

GBAS development

NAVISP EL 2 Project presentation

Webex, 18th October 2021

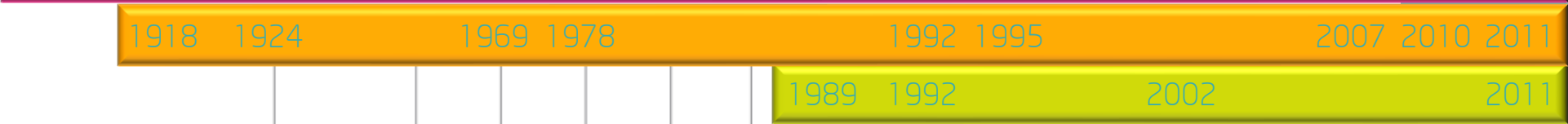
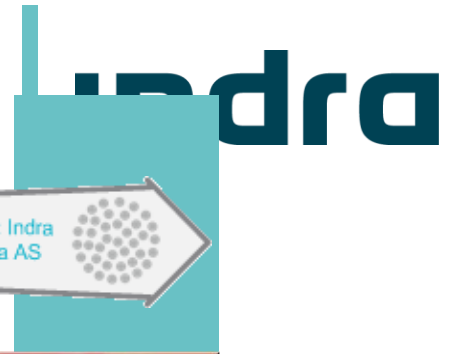
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indra



18 October 2021



Radio station installed onboard Airship Norge for North Pole expedition

GAREX 1 G/A Radio EXchange

LPDA antenna for ILS introduced

ILS production taken over by NORMARC

GAREX 1400 – 1st dual mini-computer controlled VCCS

GAREX 210 - 1st distributed microprocessor-controlled VCCS

1st NORMARC ILS delivery to China

NOVA 9000 – 1st SMR with aircraft labelling & tracking

NORMARC 7000 ILS introduced

NOVA 9000 – 1st ASMGCS with multilateration

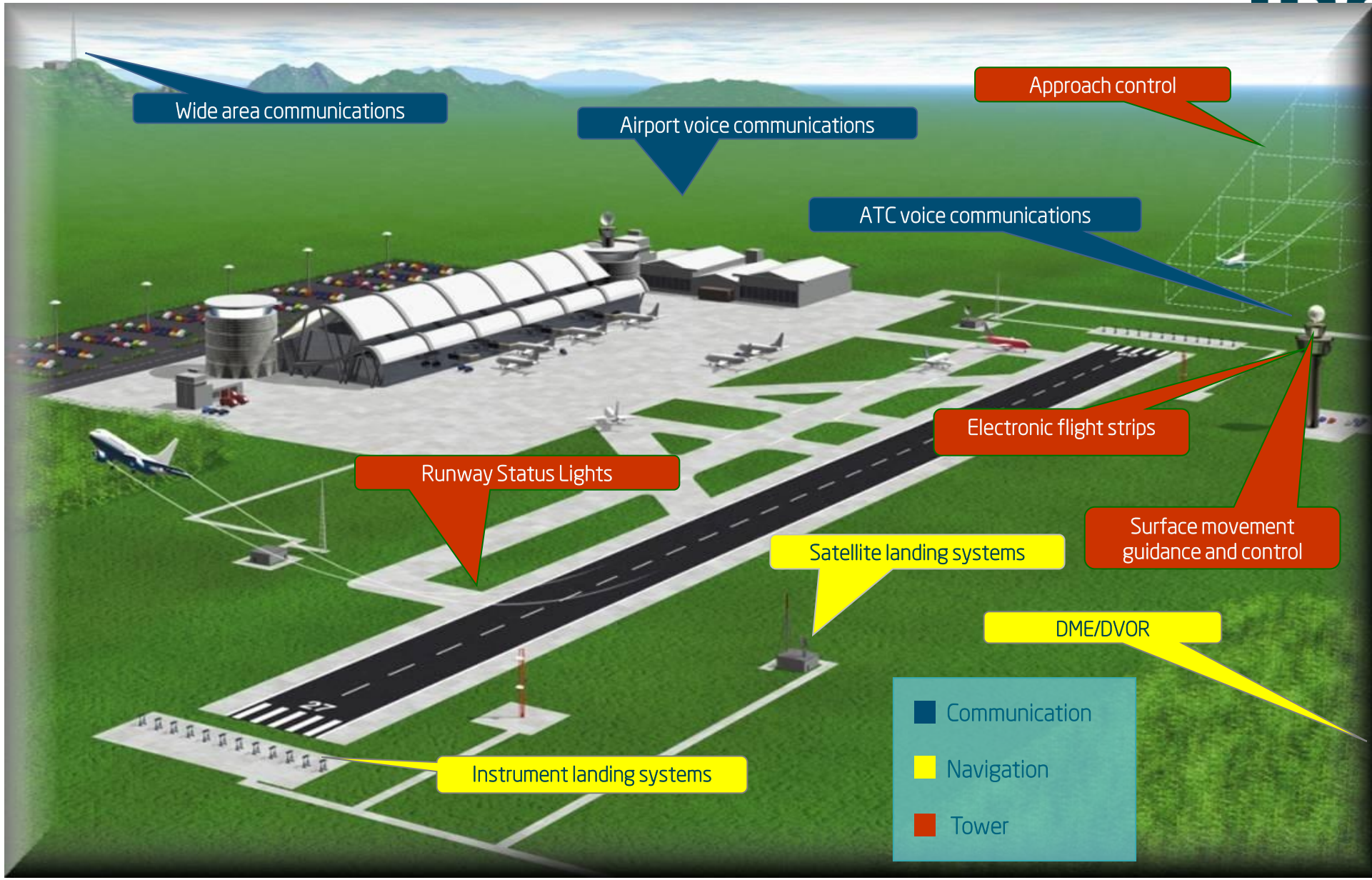
GAREX 220 AVANCE - VCCS with IP-based switching

