : **2°00'00.0000"** Degrees
Westernmost Longitude : **W 180°00'00.0**
Easternmost Longitude : **E 180°00'00.00**
Longitude Step : **2°00'00.0000"** Degree

AVIGA 2.3 Pro
© NavPos Systems



GALILEO

ENABLED SVs : 30

1 2 3 4 5 6 7 8 9 10 11
12 13 14 15 16 17 18 19 20 21 22
23 24 25 26 27 28 29 30

GALILEO : **SAS_INTEGRITY_E1E5**
Mask Angle : **5.00**
Current Time : **03:15:00.00**
Type Of Protection Radius : **VPL**
FD False Alarm Rate : **6.67e-005**
FD Miss Rate : **1.00e-003**
Northernmost Latitude : **N 90°00'00.0000**
Southernmost Latitude : **S 90°00'00.0000**
Latitude Step : **2°00'00.0000"** Degrees
Westernmost Longitude : **W 180°00'00.0**
Easternmost Longitude : **E 180°00'00.00**
Longitude Step : **2°00'00.0000"** Degree

AVIGA 2.3 Pro
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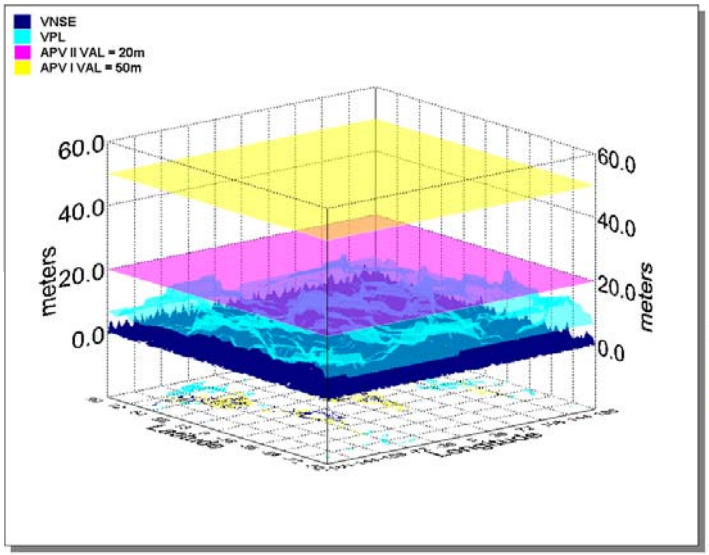

GALILEO

ENABLED SVs : 30

1 2 3 4 5 6 7 8 9 10 11
12 13 14 15 16 17 18 19 20 21 22
23 24 25 26 27 28 29 30

GPS

ENABLED SVs : 28

01 02 03 04 05 06 07 08 09 10 11
13 14 15 17 18 20 21 22 23 24 25
26 27 28 29 30 31

UERE Model : **UERE**
Mask Angle : **5.00**
Current Time : **08:30:00.00**
Type Of Protection Radius : **VPL**
FD False Alarm Rate : **6.67e-005**
FD Miss Rate : **1.00e-003**

AVIGA 2.3 Pro
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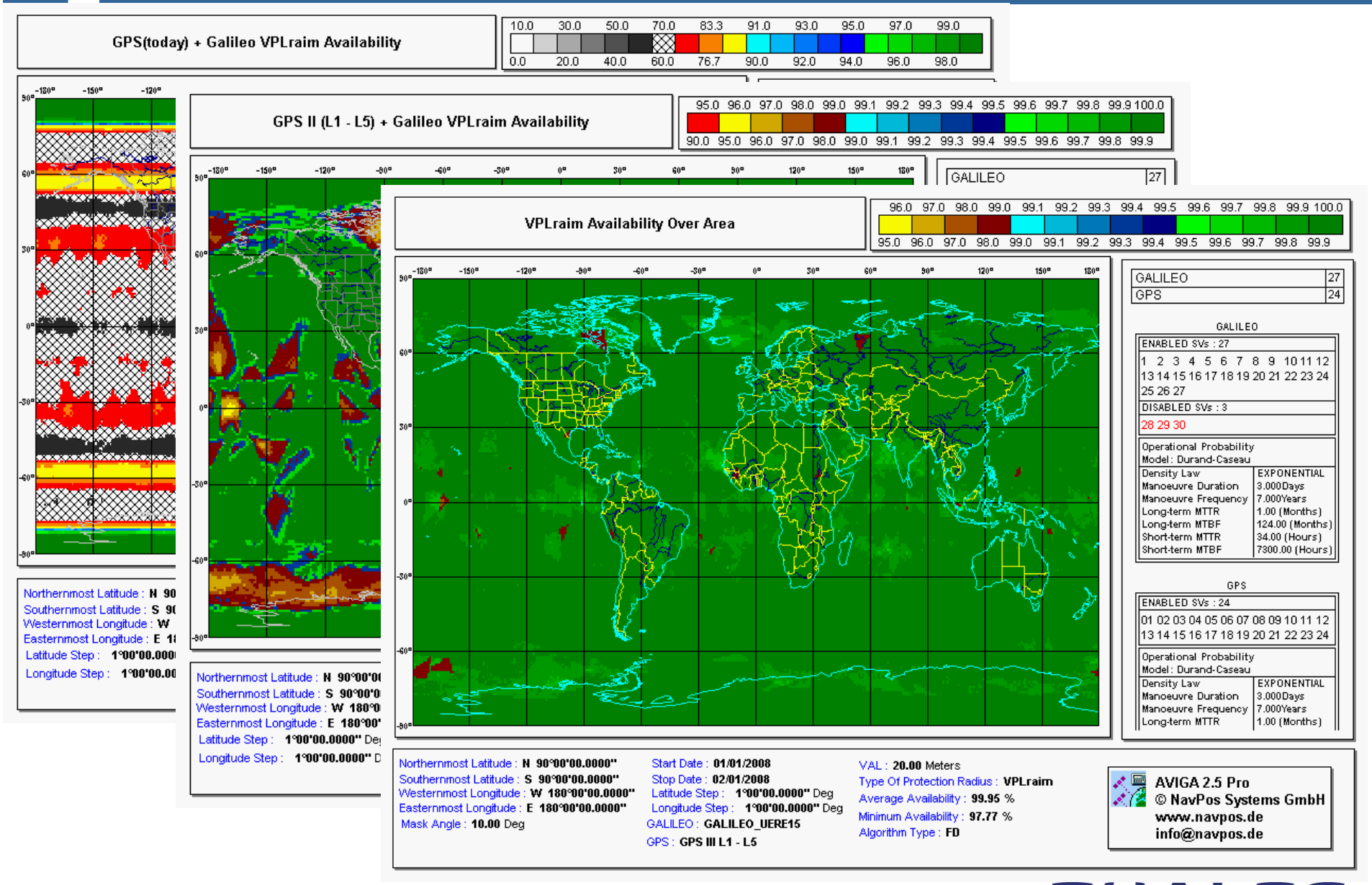
GPS+Galileo APV-II Vertical RAIM Availability



