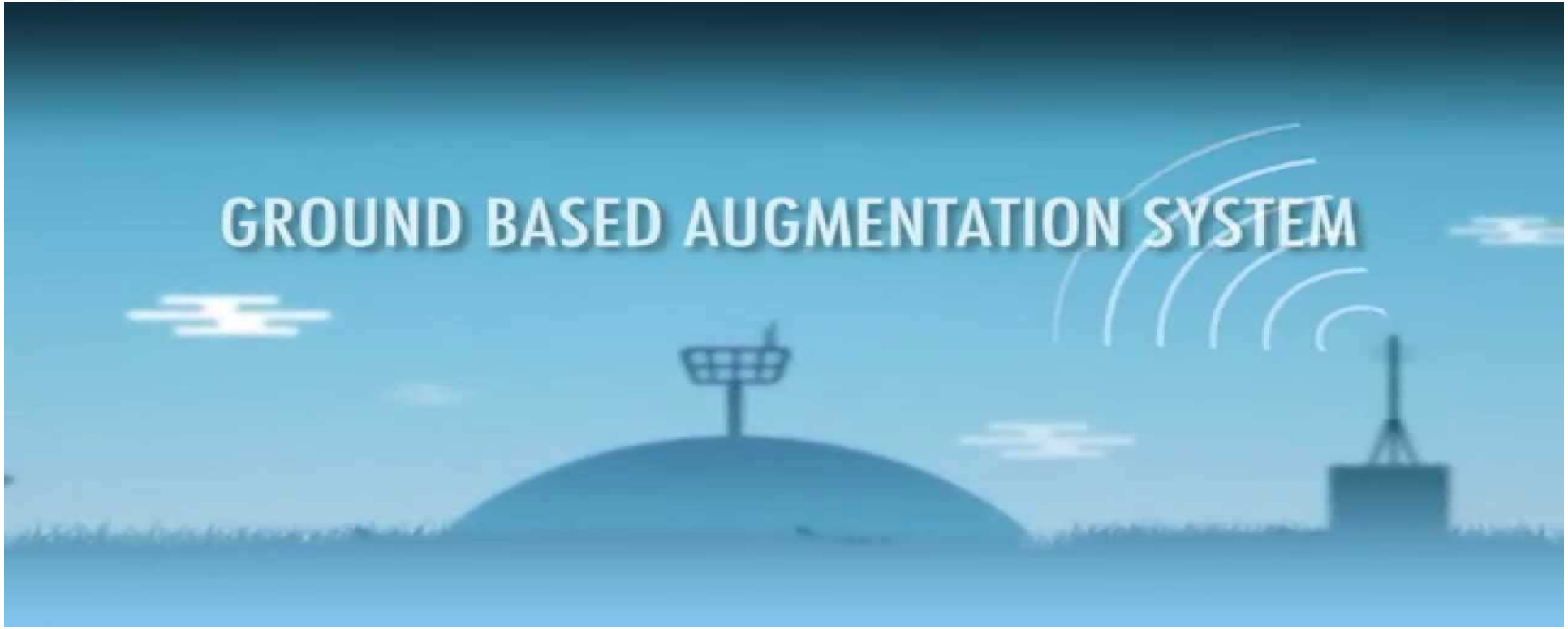

IMEA-GA

Impact of user **M**ultipath **E**rror on **A**vailability of Integrity in **G**BAS **A**pplications

Vienna – UNOOSA

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- Working Packages
  - WP1: GBAS Parameters Assumptions
  - WP2: Simulation Planning/ Performing
  - WP3: Results Analysis
- Conclusions and Findings

Motivation and Targets

1. A previous study indicated that multipath, especially user multipath, is a major error source in achieving CAT II/III requirements with Galileo GBAS as well as with GPS GBAS. The previous study gave only some indications on the impact of user multipath.

2. Systematic investigation by a methodical variation of parameters is needed. Investigation of the reasons and mitigation methods is needed as well.

3. The Purpose of this paper is titled as "Impact of Multipath Error on Availability of integrity in GBAS Application " and abbreviated as "IMEA-GA" study.

5. The project was sponsered by THALES/Germany and defended by ENAC/France.

4. Our Target is Trying to Answer The following Question:

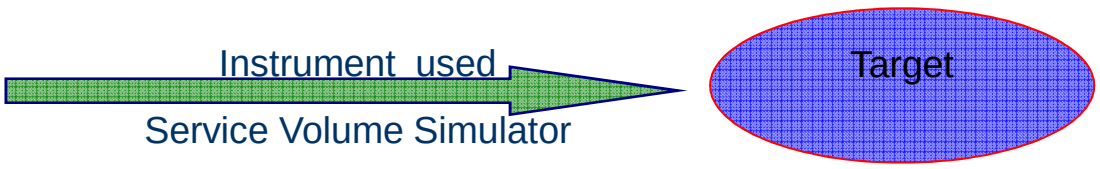
- **Which Level of Multipath Error Mitigation Is needed to Meet the Aeronautical Requirements for CAT II/III?**

Background:

1.ENAC Courses

2.THALES Documents

3.Standards(RTCA,ED)



Working Packages

WP1: GBAS Parametrs Assumptions

WP2: Simulations Planning/Performing

WP3: Results Analysis

WP1:GNSS Local Element:Performance Indicators

GNSS Constellation
GPS 24/GPS 29
Galileo 27

Space → Ground

Space → Airborne

Standard	Future
GAD , SF	GAD , DF
A, B, C	A, B, C

Standard	Future
AAD , SF	AAD , DF
A , B	A , B

Aircraft(User)

Ground → Airborne

VDB

Standard	Future
AMD	AMD
A , B (A / 2)	A / 4 , (A / 10)

Ground Reference Station (GS)

Ground ↔ ATC

ATC

GAD:Ground Accuracy Designator

AAD:Airborne Accuracy Designator

AMD:Airborne Multipath Designator

WP1: GNSS Local Element :Service Level

Performance Requirements	GBAS Service Level	Accuracy		Integrity				Continuty
		Lateral NSE 95%	Vertical NSE 95%	Integrity Probability	Time to Alert	Lateral Alert Limit	Vertical Alert Limit	Continuty Probability
APVI	A	16.0 m (52 ft)	20 m (66 ft)	$1\text{-}2 \times 10^{-7}$ In any 150 s	10 s	40 m (130 ft)	50 m (160 ft)	$1\text{-}8 \times 10^{-6}$ In any 15 s
APV II	B	16.0 m (52 ft)	8.0 m (26 ft)	$1\text{-}2 \times 10^{-7}$ In any 150 s	6 s	40 m (130 ft)	20 m (66 ft)	$1\text{-}8 \times 10^{-6}$ In any 15 s
CAT I	C	16.0 m (52 ft)	4.0 m (13 ft)	$1\text{-}2 \times 10^{-7}$ In any 150 s	6 s	40 m (130 ft)	10 m (33 ft)	$1\text{-}8 \times 10^{-6}$ In any 15 s
CAT II/IIIB	D	5.0 m (16 ft)	2.9 m (10 ft)	$1\text{-}1 \times 10^{-9}$ In any 15 s vert, 30 s lat	2 s	17 m (56 ft)	10m(USA) 5/2.5m EU	$1\text{-}8 \times 10^{-6}$ In any 15 s
	E	5.0 m (16 ft)	2.9 m (10 ft)	$1\text{-}1 \times 10^{-9}$ In any 15 s vert, 30 s lat	2 s	17 m (56 ft)	10m(USA) 5/2.5m EU	$1\text{-}4 \times 10^{-6}$ In any 15 s
	F	5.0 m (16 ft)	2.9 m (10 ft)	$1\text{-}1 \times 10^{-9}$ In any 15 s vert, 30 s lat	2 s	17 m (56 ft)	10m(USA) 5/2.5m EU	$1\text{-}2 \times 10^{-6}$ In any 15 s vert, and $1\text{-}2 \times 10^{-6}$ In any 30 s lat

CAT II / III Requirements are not fixed yet

Basic Assumptions 1/2

- The basic parameters are those parameters that have been used nowadays in the GPS constellation they are derived from the ICAO standards, they are representing the nowadays single frequency parameters using the standard ICAO error models values of A, B, and C letters parameters for the GAD (Ground Accuracy Designator). And the standard values of letter A and B letters for AAD(Airborne Accuracy Designator), And the standard values of A and B for AMD(Airborne Multipath Designator).