NORMARC 8000 - 1st Satellite Landing System in commercial operation

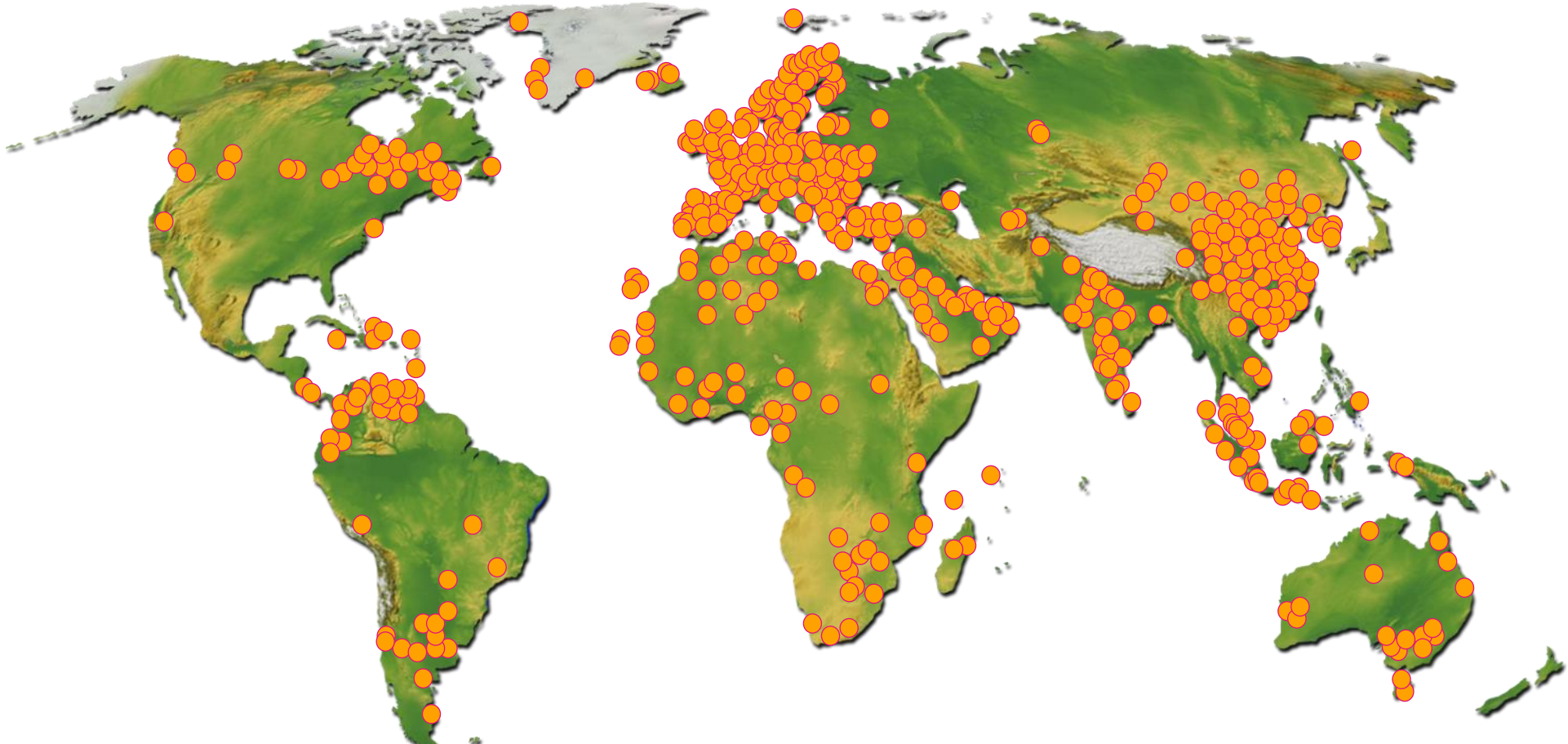
NORMARC ILS delivery # 200 to China

SESAR activities started NORMARC GBAS

NOVA enhanced safety nets routing, guidance



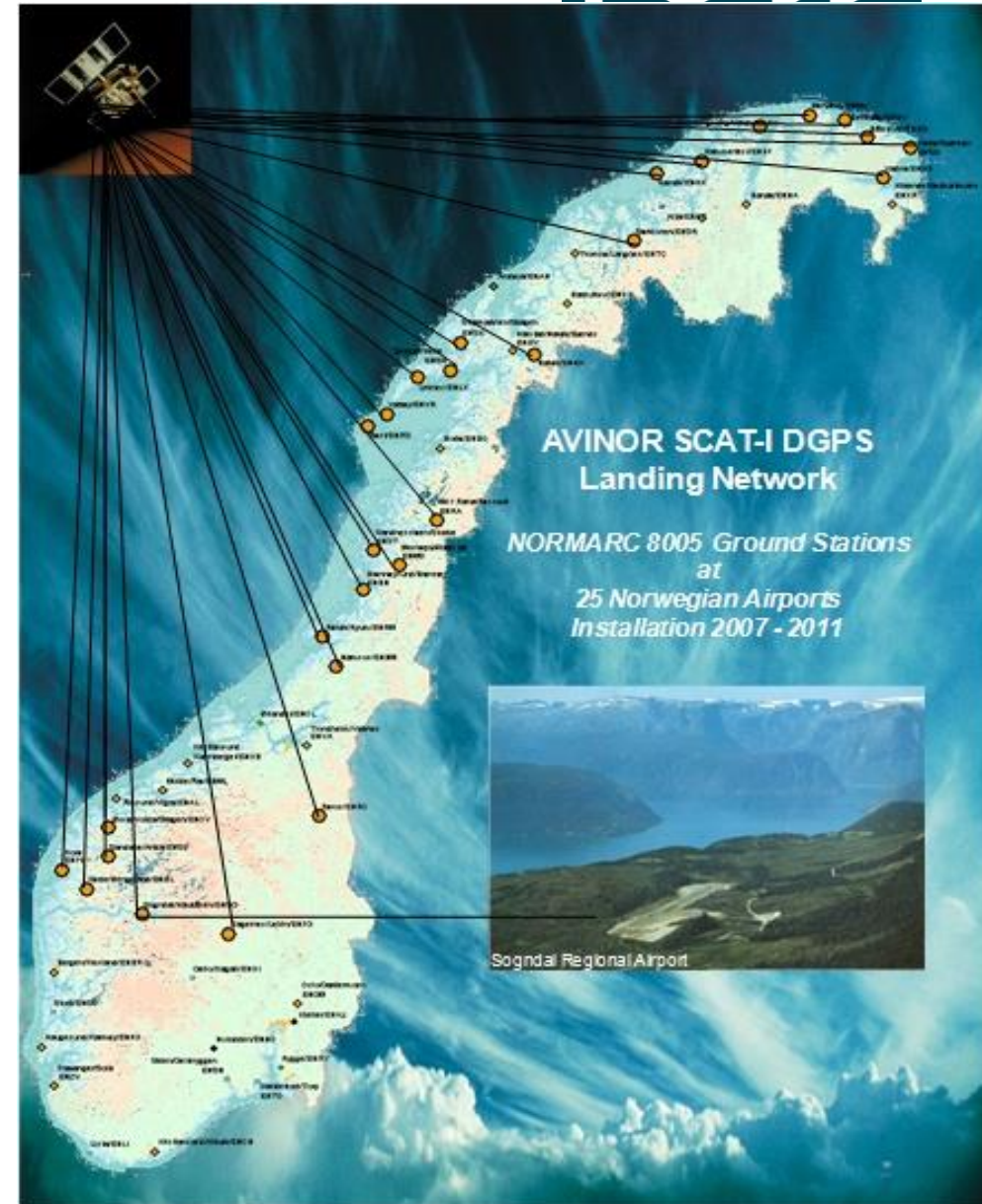
Indra Navia – Worldwide



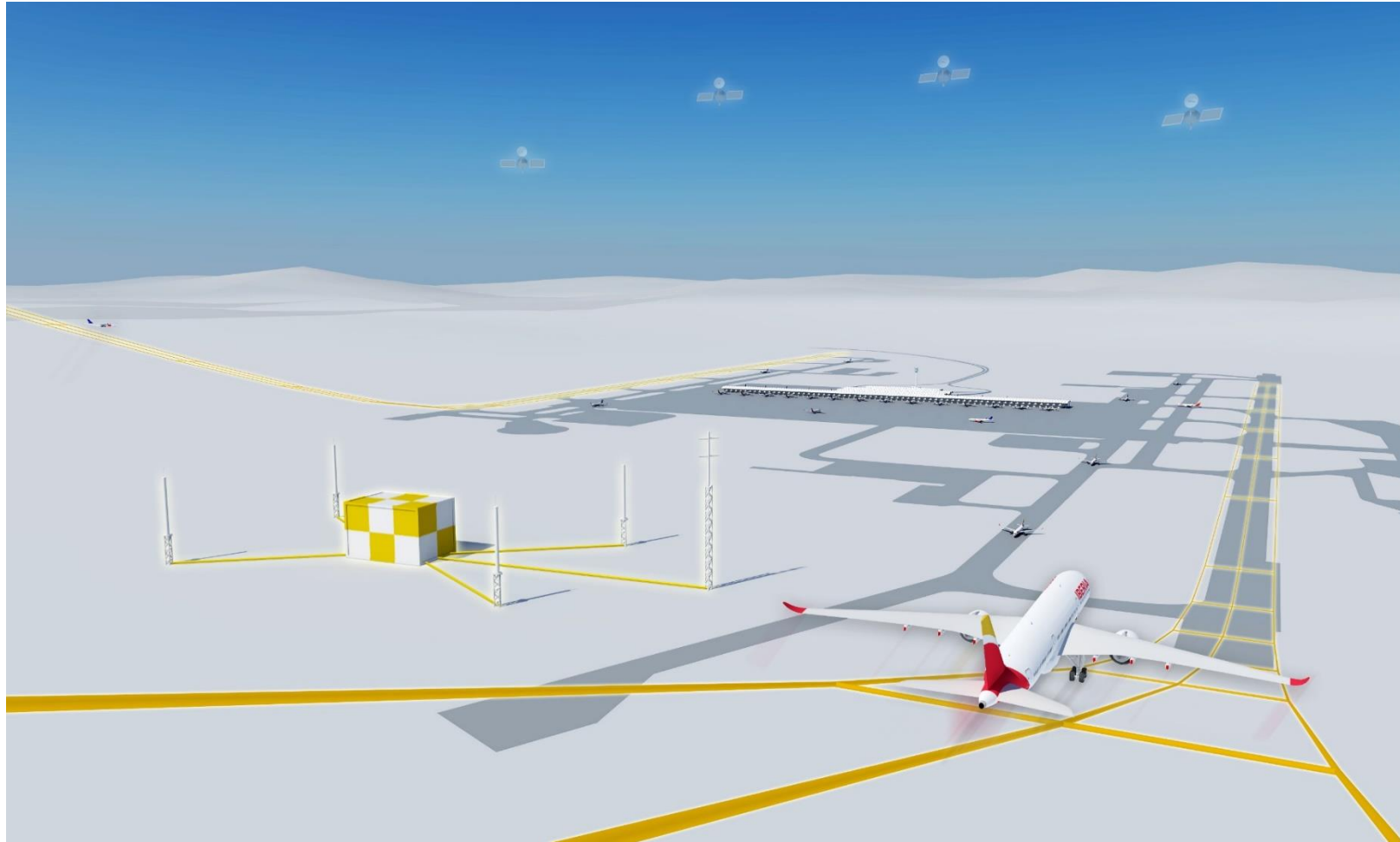
Indra Navia has systems at 1200 airports in 120 countries

SCAT-I Approval Program

- Indra has worked with FAA from 1998 to 2004 on the GBAS SCAT-I approval program
- Service Deployment Agreement obtained from the Norwegian Civil Aviation Authority in 2005 and first system in operation in 2007
- Implementation of the SCAT-I system is a success in Norway
- In operation at 17 airports
- SCAT-I scheduled for operation until at least 2025



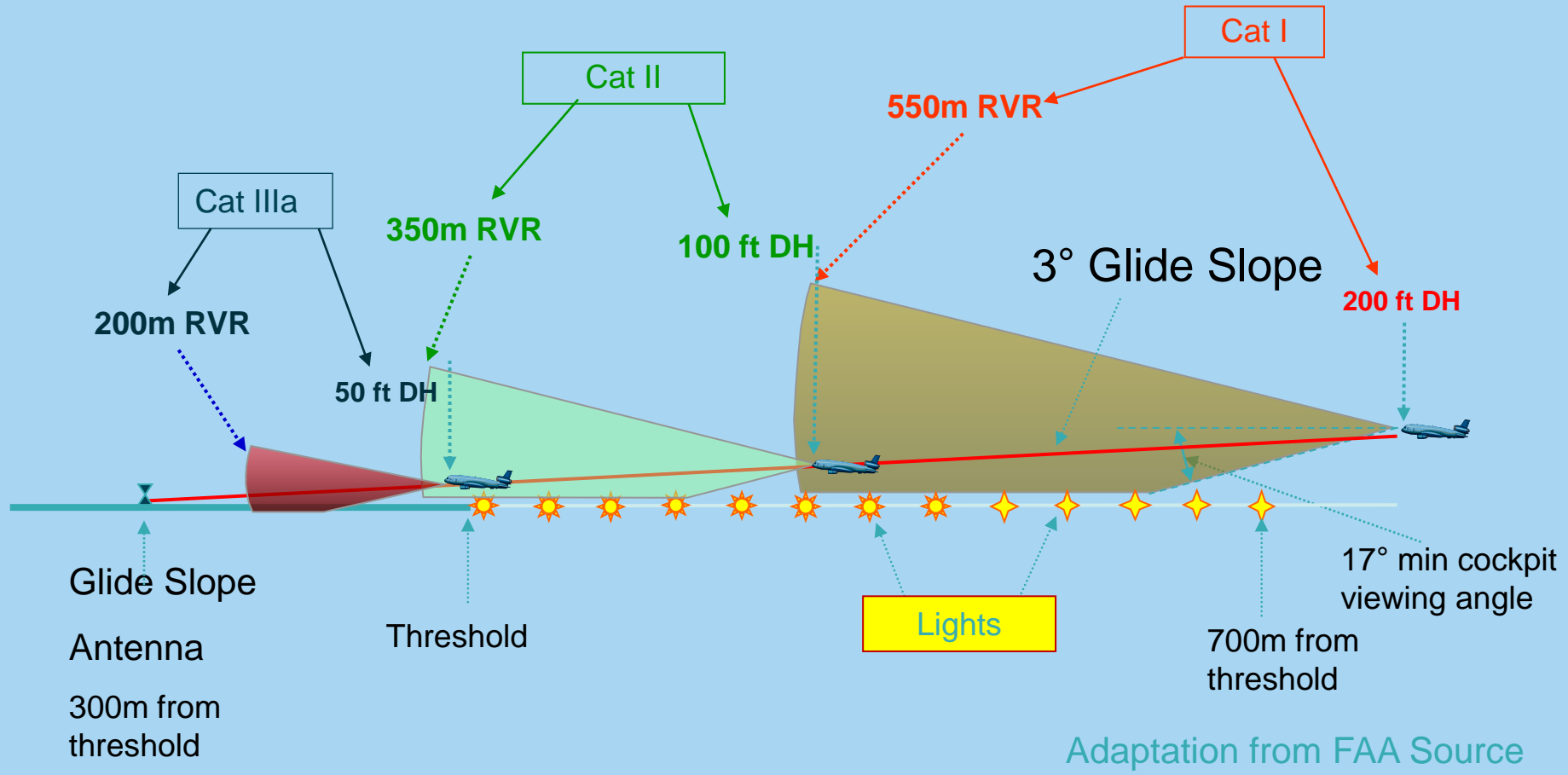
General GBAS architecture – Cat I/II/III landings