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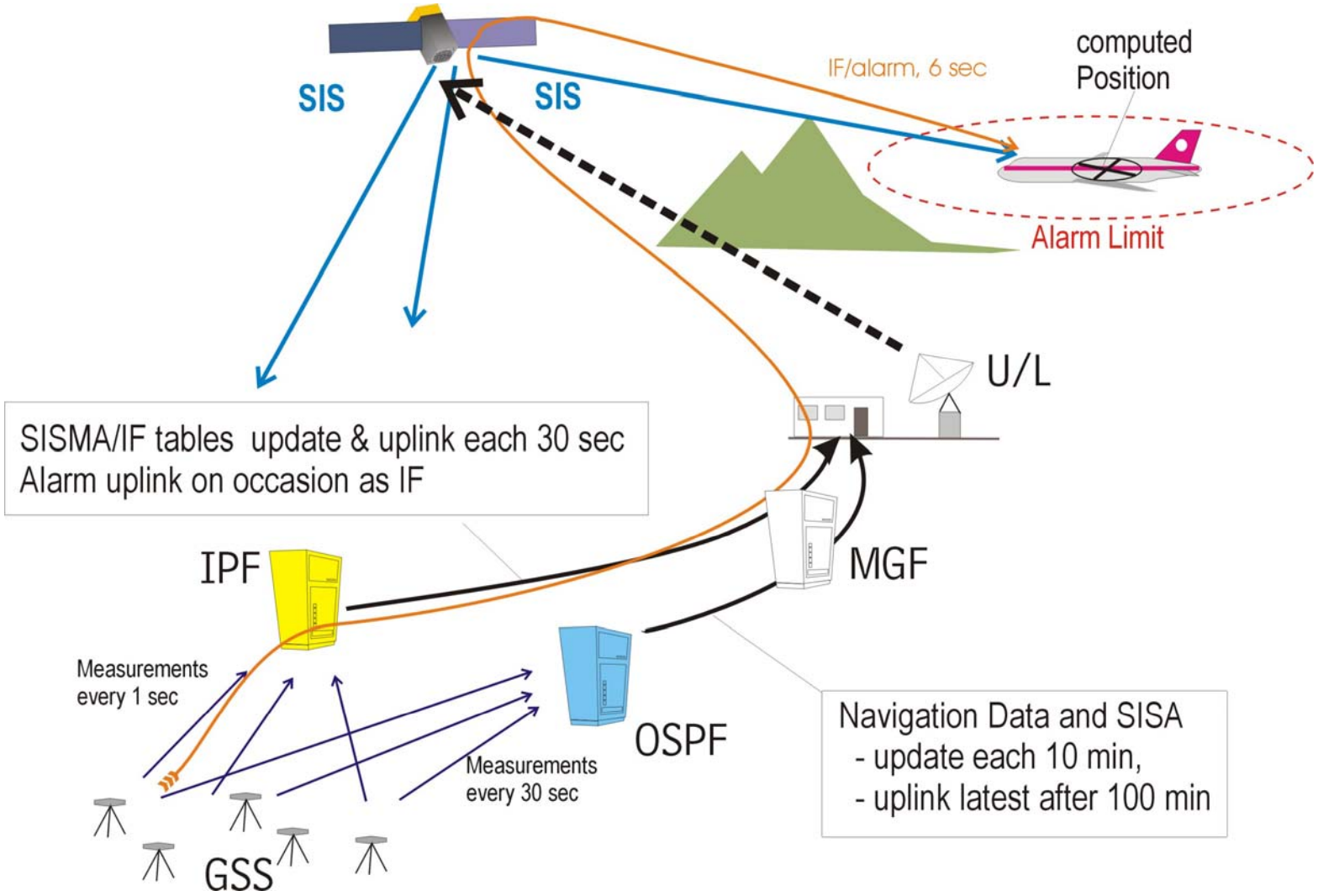
Galileo Integrity Concept



GSS = Galileo Sensor Station U/L = Uplink Station	IPF = Integrity Processing Facility OSPF = Orbitography and Time Synchronisation Processing Facility