- The hypothesis of fault-free receivers was assumed. And the negligible troposphere error also, 4 ground station reference receivers and 100 sec convergence time for the smoothing filter.

- Its assumed to perform the simulation globally, 90ºN to 90ºS, and 180ºE to 180ºW

Basic Assumptions 2/2

- It's assumed that the UDRE error Budget for GPS/GBAS System will be the same as UDRE error Budget for GALILEO/GBAS system during the simulations to be comparable with other studies.

- It's assumed also to limit the simulations on the vertical alert limit values only due the sensitivity of this parameter in the final approach over the lateral alert limit values.

- Simulations will be performed for single GNSS constellation only.

- The mask angle for GPS is assumed to be 5^{o}, and for Galileo will be 10^{o}.

WP1: Assumptions for the Simulations

Additional/Future Assumptions

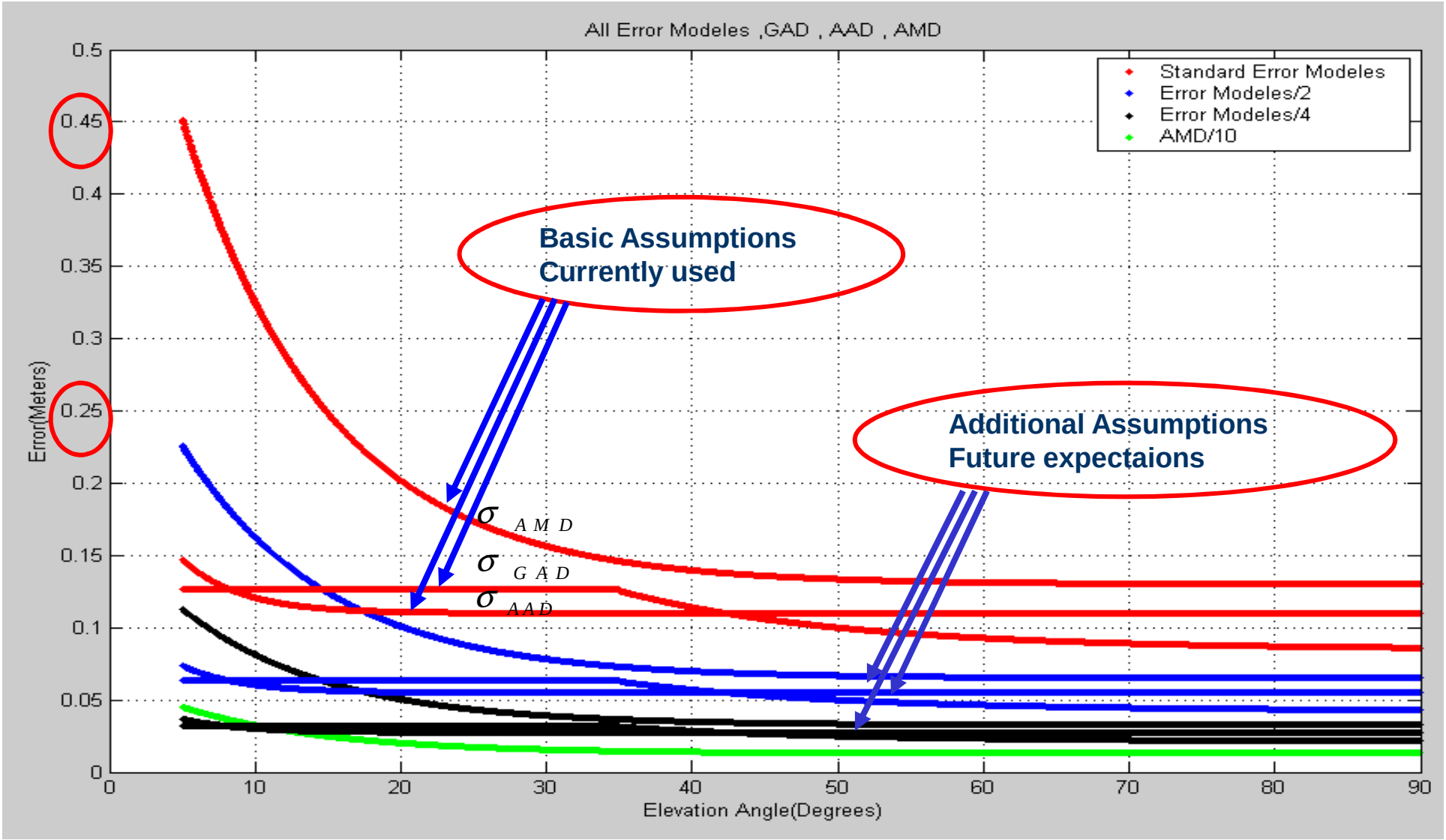
* The additional parameters are those which have been modified due to the expected improvement of the new GNSS2 world, including the modernized GPS and Galileo constellation as they will use new signal structure (BOC signals), as well as the state of the art technologies that will take place in the domain of UMPE mitigation.

* Some of those additional assumptions were proposed by the working groups 28 and 62 in EUROCAE publications. They are representing the nowadays dual frequency parameters. The standard ICAO error models will be divided by a factor of 2 for both GAD and AAD parameters.

* Based on the discussions with experts, its assumed that a reduction of AMD by a factor 4 should be possible. A reduction by a factor of 10 seems to be over optimistic but it is taken into account in the simulation work.

WP1: Parameters Assumptions

Multipath error is the major error source among other errors



WP1: Parameters Assumptions

$$\sigma_i^2 = \sigma^2_{pr\_gnd,i} + \sigma^2_{tropo,i} + \sigma^2_{iono,i} + \sigma^2_{air,i}$$

$\sigma^2_{pr\_gnd,i}$: is the total (post correction) fault free noise term provided by the ground function (via VDB) for satellite *i*.

$\sigma^2_{tropo,i}$: is a term which is computed by the airborne equipment to cover the residual tropospheric error for satellite *i.*

$\sigma^2_{iono,i}$: is the residual ionospheric delay (due to spatial decorelation) uncertainty for the ranging source.

$\sigma^2_{air,i}$: is the standard deviation of the aircraft contribution to the corrected pseudorange error for the ranging source. The aircraft contribution includes the receiver contribution and standard allowance for airframe multipath.

$$\sigma^2_{air,i} = \sigma^2_{receiver}(\theta_i) + \sigma^2_{multipath}(\theta_i)$$

WP1: Parameters Assumptions

GPS 24 Satellites Almanac (Nominal constellation):

1. Epoch date: June 30, 1993 at 23:34:24.
2. GPS week 703, 344064 second:
3. Simulations will be for 12 hours period.
4. Mask angle will be 5°