Approach Categories

Number of PA Runway Ends:
Worldwide about 3500
Europe: CAT I: \approx 770
CAT II: \approx 70
CAT III: \approx 180

- Scaled illustration



Preliminary System Safety Assessment – PSSA

- Purpose:

- Ensure that the design has the potential to meet the applicable safety requirements
- Allocate safety requirements to:
 1. Monitoring algorithms (Probabilities of Missed detection and Probabilities of False Alarms)
 2. Equipment (built-in mitigations)
 3. Design Assurance levels (software and hardware, as applicable)
 4. Operations and maintenance

- Includes budgetary fault trees for:

- a) Integrity
- b) Continuity
- c) Out-of-slot radiation

... to support 2., 3. and 4 above, and to assess whether the quantitative requirements applicable to a), b) and c) can be met

PSSA Summary

- Fault tree statistics:

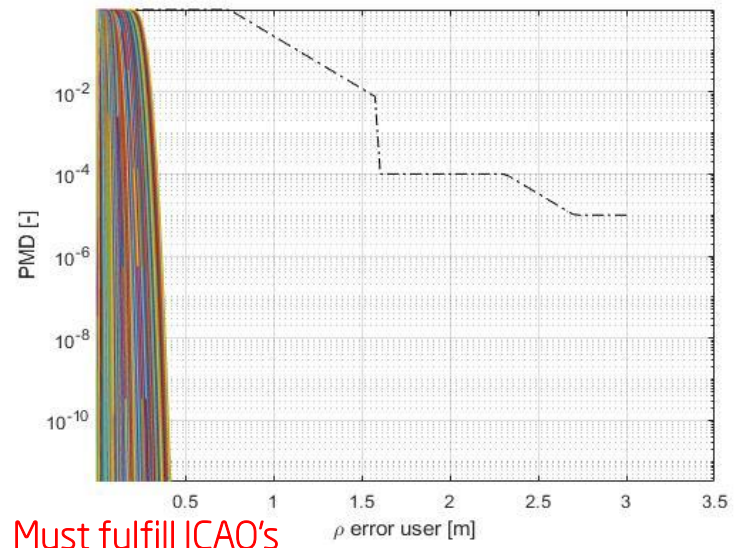
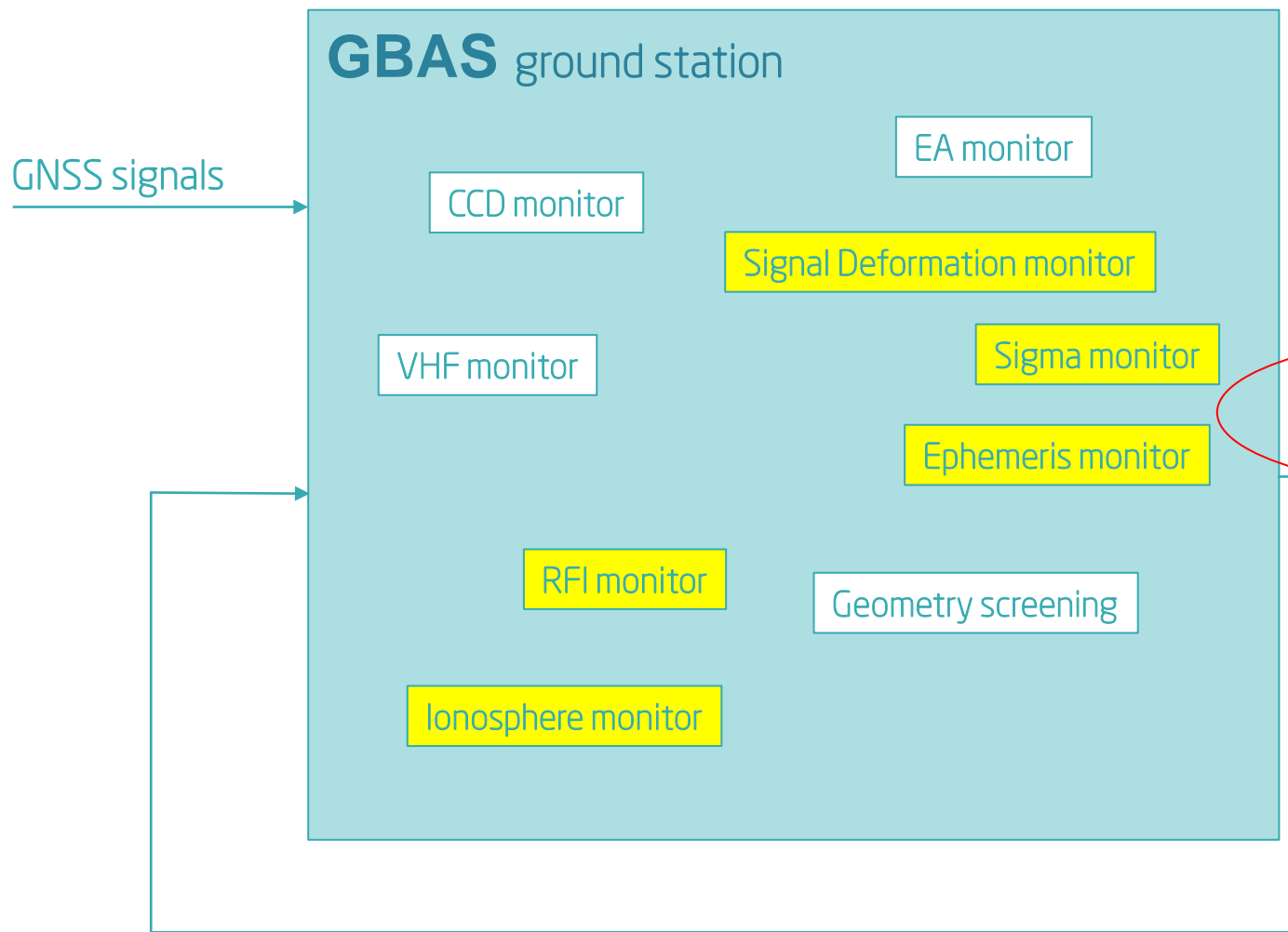
- 170 Gates
- 394 events
- 77 quantitative failure models

- Fault tree results:

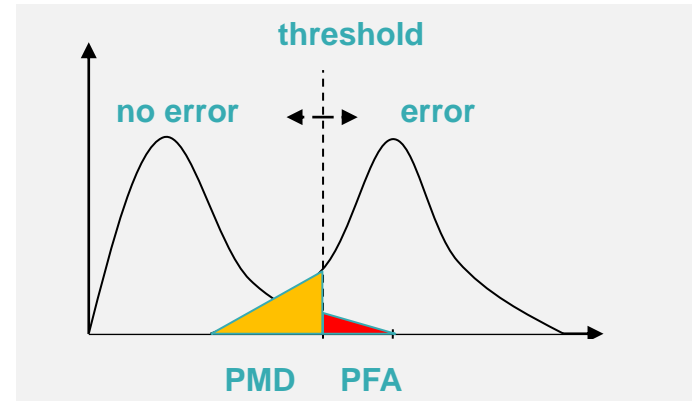
- Ground station integrity faults: max probability: $3.9E-11$ / 15 s approach w/ 1 year maintenance interval
 - Requirement: $1 E-9$ in any 15 s
- Ground station continuity - provided for a variety of GS configurations and various repair times:

Mean Time to Repair (MTTR)	Continuity (per 15 s)	Unavailability (per hour)	Availability
MTTR = 1h	3.336E-08	8.995E-06	0.999991
MTTR = 6h	3.345E-08	4.903E-05	0.999951
MTTR = 12h	3.355E-08	9.720E-05	0.999903
MTTR = 24h	3.375E-08	1.940E-04	0.999806