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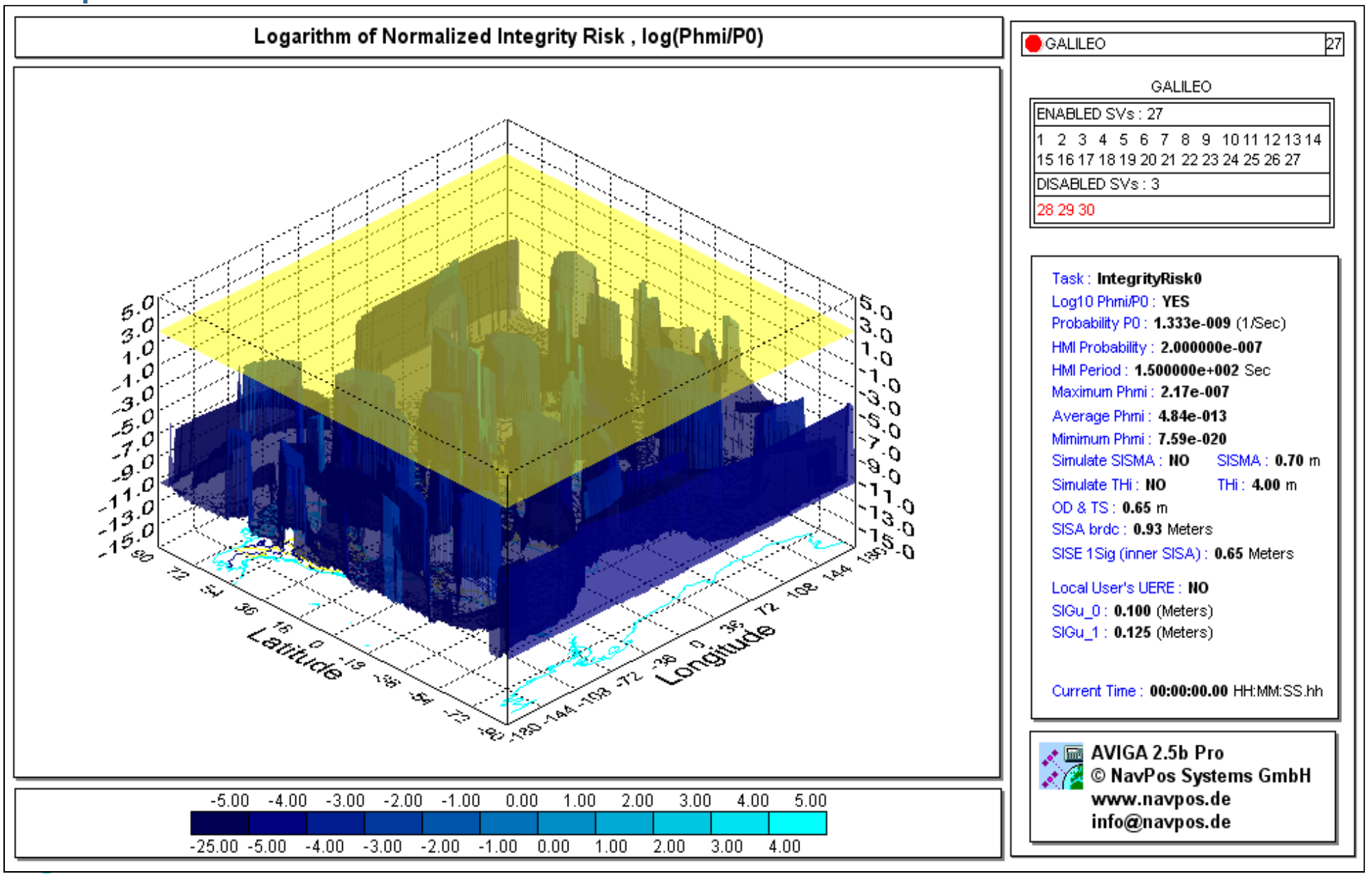
Logarithm of Normalised Galileo Integrity Risk