GPS 29 Satellites Almanac

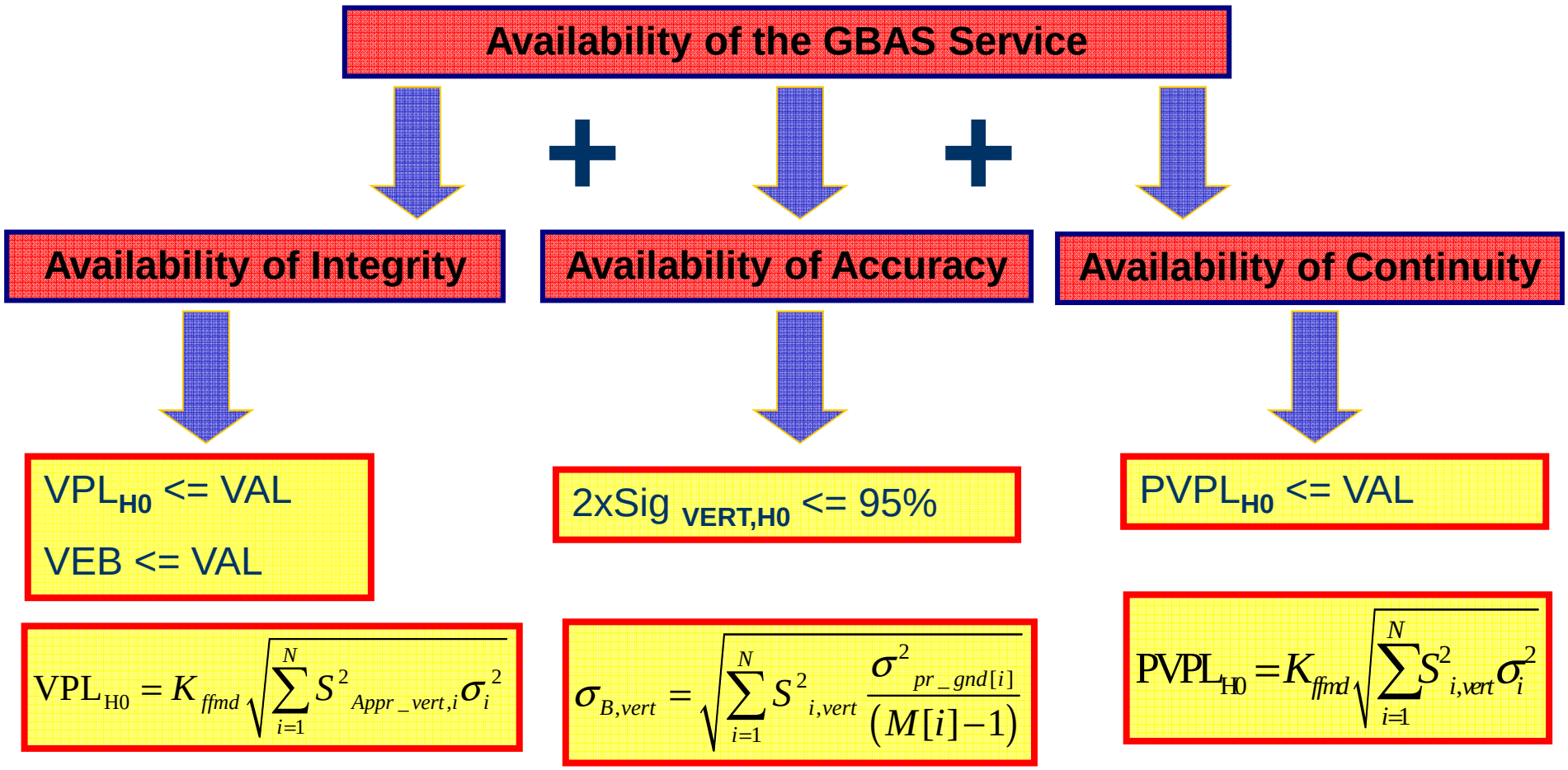
1. Epoch date: February 17, 2006
2. GPS week 338
3. Simulations will be for 12 hours period.(periodicy is 11h and 58min)
4. Mask angle will be 5°

GALILEO Satellites Almanac

1. Simulations will be for 10 days period.
2. Elevation angle will be 10°(Galileo specification)

All parameters were verified by GBAS experts at Thales

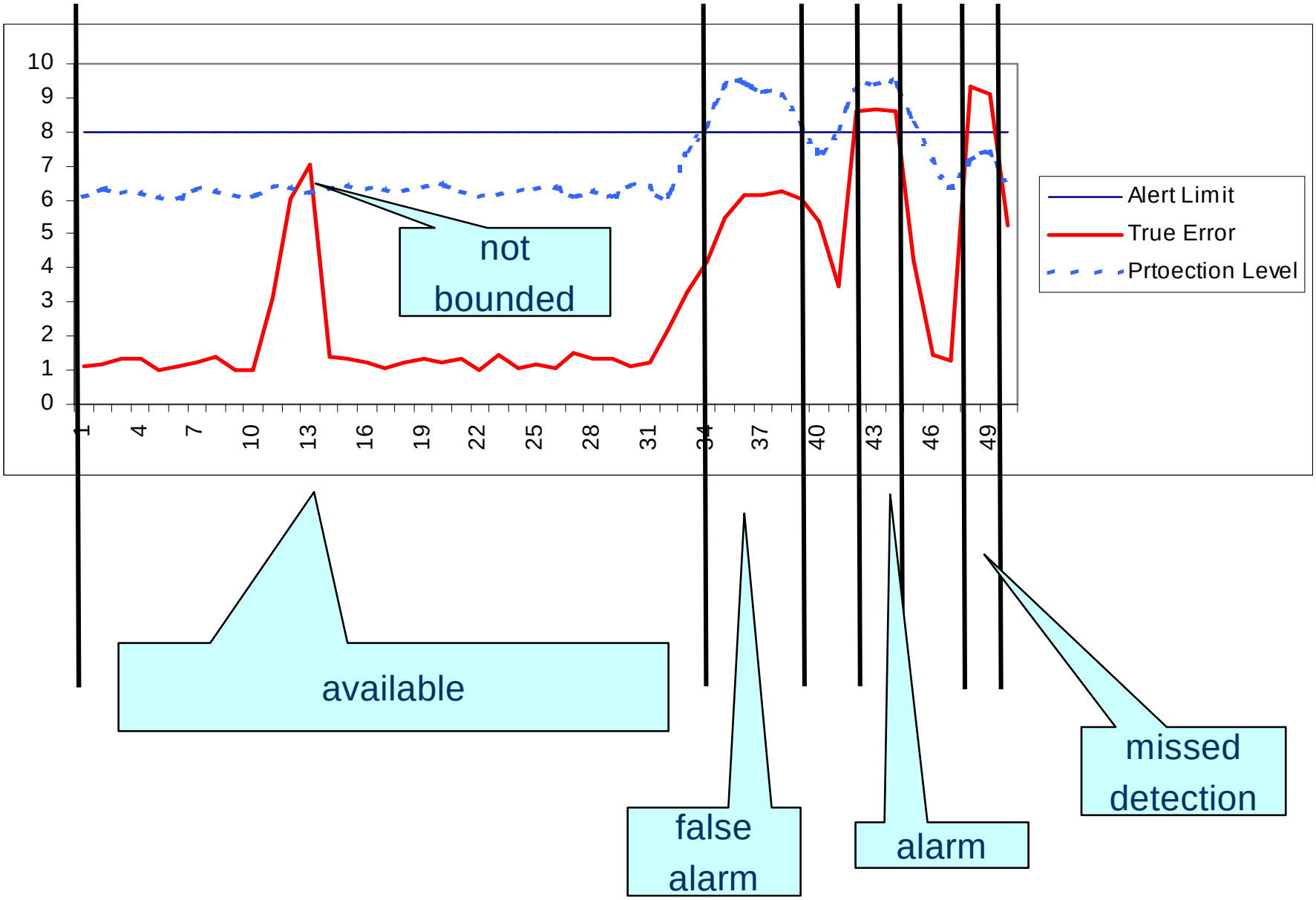
WP1: Availability of GBAS Service



The needed Avialability for CAT I is 99.75% and for CAT II/III is 99.99%

These equations are full detailed in the standard

WP1: Integrity indicator (Protection Level)/Position Error /VAL



Critical satellite :

is the satellite that expected to be available in the duration of approach but whose loss would cause a protection level to exceed its associated alert limit at some point along the approach.

- The airborne subsystem shall verify that number of the critical satellites doesn't exceed the maximum allowable numbers shown below as defined by RTCA DO-245A.

GSL	Allowable Critical Satellites
A,B,C,D	High enough "no check is necessary"
E	4
F	2 vertical ,or 1 Lateral