- Out of slot: $8.8E-9$ in / 15 s
 - $1E-7$ in any 15 seconds

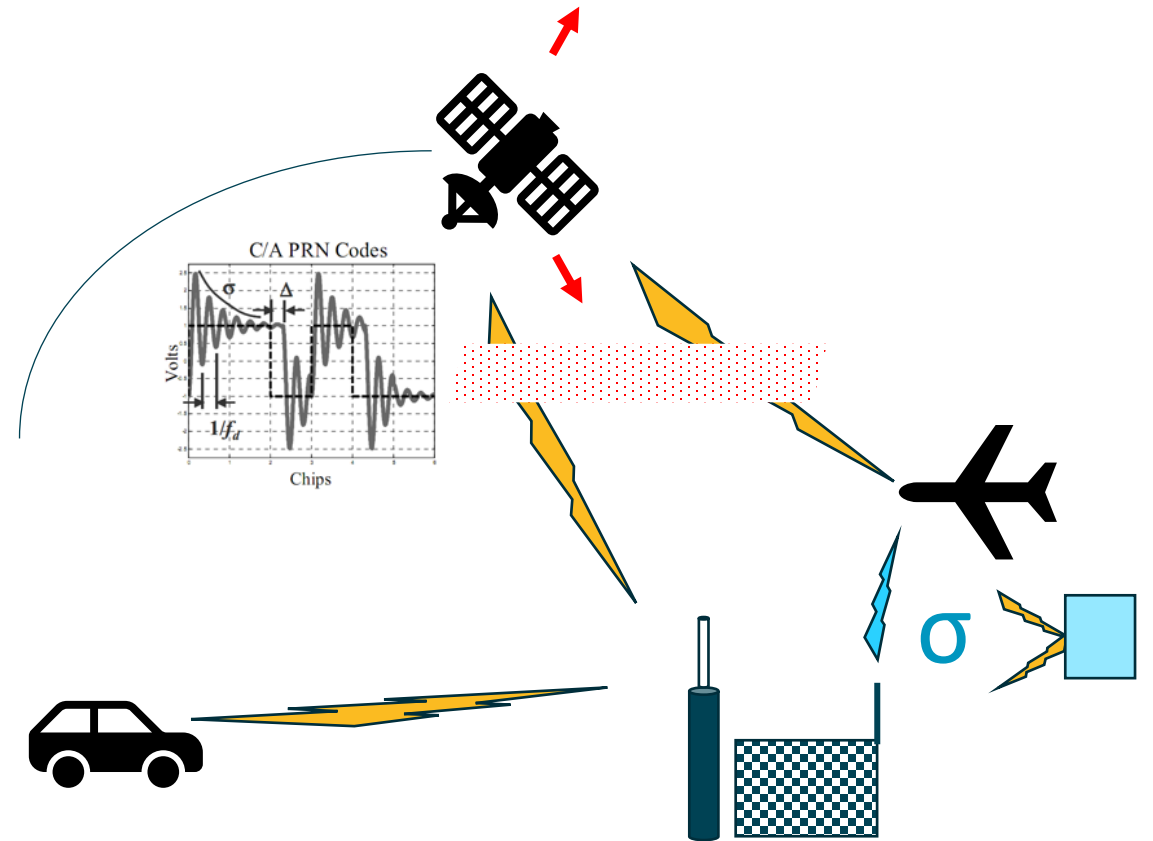


Correction signals to the aircraft on VHF

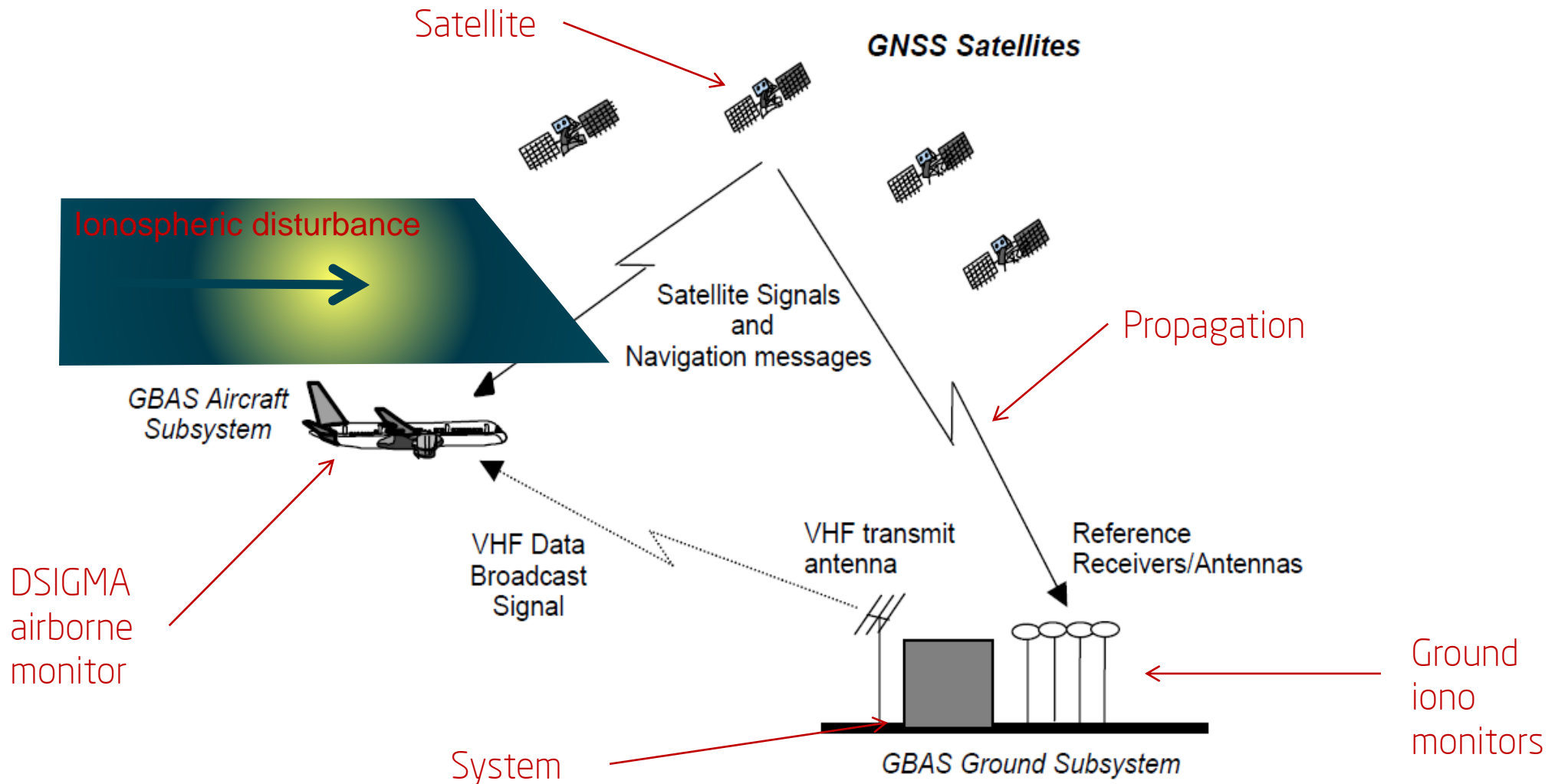


GAST D monitors

- Sigma monitor
- Ephemeris monitor
- Radio Frequency Interference monitor
- Signal Deformation Monitor
- Ionosphere monitor

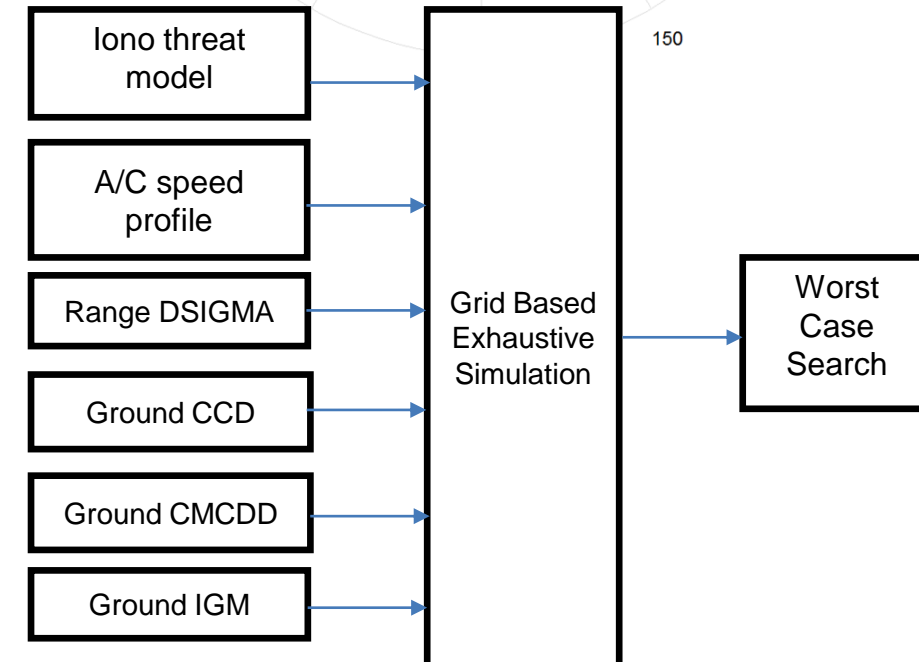
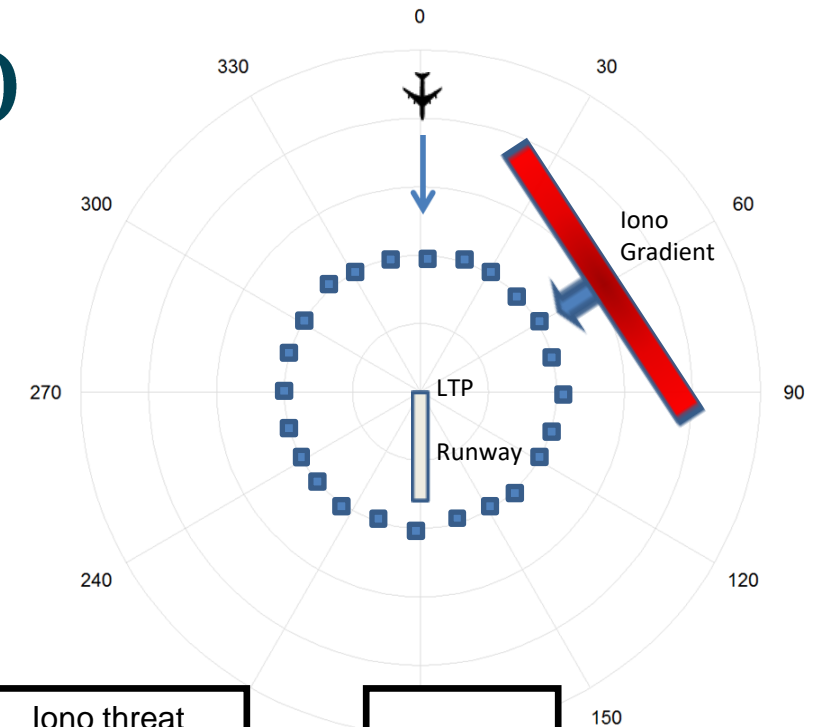