GALILEO 27

GALILEO

ENABLED SVs : 27

1 2 3 4 5 6 7 8 9 10 11 12 13 14
15 16 17 18 19 20 21 22 23 24 25 26 27

DISABLED SVs : 3

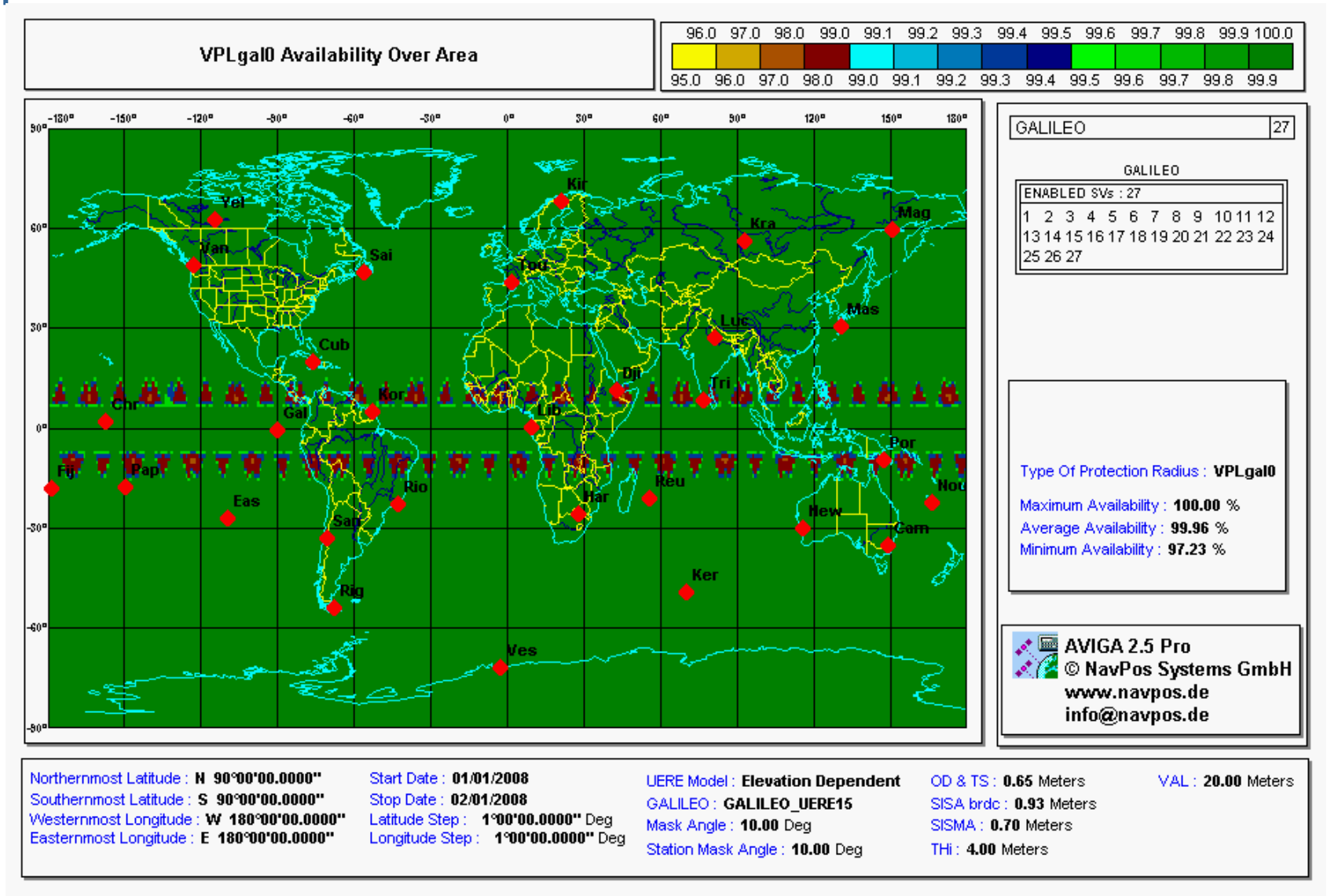
28 29 30

Task : **IntegrityRisk0**
Log10 Phmi/P0 : **YES**
Probability P0 : **1.333e-009** (1/Sec)
HMI Probability : **2.000000e-007**
HMI Period : **1.500000e+002** Sec
Maximum Phmi : **2.17e-007**
Average Phmi : **4.84e-013**
Mimimum Phmi : **7.59e-020**
Simulate SISMA : **NO** SISMA : **0.70** m
Simulate THi : **NO** THi : **4.00** m
OD & TS : **0.65** m
SISA brdc : **0.93** Meters
SISE 1Sig (inner SISA) : **0.65** Meters

Local User's UERE : **NO**
SIGu_0 : **0.100** (Meters)
SIGu_1 : **0.125** (Meters)

Current Time : **00:00:00.00** HH:MM:SS.hh

Galileo APV II VPLGAL Availability



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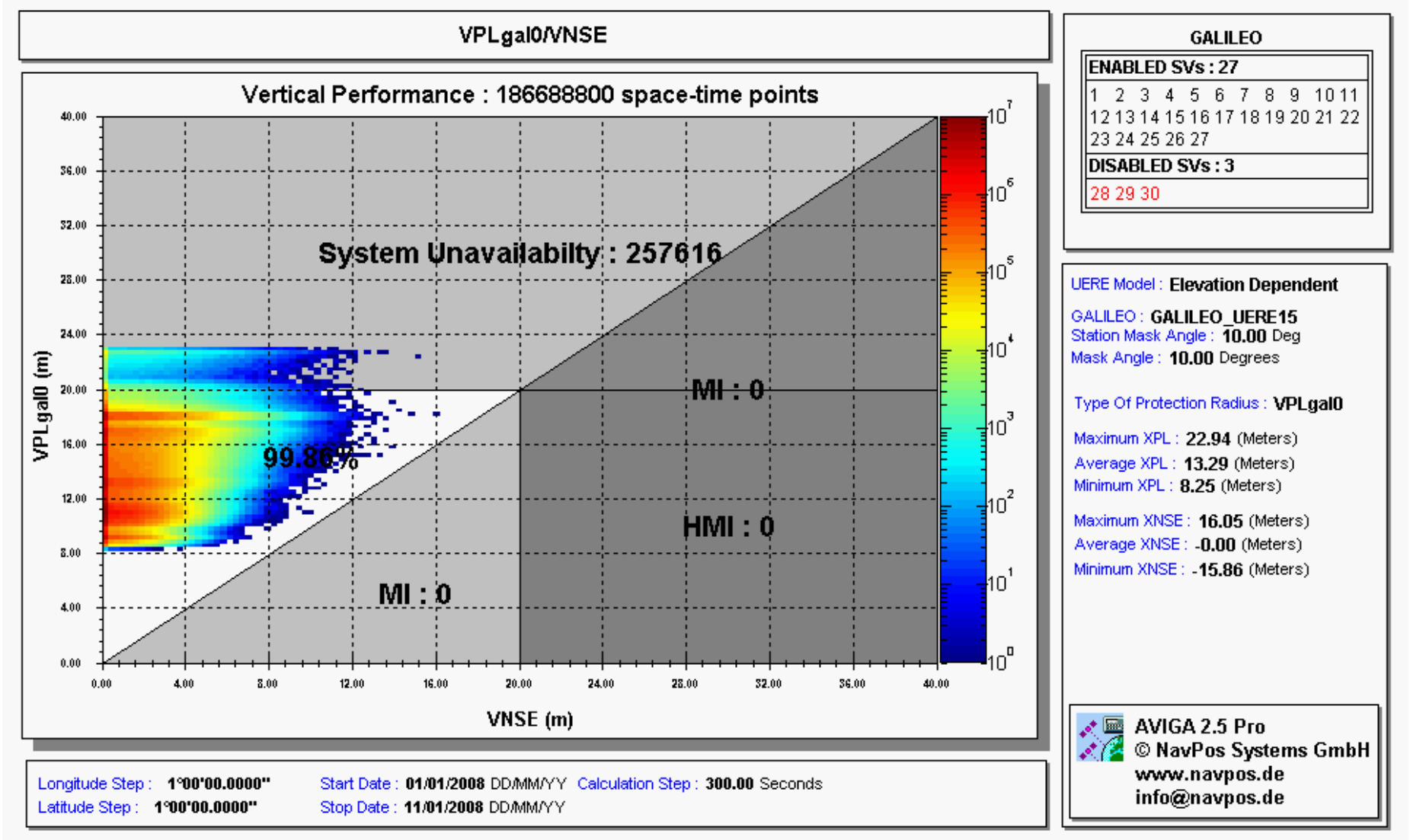
Galileo VPL/VNSE Availability