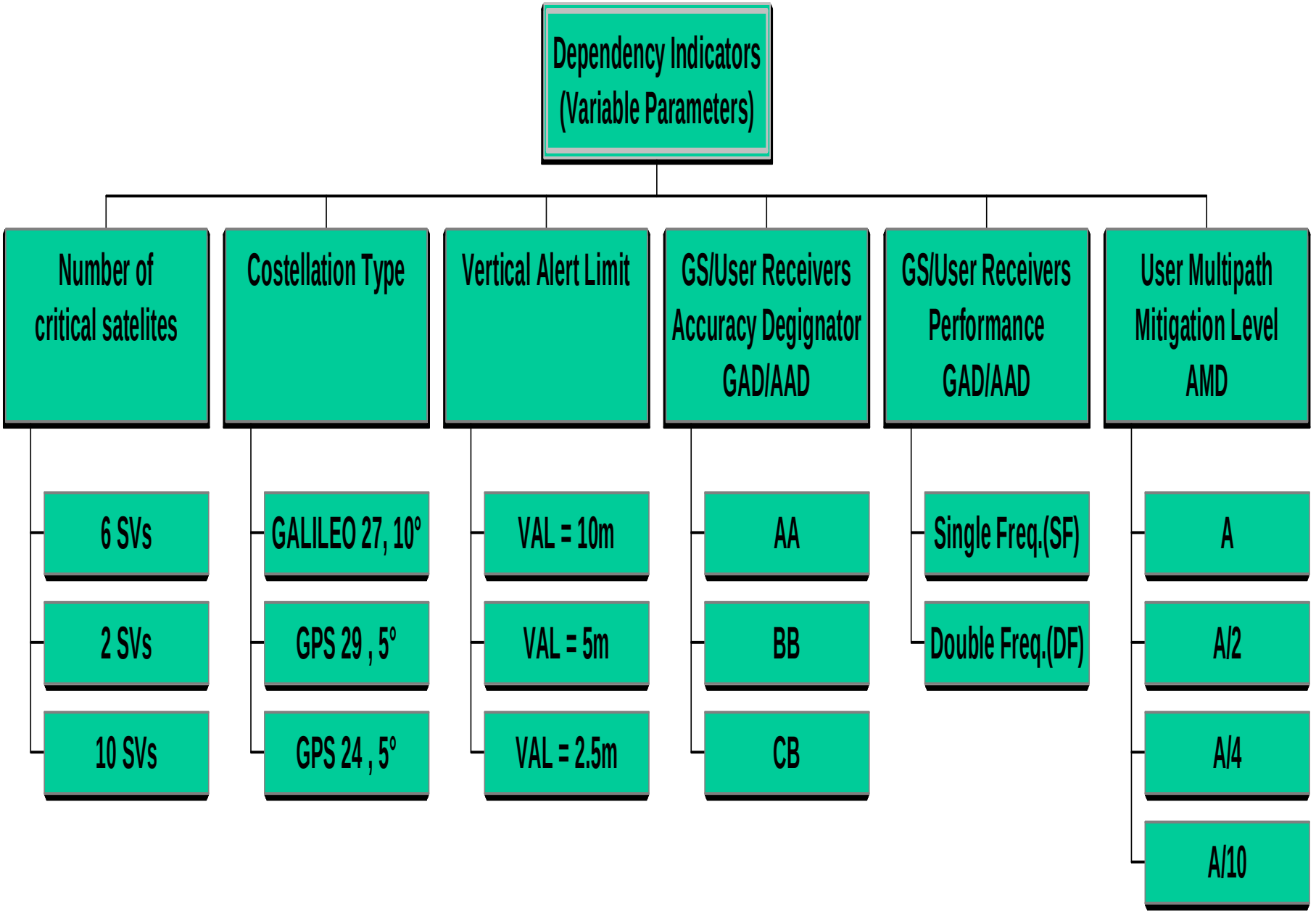
Working Packages

WP1: GBAS Parametrs Assumptions

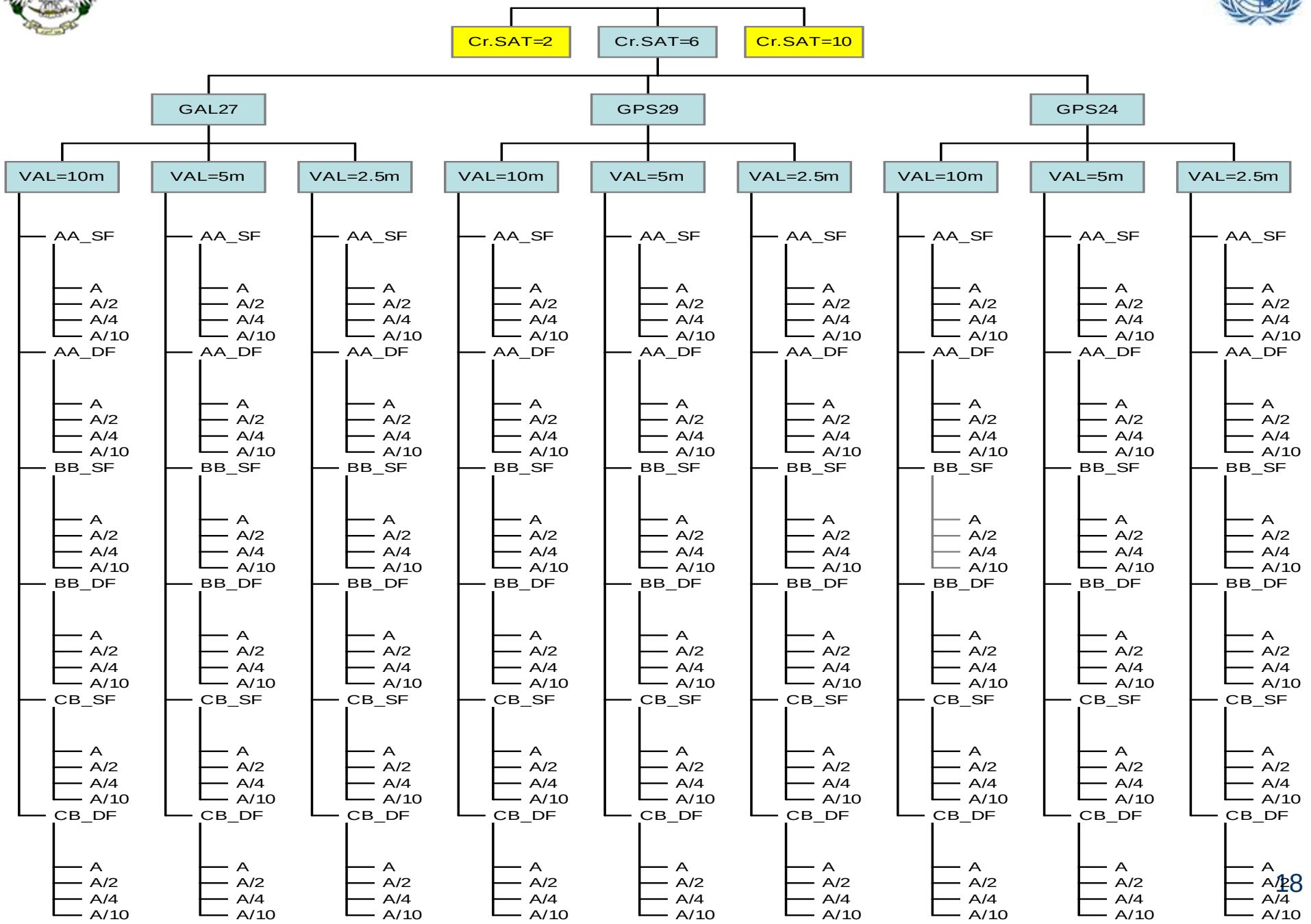
WP2: Simulations Planning/Performing

WP3: Results Analysis

WP2 :Baseline Planning



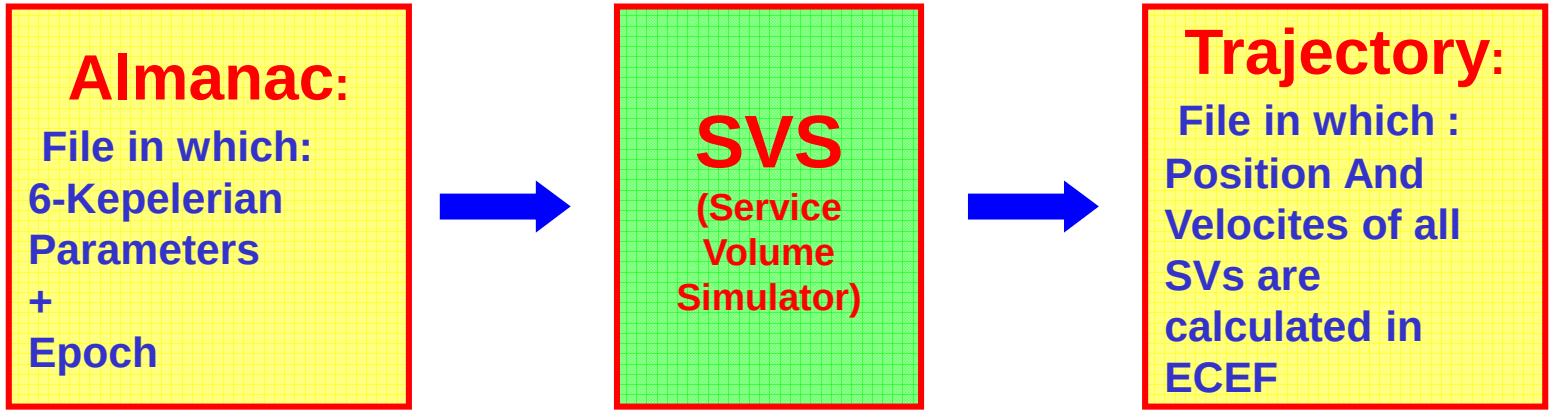
Simulation Groups



WP2: Simulation Steps

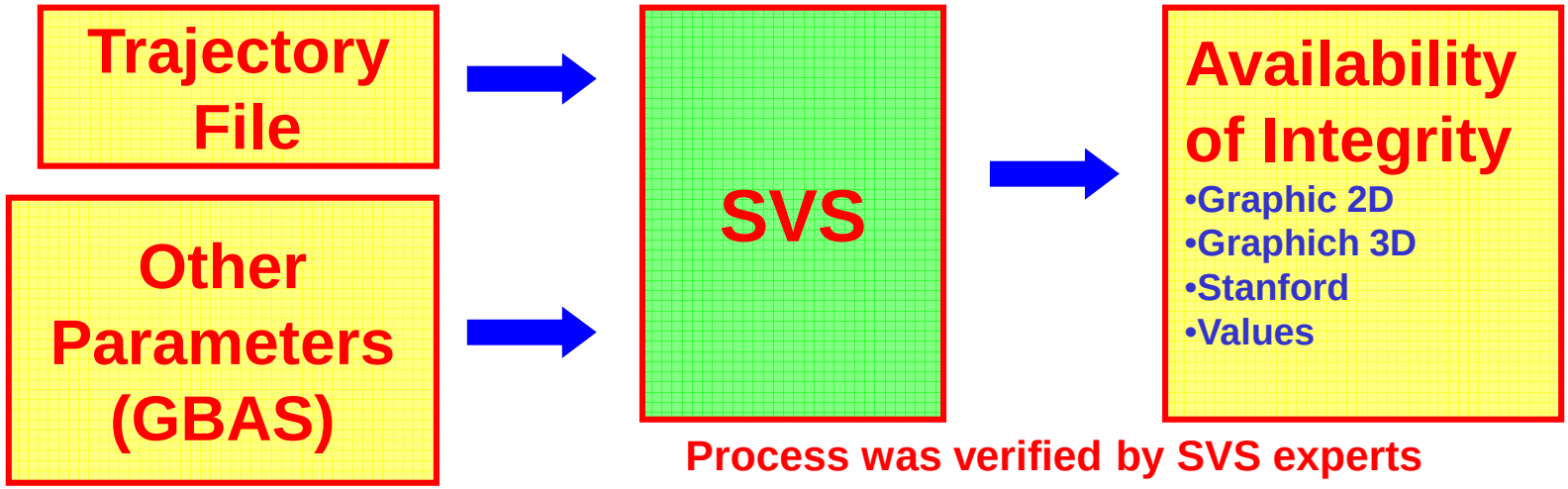
Simulation Step 1:

Calulation of Trajectory for a Satellite System



Simulation Step 2:

Calulation of Availabilty of Integrity for specific paramters



Process was verified by SVS experts

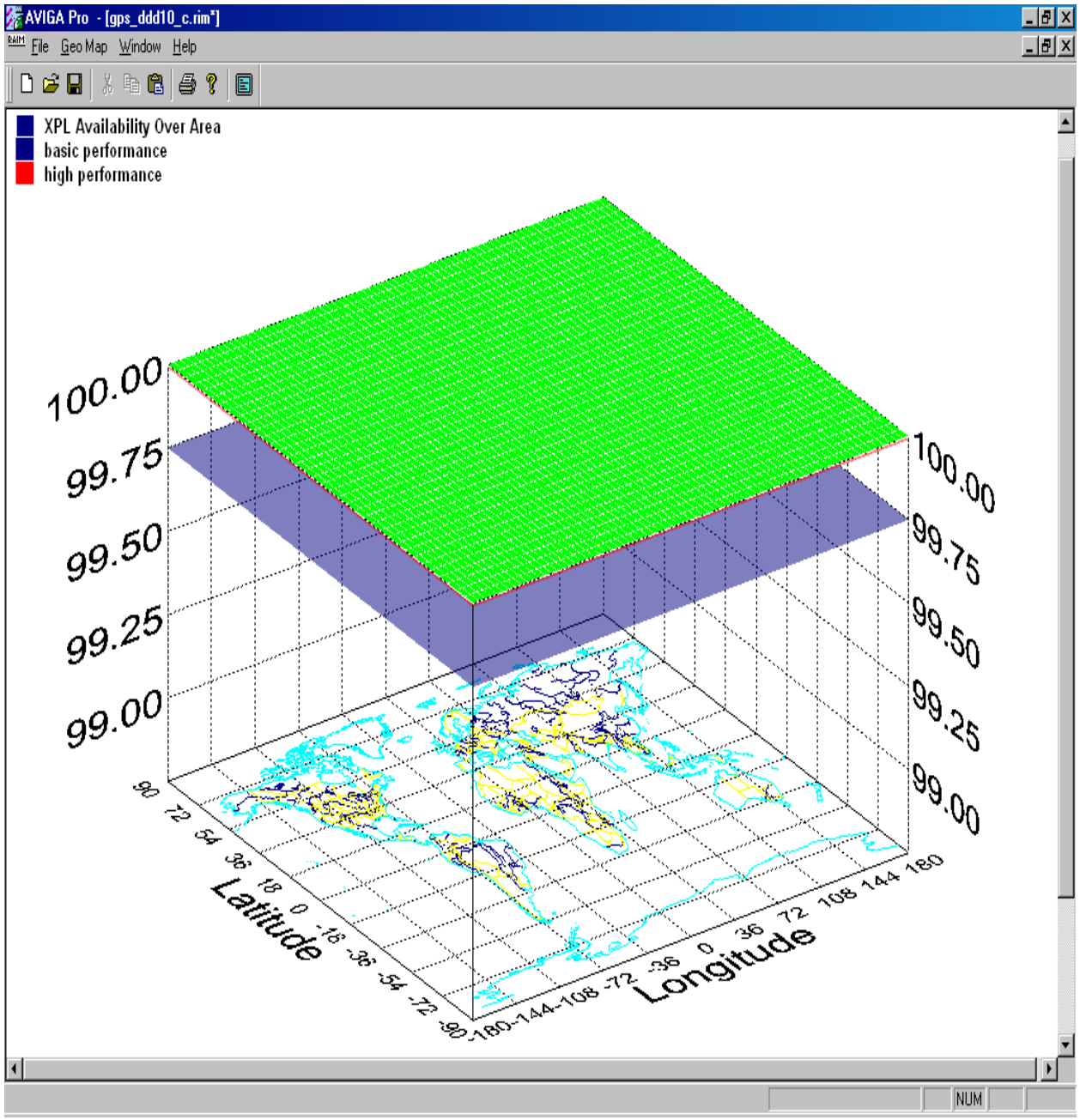
Working Packages

WP1: GBAS Parametrs Assumptions

WP2: Simulations Planning/Performing

WP3: Results Analysis

WP3:Results Analysis :Example from GPS

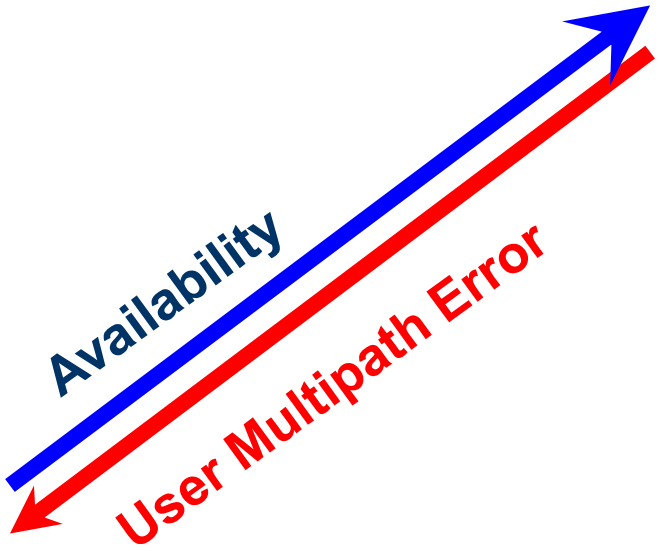


MP=A, Availability =99.983730%

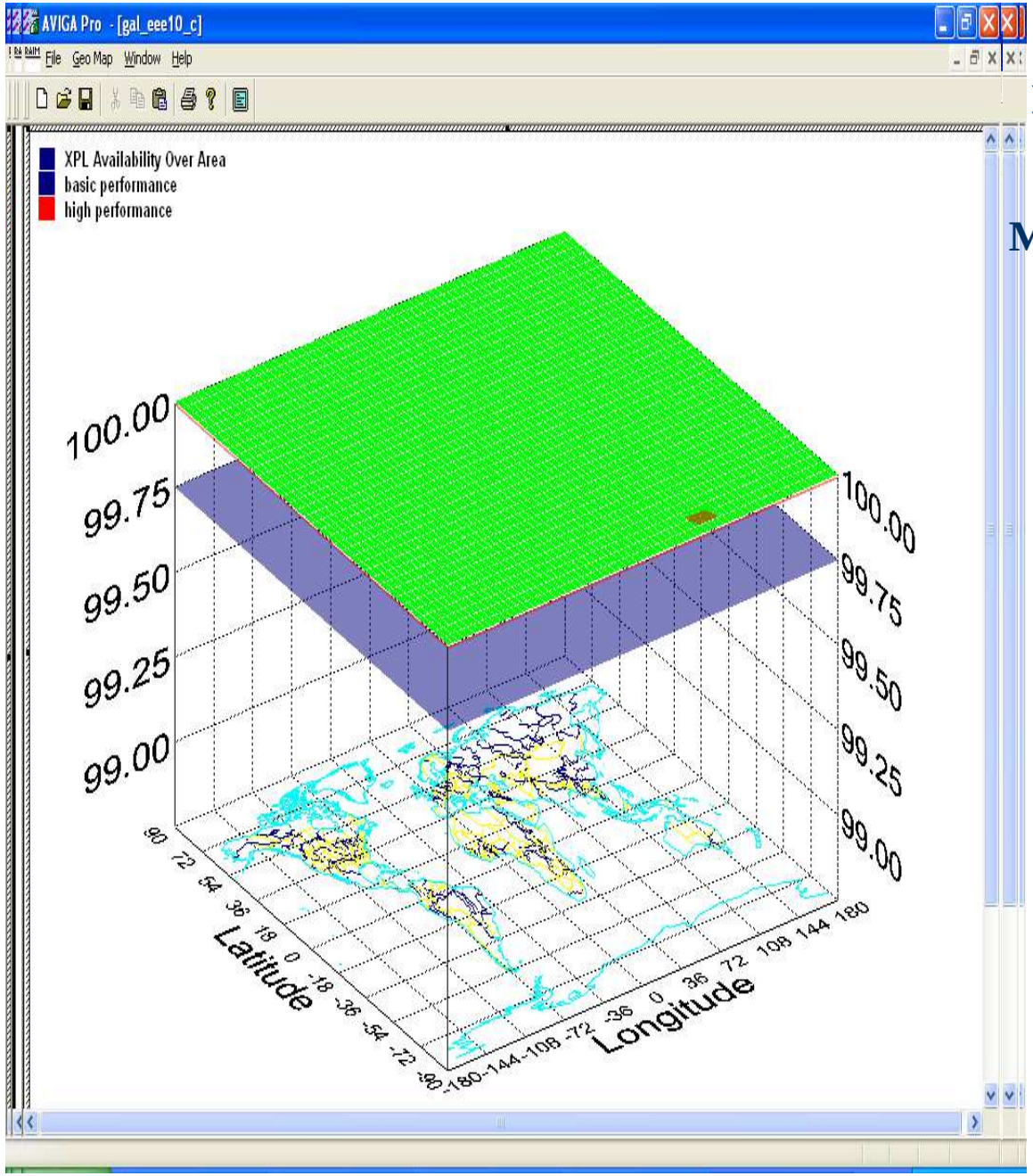
MP=A/2, Availability = 99.996541 %

MP=A/4, Availability = 99.999231%

MP=A/10, Availability = 100.000000%



WP3 :Results Analysis :Example from Galileo

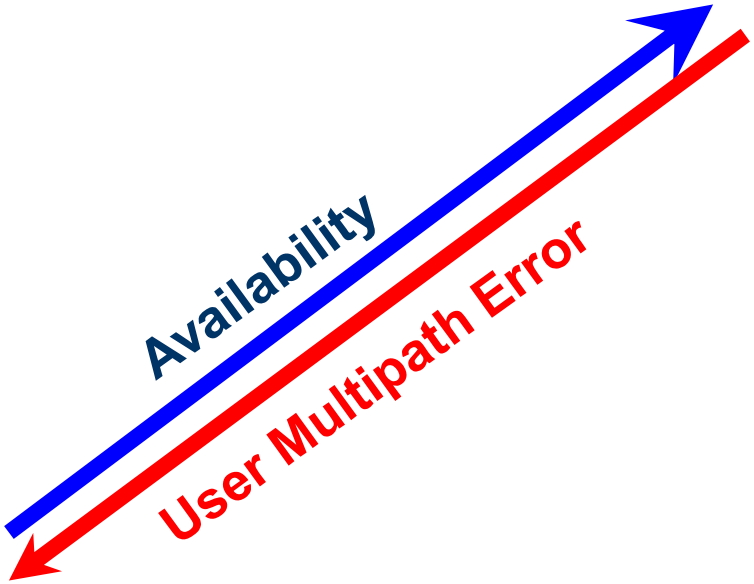


MP=A, Availability =96.924815%

MP=A/2, Availability = 99.964120%

MP=A/4, Availability = 99.990490%

MP=A/10, Availability = 99.999948%



WP3 :Results Analysis Group 1

VAL	Constellation Type	Group1:User Multipath mitigation level needed to meet Aeronautical Availability Requirements											
		99.99%						99.75%					
		AA_SF	BB_SF	CB_SF	AA_DF	BB_DF	CB_DF	AA_SF	BB_SF	CB_SF	AA_DF	BB_DF	CB_DF
10 m	GALILEO 27	A	A	A	A	A	A	A	A	A	A	A	A
	GPS 29	VC	A	A	A	A	A	A	A	A	A	A	A
	GPS 24	VC	A/2	A	A	A	A	A/10	A	A	A	A	A
5 m	GALILEO 27	NV	VC	A/2	A/4	A	A	NV	A/2	A	A/2	A	A
	GPS 29	NV	VC	VC	VC	VC	A/10	NV	VC	A/2	VC	A/2	A
	GPS 24	NV	VC	VC	VC	VC	VC	NV	VC	A/10	VC	A/2	A/2
2.5 m	GALILEO 27	NV	NV	NV	NV	NV	V	NV	NV	NV	NV	NV	V
	GPS 29	NV	NV	NV	NV	NV	V	NV	NV	NV	NV	NV	V
	GPS 24	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV

A, A/2, A/4, or A/10: are the needed UMPE mitigation levels with associated parameters to meet the desired availability of 99, 75% or 99.99%. in GBAS applications

VC: means ***VERY CLOSE to the 3rd UMPE Mitigation Level A/10*** (Availability >99,00%):

C: means ***CLOSE to the 3rd UMPE Mitigation Level A/10*** (98, 00 %< Availability <99,00%)