System architecture, ionospheric disturbance



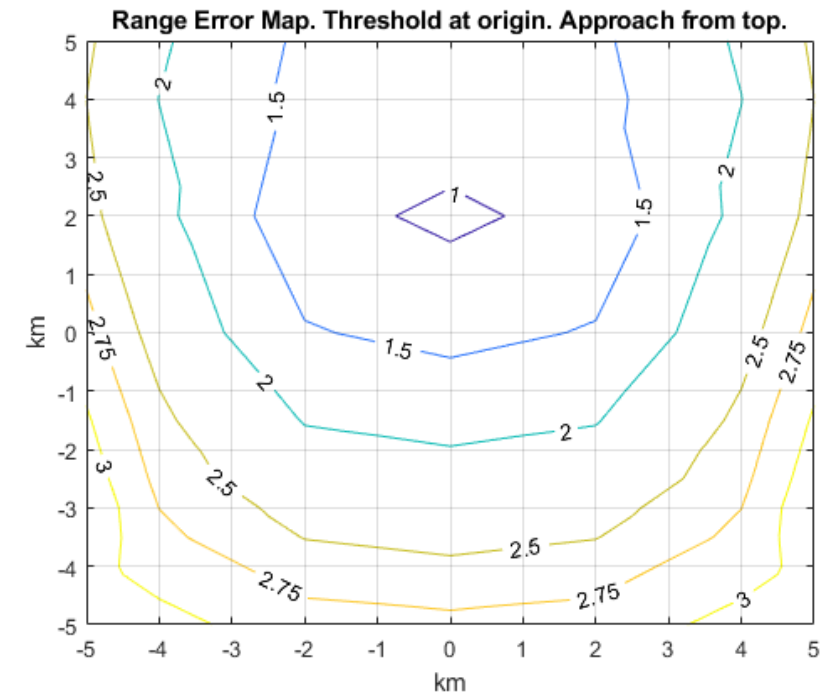
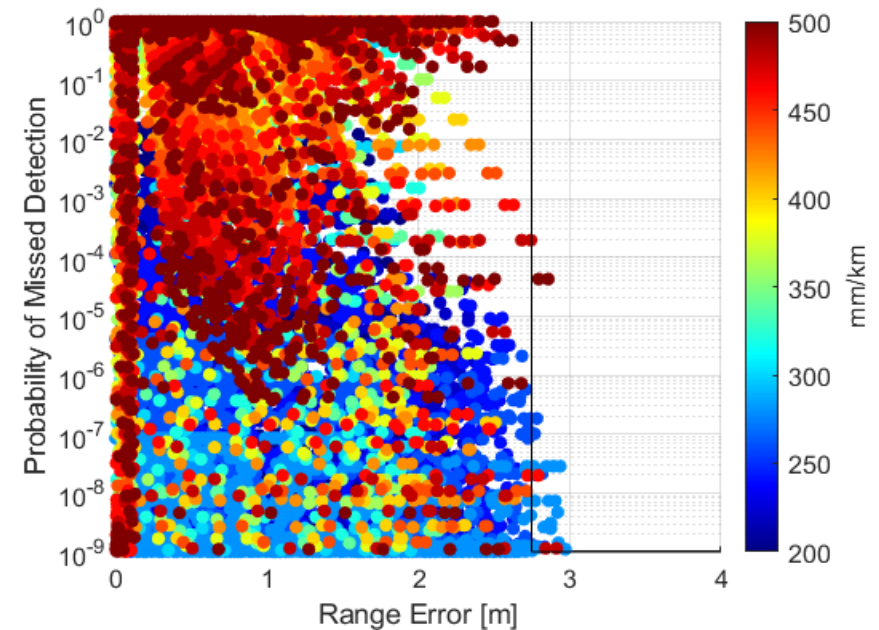
Ionosphere Monitoring for GAST D

- Ionospheric gradients may result in large errors (several meters) on the corrected pseudorange.
- Broadcast integrity (EIG) parameters used by airborne geometry screening.
- Fast moving gradients can be detected by both air and ground (DSIGMA, CCD, CMCDD monitors).
- Slow moving gradients are challenging. Can be detected by the ground Ionospheric Gradient Monitor (IGM) using carrier phase double differences across antenna/receiver baselines.
 - Sensitivity to baseline lengths and directions.
 - Anomalous troposphere may confound the monitor.
 - Long baselines or a dual frequency receiver resolves the tropospheric issue.
- Worst case simulations show compliance with integrity requirements.



Ionospheric Gradient Simulation

- The top right figure shows P_{MD} as function of range error for a GBAS located 5 km from LTP. 2.75m range error is marked.
- The bottom left figure shows range error at $10^{-9} P_{MD}$ for different GBAS locations wrt LTP at the origin.
- Broadcasting EIG values larger than 2.75m will require an availability simulation to show that it will be acceptable.
- Improving IGM performance will improve the results.
- The ionospheric threat space proposed by ICAO is mitigated for distances between GS and LTP up to almost 5 km.



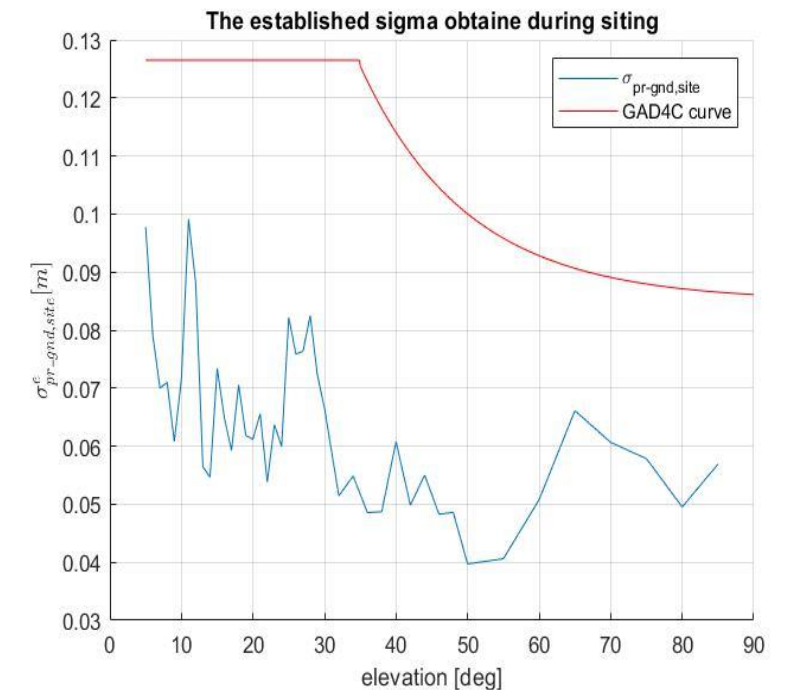
Sigma Monitor

- Beside the corrections, the GBAS ground subsystem (GS) broadcasts integrity parameters which are used by the airborne user to compute protection levels, i.e. upper confidence limits on position error in vertical (VPL) and lateral direction (LPL).
- σ_{pr_gnd} is an important integrity parameter that should represent the standard deviation of the GS contribution to the error associated with the broadcast corrections.
- The aircraft assumes this error to be normally distributed (Gaussian) with zero mean and σ_{pr_gnd} standard deviation.
- To ensure integrity, the true error standard deviation cannot be larger than this broadcast value.

Sigma Monitor II

Challenges and Solution

- The error distribution is **not** Gaussian **nor** zero-mean. Thus, σ_{pr_gnd} should **overbound** the error distribution whatever it is.
- Local conditions affect σ_{pr_gnd} , for instance the local multipath environment which can change with time, or from one season to another.
- The integrity requirements are so strict that we cannot calculate σ_{pr_gnd} statistically. Further, there is no mathematical model to calculate the error distribution online.
- Hence, σ_{pr_gnd} is constructed by using statistical and theoretical methods. Samples of the correction errors (b-values) over one day are collected during siting to calculate the standard deviation (sigma). Then, theoretical methods are used to account for all other possible sources of error.
- To guarantee the integrity, the sigma and the mean must be monitored all the time.