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EGNOS Overview

EGNOS SYSTEM

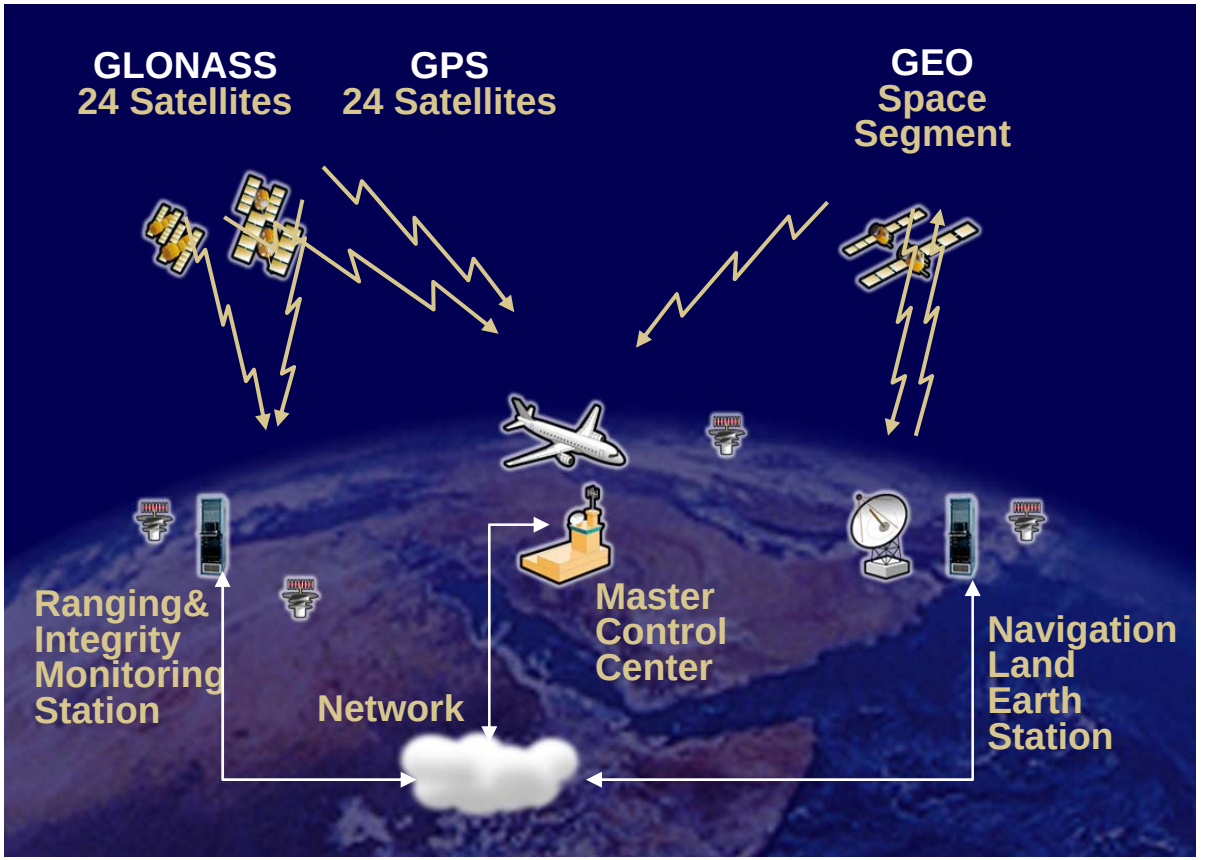
(European Geostationary Navigation Overlay Service)

Purpose :

- Signal Integrity
- Accuracy Augmentation

Status :

- Operational Readiness: passed July 2005
- Signal under Test available
- Non-safety critical ops. in 2006
- Safety critical ops. in 2007