V: mean ***VISIBLE*** (95, 00%< Availability <98, 00%)

NV: mean ***NOT VISIBLE*** (Availability <95,00%)

Worldwide averaged availability

- **Main Worldwide Averaged Results Summary for Group 1 (6 SCV).**
- **VAL = 10 m**
  - **DF:**
    - **All Dual Frequency GBAS configurations using all single GNSS constellations have achieved 99,99% Availability.**
  - **SF:**
    - **With most SF configurations it is possible to achieve 99,75% with moderate multipath mitigation**
      - **AA-SF configuration with GPS 29 and GPS 24 constellations are very close (VC) to achieve 99,99% availability**
      - **BB-SF configuration with GPS 24 constellation could achieve 99,99% availability after using A/2 UMPE mitigation level.**

WP3 :Results Analysis :Group 1

- **Main Worldwide Averaged Results Summary for Group 1(6 SCV).**
- **<u>VAL = 5 m</u>**
  - **<u>DF:</u>**
    - **Galileo theoretical constellation has nearly achieved 99,75% availability with all DF GBAS configurations.**
    - **GPS 29 achieved 99,75% availability with CB-DF configuration, but it needs A/2 UMPE mitigation level with BB-DF configuration.**
  - **<u>SF:</u>**
    - **Galileo constellation achieved 99,75% availability with CB-SF configuration, whereas GPS 29 constellation could achieve it by A/2 UMPE mitigation level and GPS 24 could achieve it by A/10 UMPE mitigation level.**

- **Main Worldwide Averaged Results Summary for Group 1 (6 SCV).**
- **VAL = 2,5m**
  - **SF and DF**
  - All GNSS constellations with all GBAS configurations were not able to achieve 99,75% availability Target with the exception of the best GBAS configuration CB-DF configurations in GPS 29 and Galileo Constellations, they are some how visible to achieve the 99,75% availability.