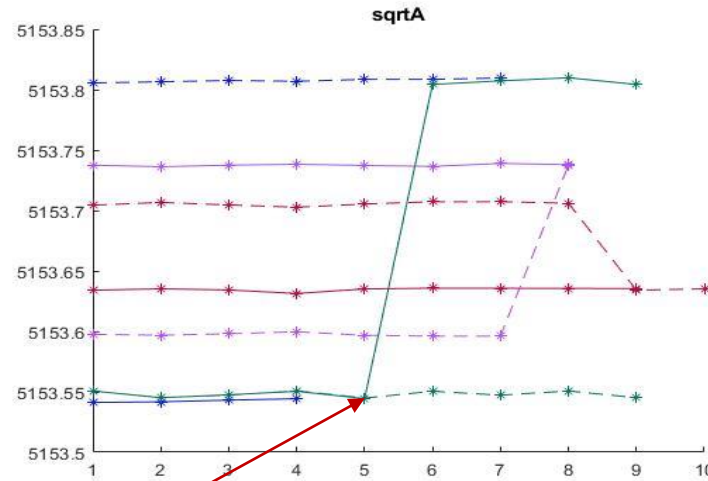
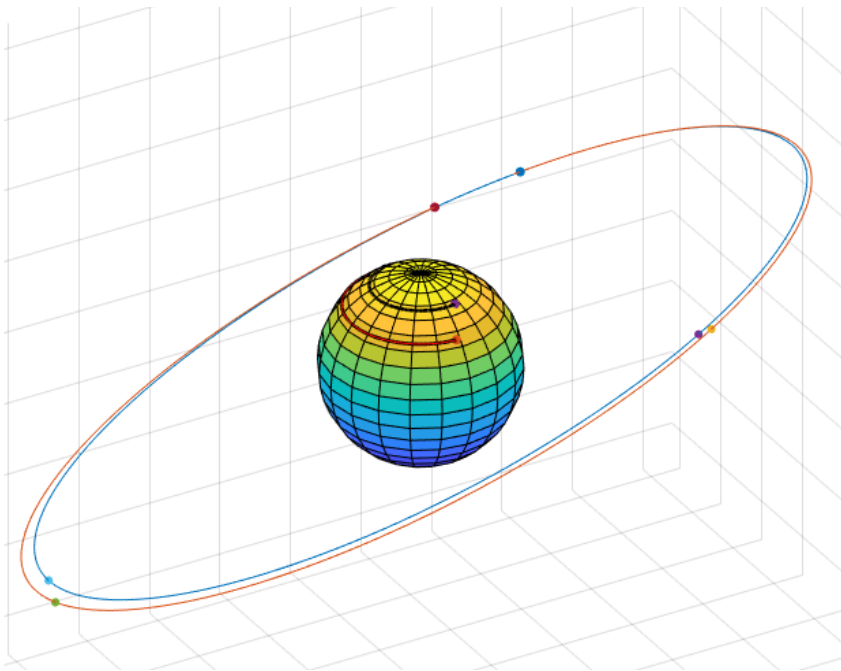
Sigma Monitor III

Monitors

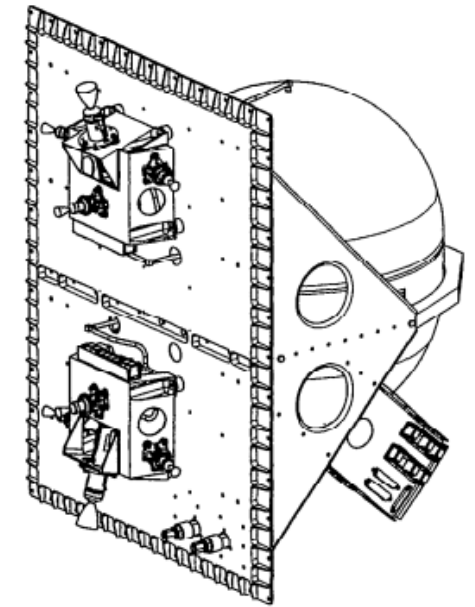
- Sigma monitor detects whether the broadcast σ_{pr_gnd} no longer represents an upper bound (overbound) on the true error standard deviation.
- Independent samples of the correction errors (b-values) are collected over time.
- The sigma of the samples is calculated every hour, day, month, year and since initialization.
- Each sigma is compared to the broadcast σ_{pr_gnd} to ensure that the latter is always larger.
- In addition, the mean of the samples is calculated every hour, day, month, year and since initialization to ensure that the mean is within the allowed limits.

Ephemeris Monitor

- Spacecraft manoeuvre (type A)
 - Including uncommanded manoeuvres.
- Broadcast error (type B)



Parameter	Explanation
t_{oe}	Ephemerides reference epoch in seconds within the week
\sqrt{a}	Square root of semi-major axis
e	Eccentricity
M_o	Mean anomaly at reference epoch
ω	Argument of perigee
i_o	Inclination at reference epoch
Ω_0	Longitude of ascending node at the beginning of the week
Δn	Mean motion difference
\dot{i}	Rate of inclination angle
$\dot{\Omega}$	Rate of node's right ascension
c_{uc}, c_{us}	Latitude argument correction
c_{rc}, c_{rs}	Orbital radius correction
c_{ic}, c_{is}	Inclination correction
a_0	SV clock offset
a_1	SV clock drift
a_2	SV clock drift rate



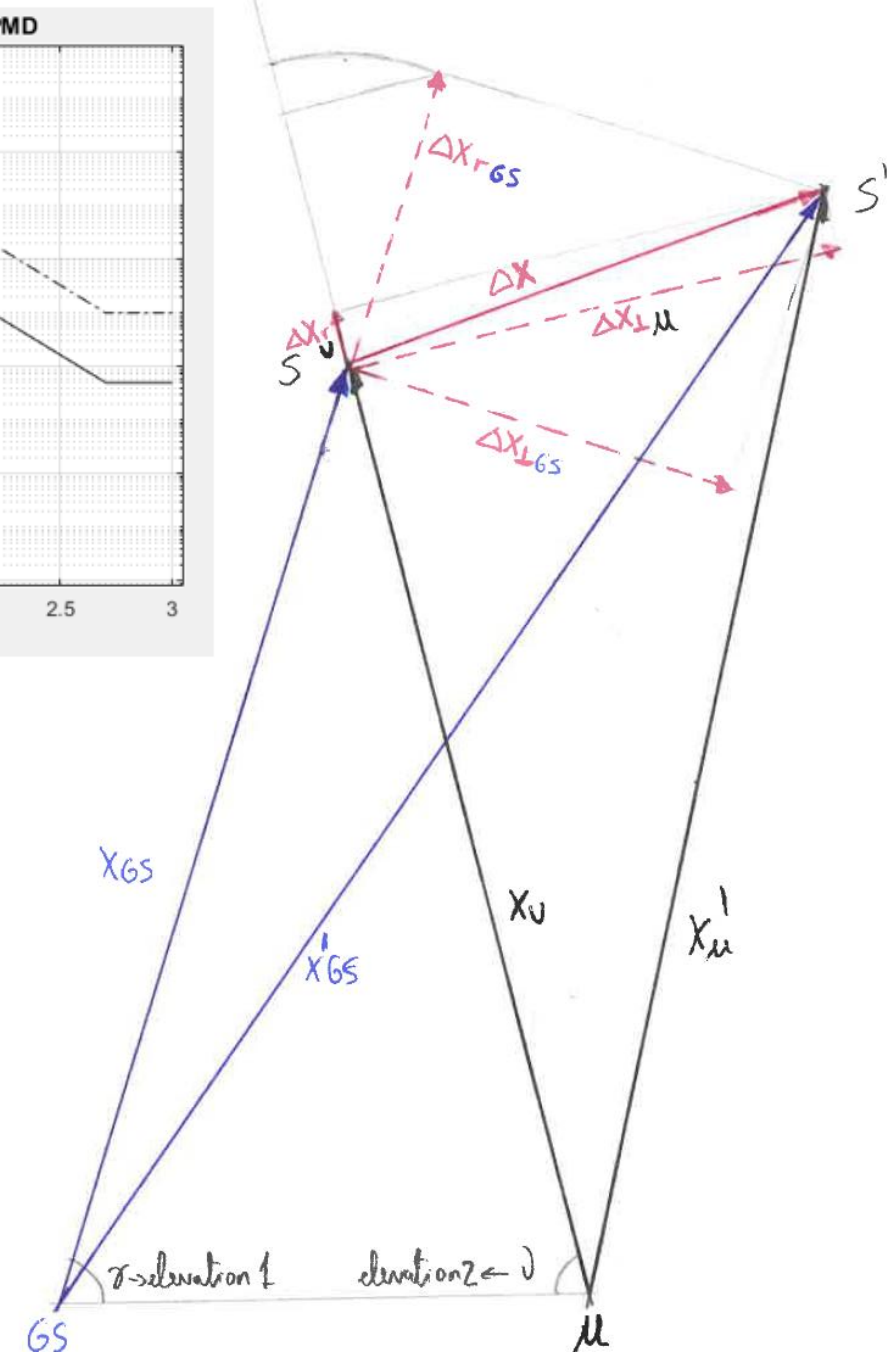
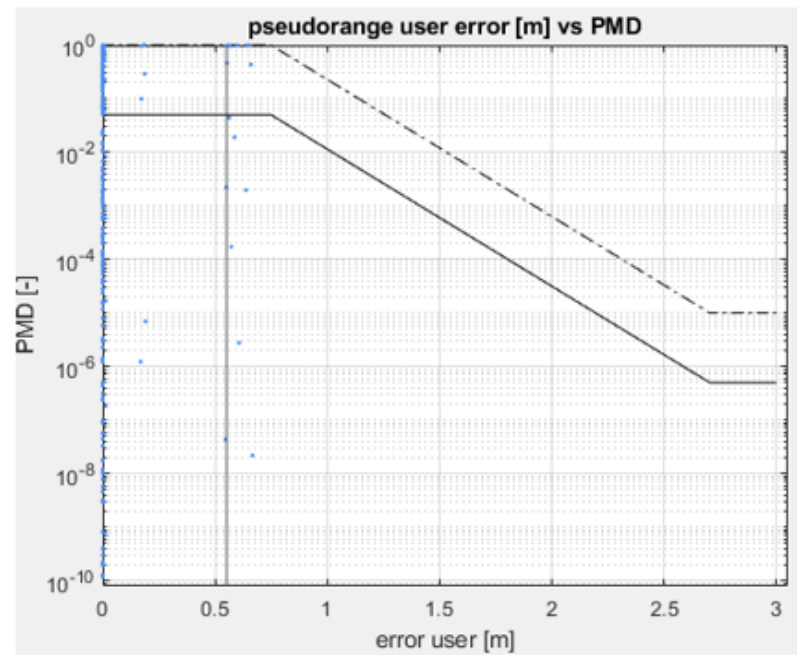
Ephemeris monitor