Regional Augmentation System of GPS/GLONASS Constellations

EGNOS is the 1st Step for Galileo

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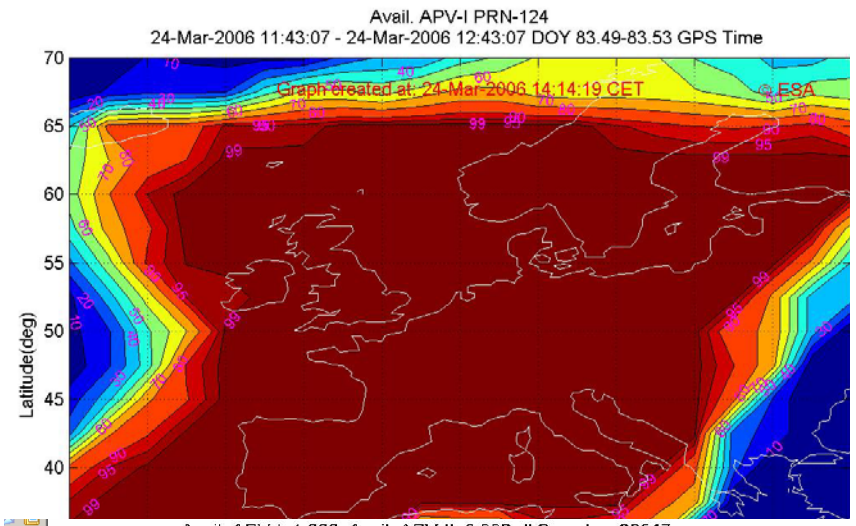
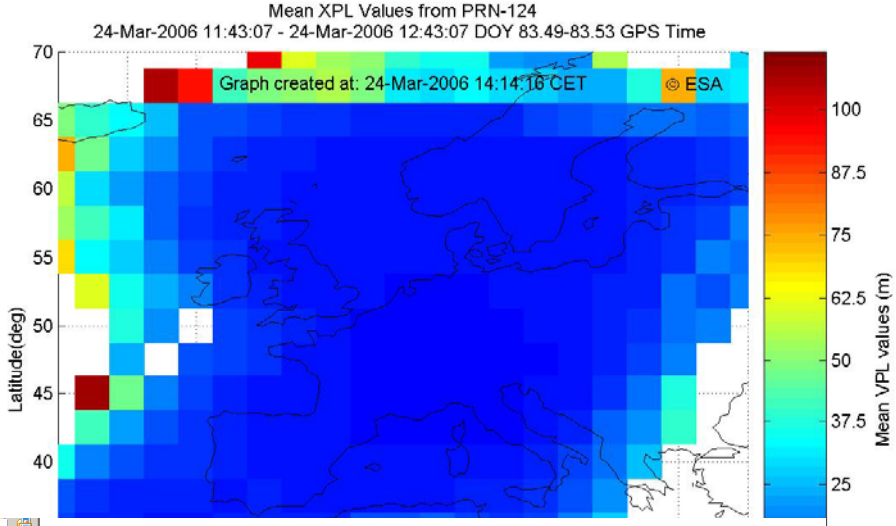
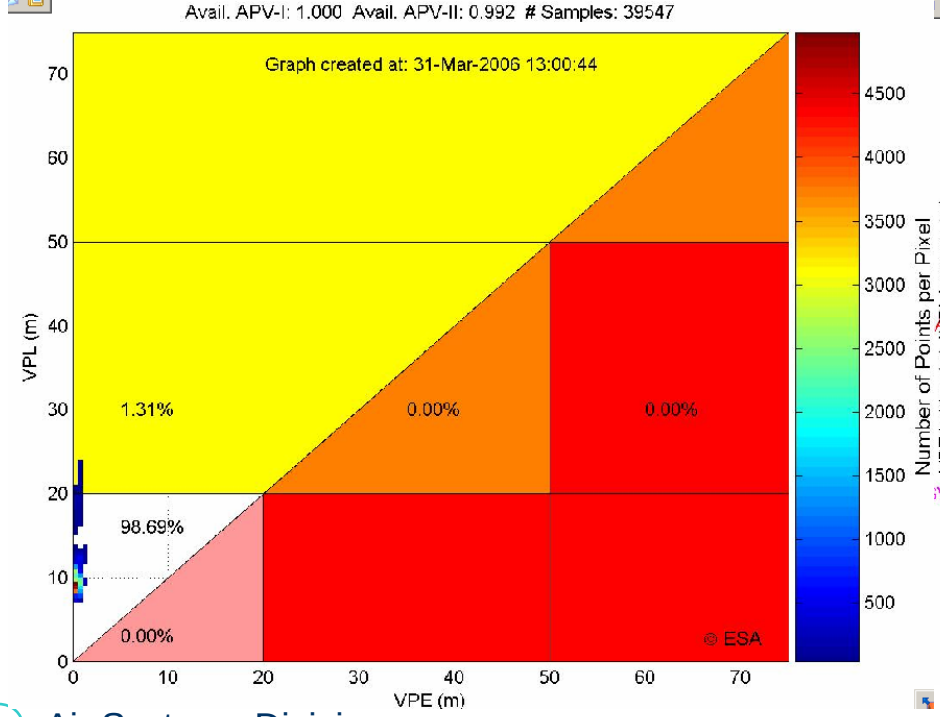
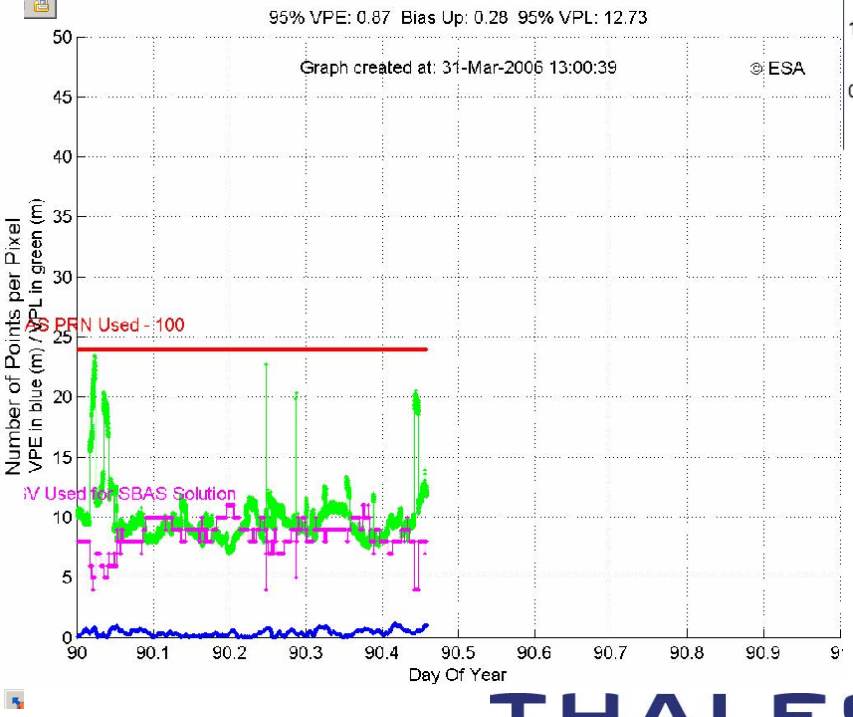
Actual EGNOS Performance









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Ground Based Augmentation Systems (GBAS)