Analysis Summary

1. Availability of GNSS-GBAS increases when the user multipath error decreases.

2. Simulations showed significantly improvement of all the selected GNSS constellation availability of integrity in GBAS system after the first level of multipath error mitigation (A/2) in comparison with other mitigation levels.

3. There was strong positively impact on availability of GBAS system in the lower VAL values against visible impact in the middle VAL values and minor Impact in higher VAL values.

4. No significant difference in the way of how different GNSS constellations response to the variation of user Multipath error levels, But more sensitive response of Galileo over GPS performance.

5. DF receivers have higher increment in availability, higher improvement, in both the maximum and the average, than the SF receiver when UMPE decreases.

6. It was clear to see major Availability improvement responses to UMPE error mitigation in CB, BB, types against less improvement responses in AA type due to using MLA antennas in.

7. The number of allowed critical satellites impact proportionally the availability.

WP3 : The main worldwide Averaged results table

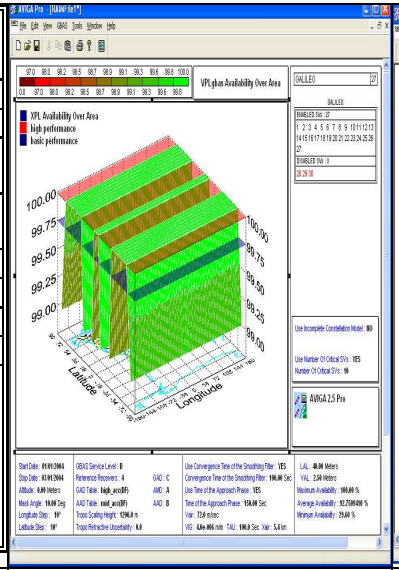
VAL	Constellation Type	Group 1+2+3 : User Multipath mitigation level needed to meet Aeronautical Availability Requirements 99,99%																	
		Group 2, CSV = 2						Group 1, CSV = 6						Group 3, CSV = 10					
		AA_SF	BB_SF	CB_SF	AA_DF	BB_DF	CB_DF	AA_SF	BB_SF	CB_SF	AA_DF	BB_DF	CB_DF	AA_SF	BB_SF	CB_SF	AA_DF	BB_DF	CB_DF
10 m	GAL 27	VC	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	GPS 29	VC	VC	A/2	A/10	A	A	VC	A	A	A	A	A	VC	A	A	A	A	A
	GPS 24	C	VC	A/2	VC	A	A	VC	A/2	A	A	A	A	VC	A/2	A	A	A	A
5 m	GAL 27	NV	VC	VC	VC	A/4	A/2	NV	VC	A/2	A/4	A	A	NV	A/10	A/2	A/4	A	A
	GPS 29	NV	C	VC	C	VC	VC	NV	VC	VC	VC	VC	A/10	NV	VC	VC	VC	VC	A/10
	GPS 24	NV	C	VC	V	VC	VC	NV	VC	VC	VC	VC	VC	NV	VC	VC	VC	VC	VC
2.5 m	GAL 27	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	V	NV	NV	NV	NV	NV	V
	GPS 29	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	V	NV	NV	NV	NV	NV	V
	GPS 24	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV

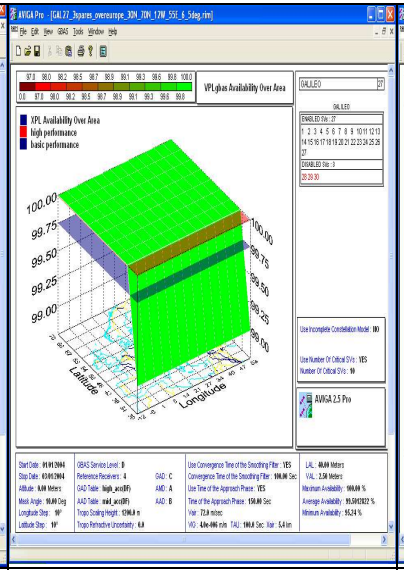
VAL	Constellation Type	Group 1+2+3 : User Multipath mitigation level needed to meet Aeronautical Requirements 99,75%																	
		Group 2, CSV = 2						Group 1, CSV = 6						Group 3, CSV = 10					
		AA_SF	BB_SF	CB_SF	AA_DF	BB_DF	CB_DF	AA_SF	BB_SF	CB_SF	AA_DF	BB_DF	CB_DF	AA_SF	BB_SF	CB_SF	AA_DF	BB_DF	CB_DF
10 m	GAL27	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	GPS 29	VC	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	GPS 24	C	A	A	A	A	A	A/10	A	A	A	A	A	A/4	A	A	A	A	A
5 m	GAL 27	NV	A/4	A	A/4	A/2	A	NV	A/2	A	A/2	A	A	NV	A/2	A	A/2	A	A
	GPS 29	NV	C	A/4	C	A/2	A/2	NV	VC	A/2	VC	A/2	A	NV	VC	A/2	VC	A	A
	GPS 24	NV	V	VC	V	A/4	A/2	NV	VC	A/10	VC	A/2	A/2	NV	VC	A/10	VC	A/2	A/2
2.5 m	GAL27	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	V	NV	NV	NV	NV	NV	V
	GPS 29	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	V	NV	NV	NV	NV	NV	V
	GPS 24	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV

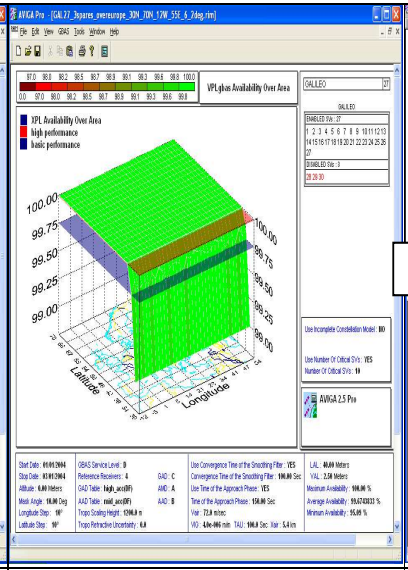
WP3 :Results Analysis of special cases: EUR(same for USA)

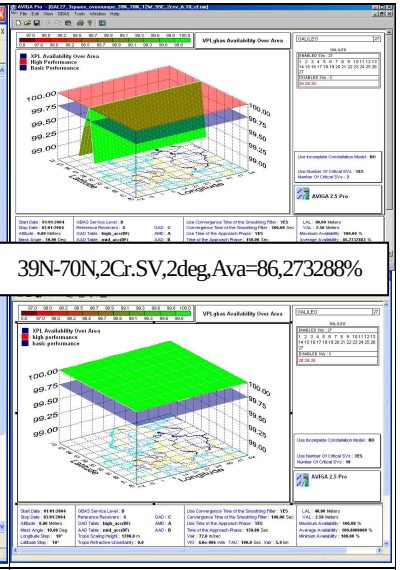
UNOOSA

CAT III 2,5 m GALILEO 27 , 10 deg	Sub-group parameter	VAL
	VAL	2,5 m
	Constellation	GAL27
	User & GS Performance	DF
	No. of Critical Satellites	10
	GSL	D
	Mask Angle	10°
	GAD	C
	AAD	B
	Expected Result:	