■ Type A monitors

- Pseudorange monitor → Received range vs expected range
- Excessive acceleration → Evaluate 1st and 2nd derivatives of the range against a threshold
- Geometry Free Triple Difference → Evaluate the spatial and time rate of change of the range against a threshold

■ Type A validation

- Simulate satellite orbits and produce a set of feasible maneuvers:
 - Grid of maneuvers from 0 to max engine thrust in all directions (along track, radial, and normal)
 - Different configuration settings (latitude/longitude, distance to user, runway orientation...)
- Check that the monitors detect satellite position changes before error at user level is above requirements



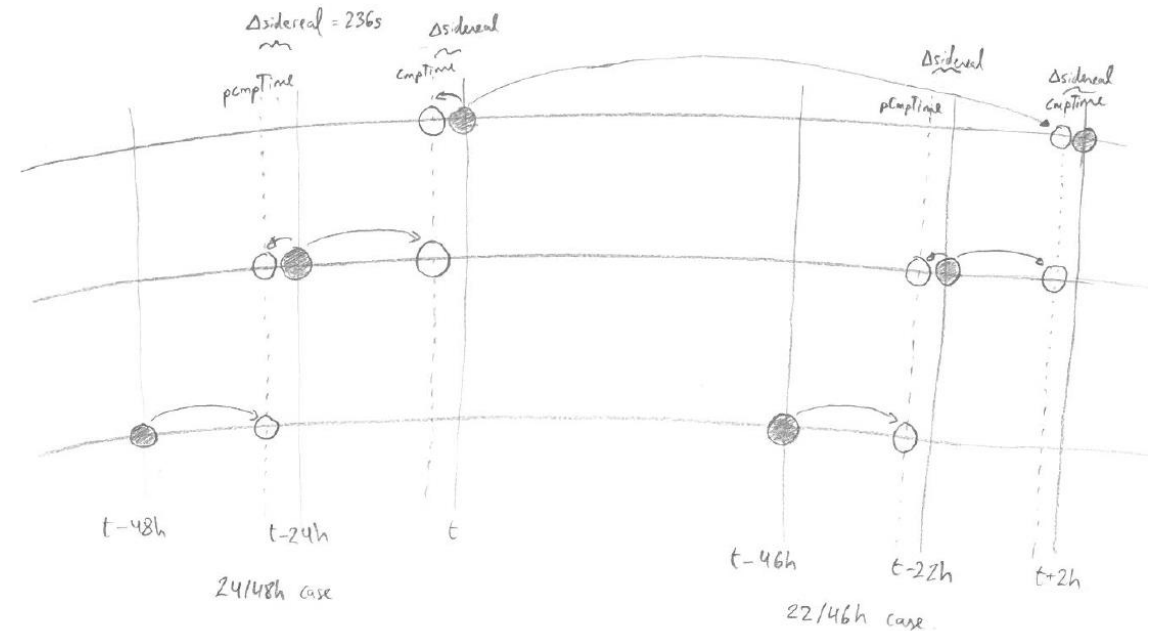
Ephemeris monitor

■ Type B monitors

- Check if today's satellite position is sufficiently similar to yesterday's position
- Variations using projected positions to $\pm 2h$ compared to yesterday position
- Variations using the day before yesterday

■ Type B validation

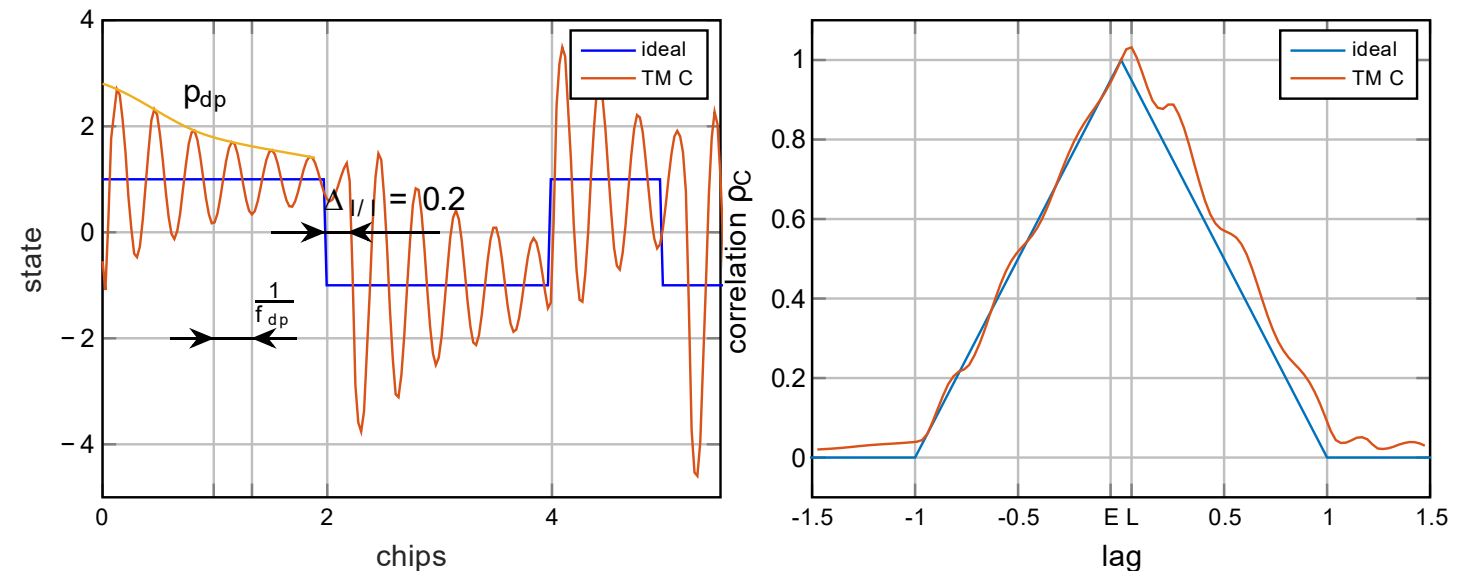
- Gather data from several years and compute standard deviation of satellite position change after a day
- Check if there are errors in data from another year \rightarrow If an error is detected analyze data to confirm detection



Signal Deformation monitor

An error detected once in one GPS satellite in 1992.

Transmit delay $\Delta_{l/l}$, and ringing (p_{dp} , f_{dp}), result in a deformed correlation peak at the receiver.

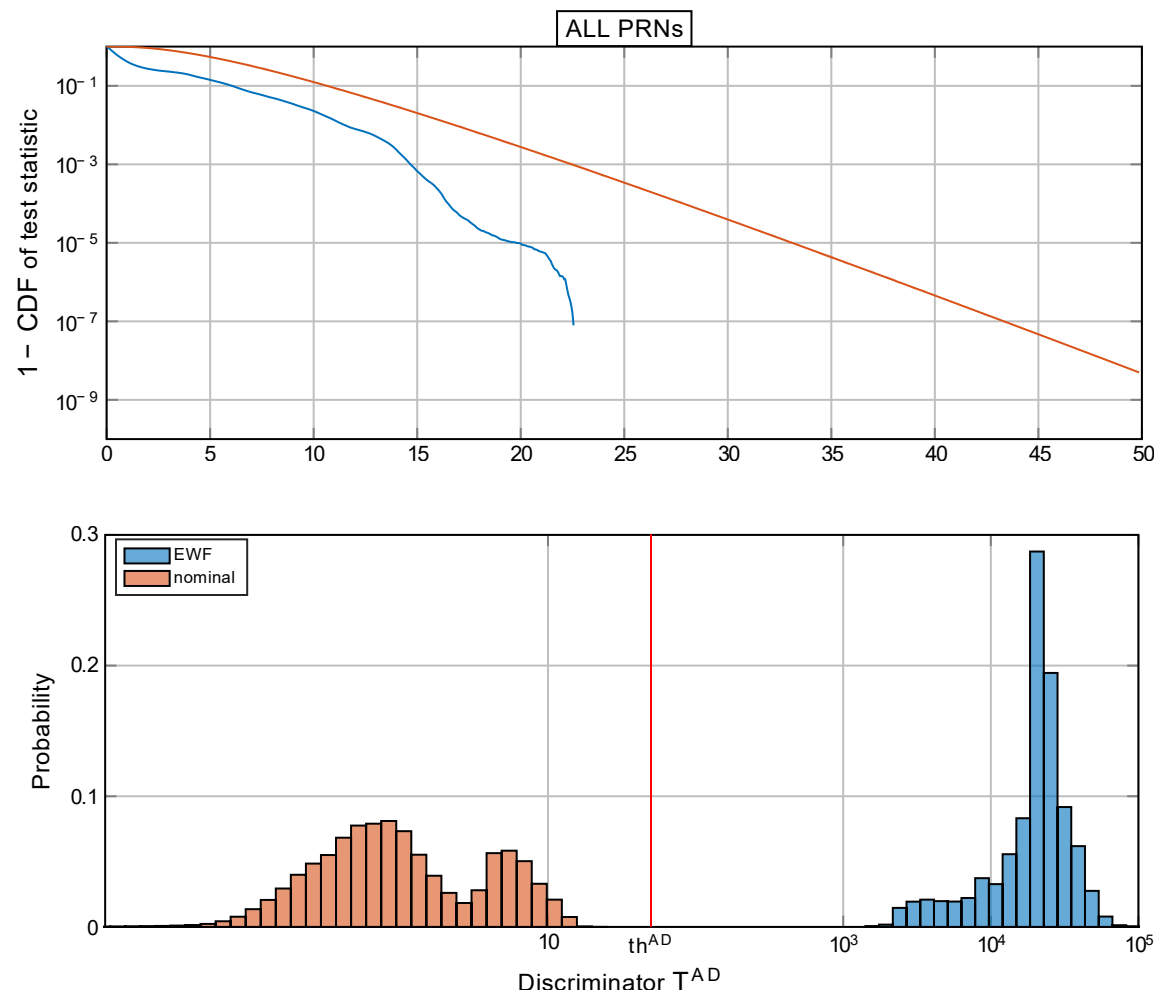


Signal Deformation monitor

The test statistic is based on differences between measured points on the correlation peak.