GBAS Architecture

Differential GNSS Reference Station

- Multiple Ground Antenna and Receiver Architecture
- Integrated Integrity Monitoring
- Redundant Processing Concept
- VHF Data Broadcast (VDB) Transmitter(s)
- Monitor and Control and Service Provider Interfaces

GBAS broadcasts digital data on the VHF link

- MT1: Range Corrections and Integrity Parameters
- MT2: Static GBAS data
- MT4: Final Approach Segment data

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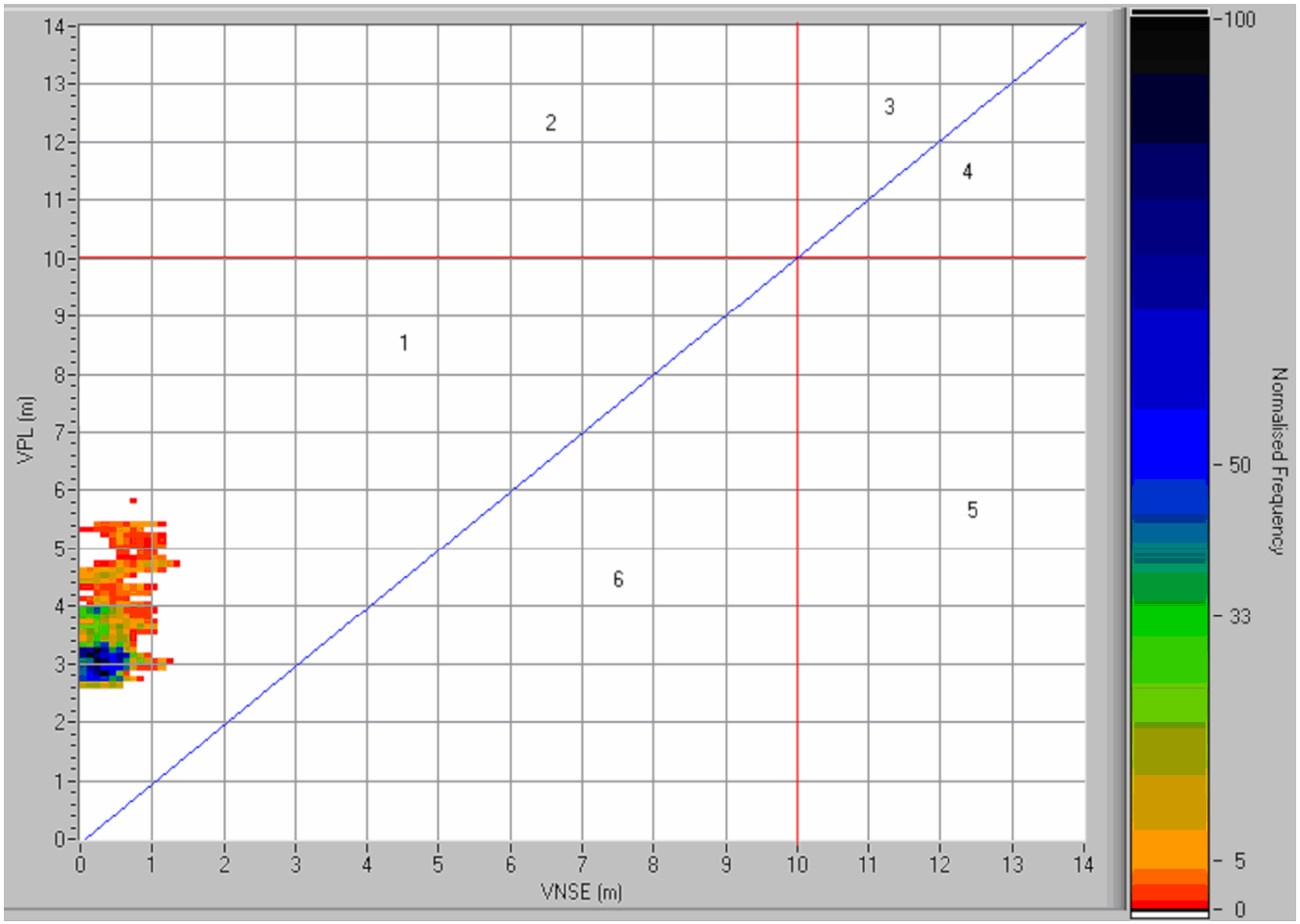
GBAS Performance provides position precision in the order of 1 m (Example Toulouse Installation)