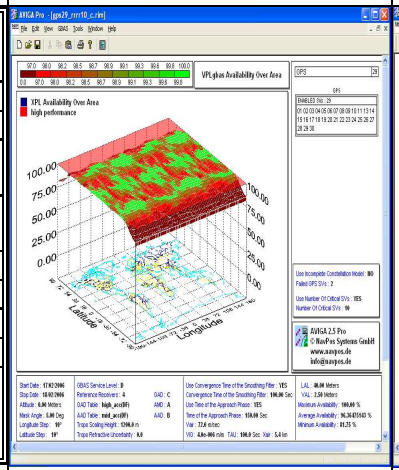


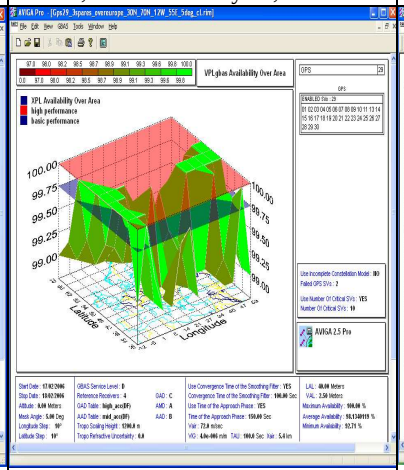


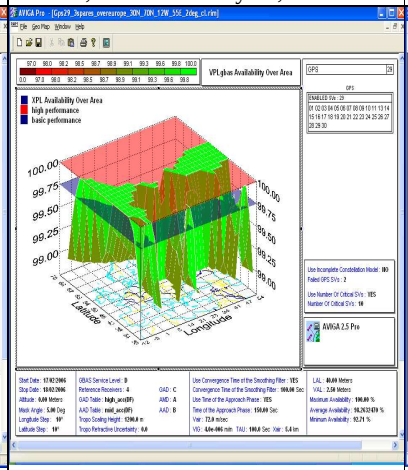
39N-70N,2Cr.SV,2deg,Ava=86,273288%

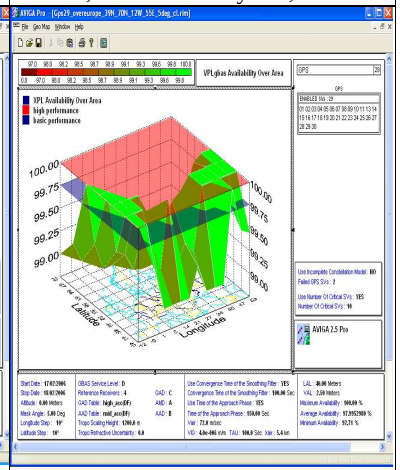
Coverage Area /Availability	Global, 5Deg Grid/Availability= 92, 750941%	30N-70N,12W-55E,5°Grid/Availability=99,501282%	30N-70N,12W-55E,2°Grid/Availability=99,674383%	39N-70N,12W-55E,5°Grid/Availability=100,0000%

CAT III 2,5 m GPS 29, 5 deg	Sub-group parameter	VAL
	VAL	2,5 m
	Constellation	GPS29
	User & GS Performance	DF
	No. of Critical Satellites	10
	GSL	D
	Mask Angle	5°
	GAD	C
	AAD	B
	Expected Result:	









Coverage Area /Availability	GLOBAL, 5DEG GRID/AVAILABILITY=96, 364751 %	30N-70N,12W-55E,5?GRID/AVAILABILITY=98,134011%	30N-70N,12W-55E,2?GRID/AVAILABILITY=98,263247%	39N-70N,12W-55E,5?GRID/AVAILABILITY=97,945298%

WP3 :Results Analysis of the special cases:

- **Galileo 27 constellation was able to meet the aeronautical availability Target of 99,75% over Europe with the given input parameters of the best GBAS configuration of CB-DF and for VAL= 2,5M, and it was very close (99,404%) over USA. But GPS 29 was not able to meet these requirements.**

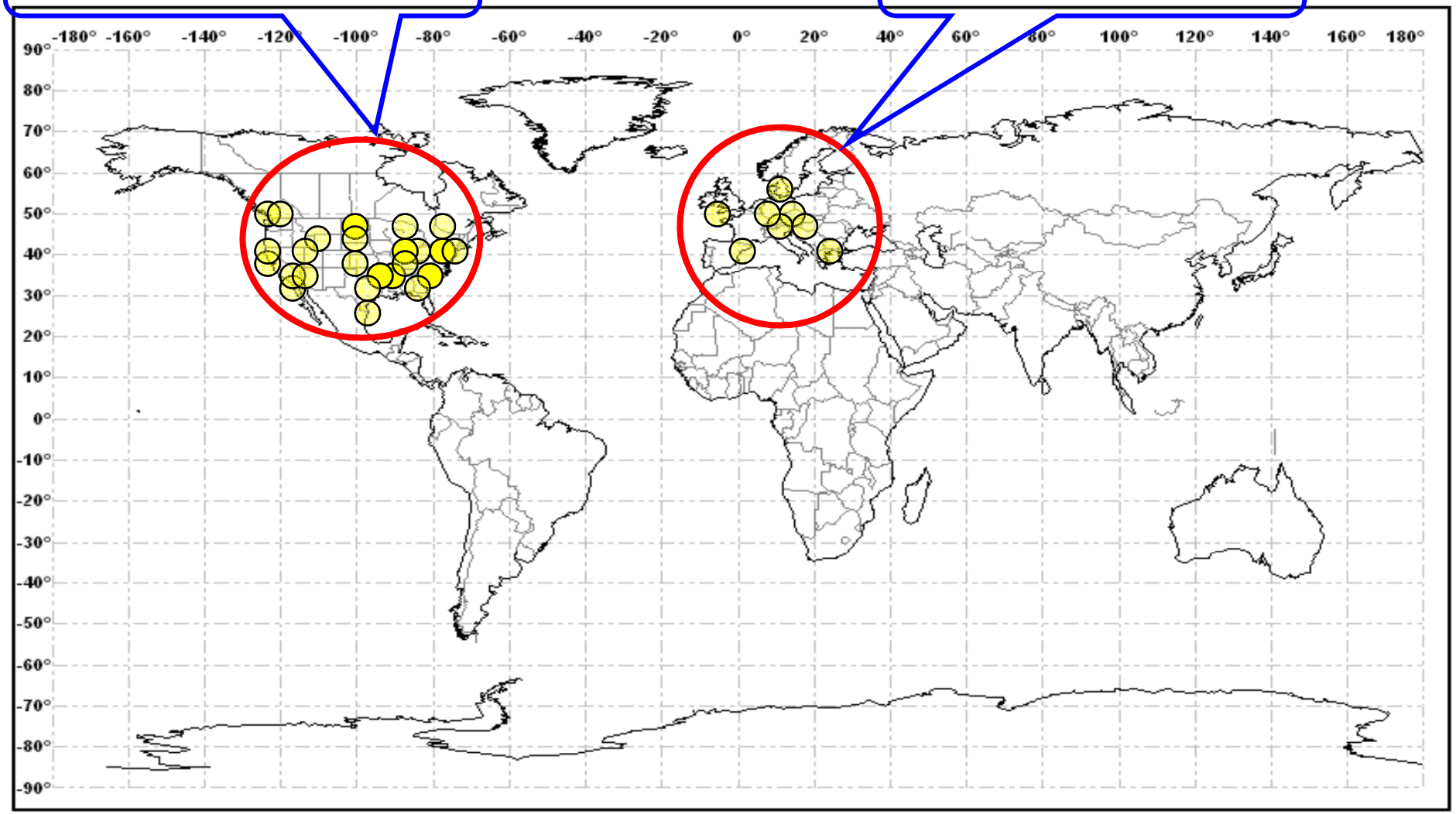
- **GPS 29 constellation shows that green spots of good availability are continuously moving and cannot always be assured over a certain geographic area like a specific airport for example.**

- **Galileo theoretical Constellation shows promising behave of the guaranteed good availability over a fixed areas of the globe, these areas look like stripes belts bounding the earth over a certain latitudes depending on the input parameters.**

WP3 :Comparison with WG 28 , Eurocae

USA:65E-127E&23N-50N

EUR:27E-9W&34N-62N



Conclusions

- The availability of integrity for GBAS was assessed by means of service volume simulation
- The parameters assumptions for the SVS were chosen based on the issued publications of the worldwide famous standards. Parameters assumptions were categorized into:currently Basic Parameters Assumptions and future Additional Parameters Assumptions
- Multipath mitigation levels were assumed to be extended to four levels: A, A/2, A/4, A/10
- methodical approach in performing the simulations
- Multipath error is a limiting factor in achieving CAT II/III In GBAS Applications. As well as DF .

Questions ???

Thanks for Listening