The multipath environment is taken into account.

Continuity and Integrity performance tests show compliance with the requirements.



Radio Frequency Interference

- On 2nd of February 2016 an incident was recorded by the prototype GAST D GBAS station at Frankfurt airport
- Incident occurred in the evening at 21:40:30 UTC lasting approximately one minute
- No usable satellites on any of the ground reference receivers
 - Loss of lock
 - Eliminated by ground station because of too low C/N0
- Use of PPDs is illegal, but we need to cope with this threat.
- The RFI monitor inflates appropriate sigmas broadcast to the aircraft based on C/N0 measurements.



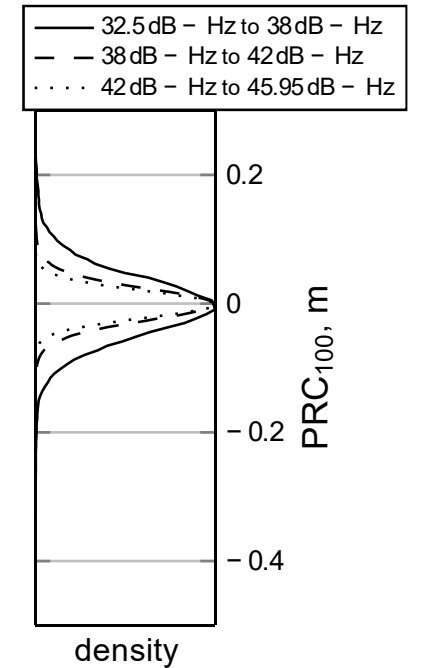
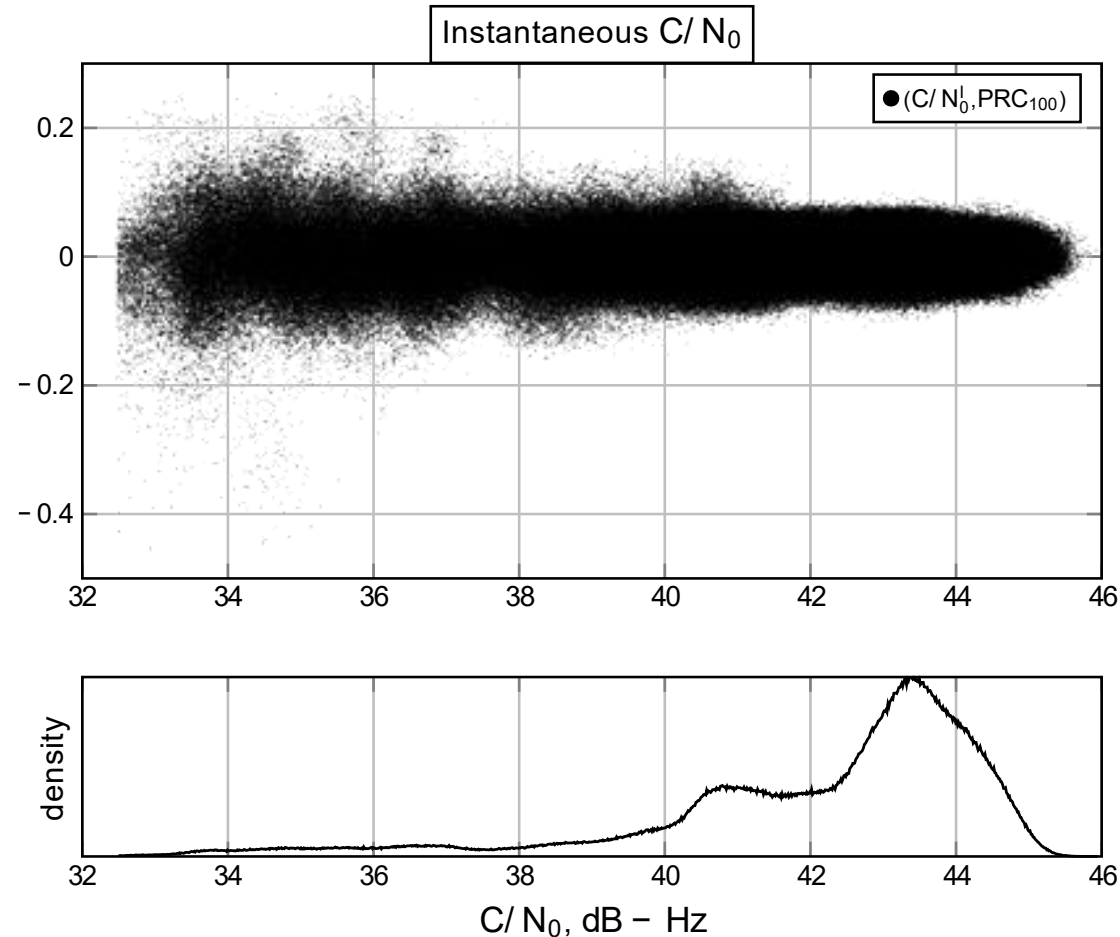
Radio Frequency Interference

Simulation campaign results in 150 different combinations of jammers and accompanying jammer-antennas locations. This amounts to over two million data points which are basis for derivation of the monitor.

All gathered valid measurements registered during the periods when the interference is active are presented for the case of instantaneous C/N_0 .

Apply moving window of certain width sliding through the measurements from minimum to maximum of C/N_0 .

Check for abnormality within each considered window and apply appropriate method to evaluate standard deviation.

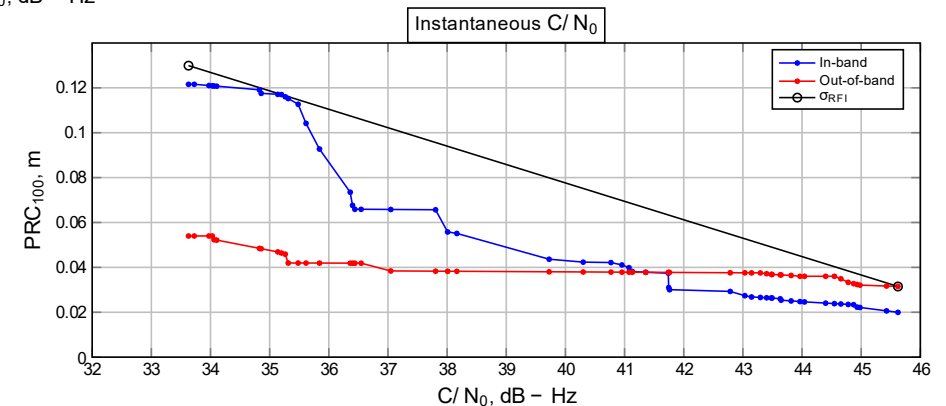
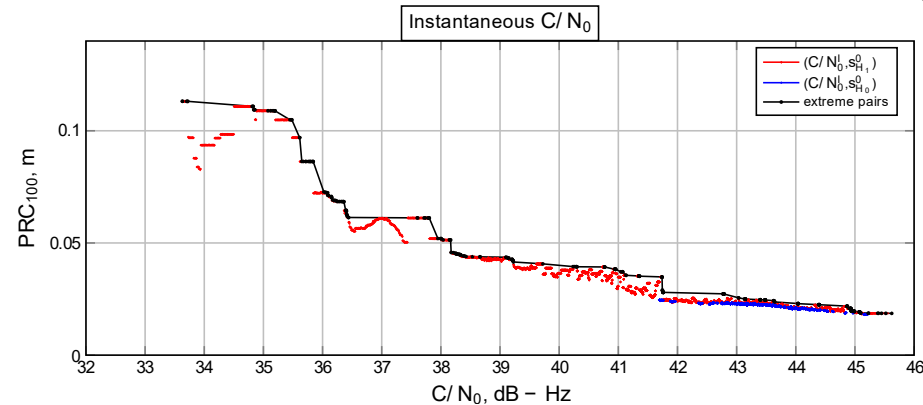
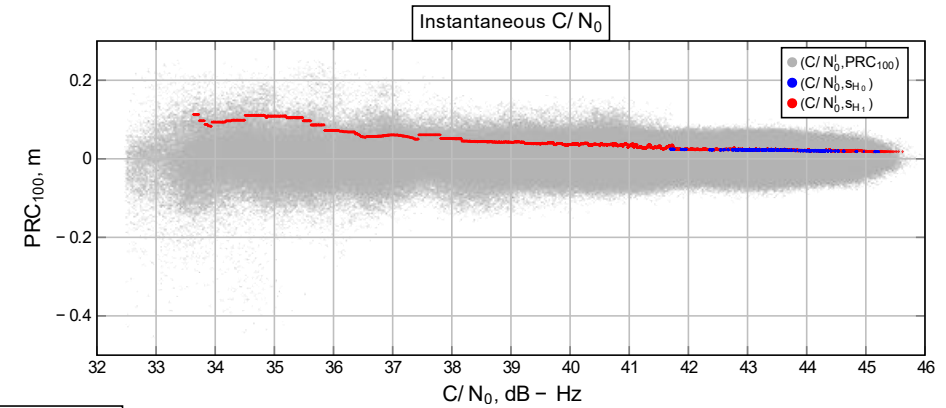


Radio Frequency Interference

Inflate for estimation uncertainty – account for possible bias that resides inside each window. Can be derived from Cochran's theorem.

Envelope the standard deviation in order to minimise the number of points determining the overbounding function.

Account for the out-of-band interference as it does impact the reception differently than in-band jammers. Form the final – linear representation of the overbounding function



Conclusion for main goal achievement:

The performance of the 5 monitors meets the ICAO GAST D requirements with respect to availability, continuity and integrity.

indra

At the core

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