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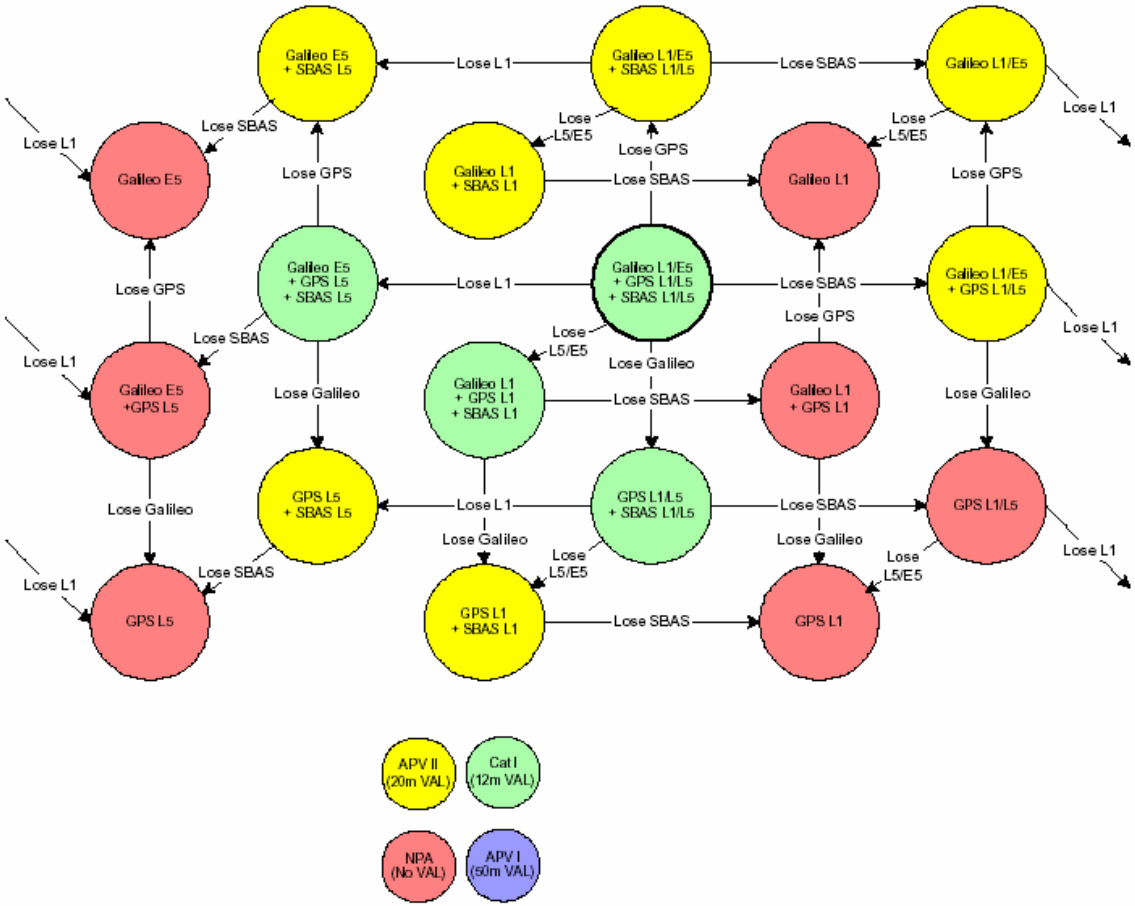
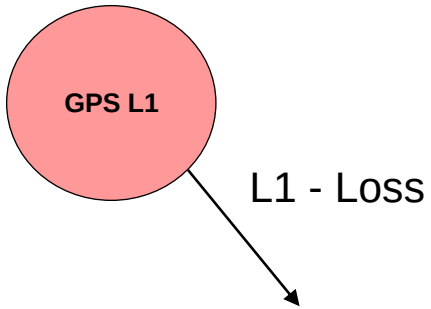
Benefits of GPS & Galileo Interoperability

The Vision:
Robust Satellite Navigation using EGNOS/GPS and Galileo



For Comparison: Situation of today



Source: ICAO GNSS-Panel No. 4, April 2003, WP17

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Benefits of Combined GPS/EGNOS/Galileo Use (1)

- Performance Benefits of Interoperability :
  - Improved signal availability and accuracy
  - Reduced integrity risk
  - SBAS/GPS + Galileo expected to achieve CAT-I
  - GBAS using GPS + Galileo expected to achieve CAT-II/III
- Safety and Robustness Benefits :
  - Navigation Performance comparable to CAT-I potentially achievable
    - at all flight levels and for all phases of flight
    - at unequipped ground locations, regions with no infrastructure
    - for vertical guided approaches to all runway ends
    - SAR operations supported by improved accuracy & integrity
    - Providing enhanced situation awareness, e.g. with ADS
  - Operational redundancy due to Combination of various GPS and Galileo Signals : GAL(L1/E5) + GPS(L1/E5) + SBAS (L1/L5)

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Benefits of Combined GPS/EGNOS/Galileo Use (2)

- Benefits to Air Navigation Service Providers and Airports :
  - Same Performance Levels at Lower Investment Costs
  - Virtually every runway in US and EUR could benefit from all weather CAT-I precision approach capability
  - Improved Use of Airspace and Capacity in Terminal Area
  - Significant Service Extension at Regional Airports
  - Many follow-on enhancements enabled: trajectory planning, gate-to-gate operations, seamless air navigation
  - New Operational Procedures could be established, including
    - Enabling Closely Spaced Parallel Approaches
    - Converging Approaches in Marginal Meteo Conditions
    - Curved Approaches (P-RNAV)
    - Guided missed approaches
    - etc.

Benefits of Combined GPS/EGNOS/Galileo Use (3)

- Benefits to Airlines and Passengers :
  - Reduction of Air Traffic Congestion
  - Reduction of Delay Times
  - Enabler for Substantial Cost Benefits for Airlines and Passengers
  - Infrastructure Cost Reduction in Terms of Equipment
  - Airlines could Operate more frequently from Regional Airports
  - Enhanced Redundancy and Safety of future on board Navigation Equipment using multiple Navigation Sources (e.g. GPS, Galileo, INS, etc.)

Technical Conclusions

RAIM

- RAIM is expected to achieve APV I with Galileo worldwide
- APV II is not expected to be achievable with Galileo RAIM alone
- APV II eventually achievable with GPS+Galileo, further analysis needed

SBAS

- EGNOS Regional Integrity En-Route to APV II achievable over service region (available in 2007)
- Expected: CAT I navigation performance could be reached in conjunction with a combined augmented SBAS/GPS/GALILEO Constellation

Galileo

- Galileo Global Integrity will serve En-route to APV II navigation

GBAS

- GBAS CAT I achievable using GPS or Galileo
- GBAS CAT II/ III achievable using combined GPS and Galileo

Programmatic Conclusion

- **Satellite Navigation has considerable potential to provide needed Navigation Performance in an Integrated CNS/ATM Concept**
- **Having two Redundant Satellite Navigation Systems in place enhances Navigation Safety**
- **Combination of GPS&Galileo offers Advanced Performance and Service Levels**
- **GPS/Galileo Interoperability is Key to an Integrated CNS/ATM Concept**