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CAT II/III GBAS Implementation Challenges

NKG General Assembly 2014

"Reference Frames, Positioning and Navigation Seminar"

Gøteborg, 03.09.2014

Outline

Ground Based Augmentation System (GBAS)

- Architecture
- Operational Benefits

GBAS Projects at SINTEF ICT

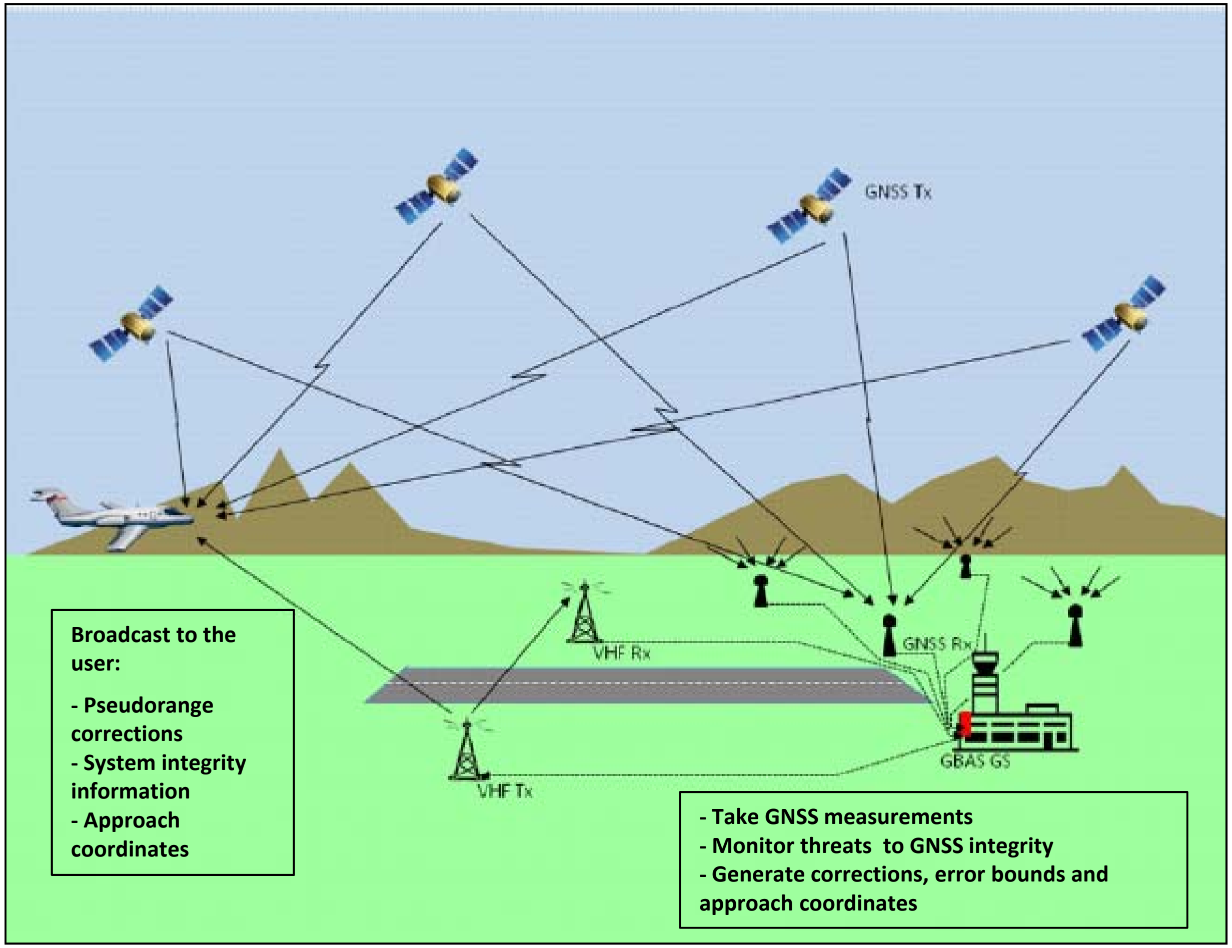
- NORGAL - Nordic concept for CAT III GBAS based Automatic Landing
- SESAR JU: WP 15, P15.3.7 – MC/MF CAT II/III GBAS

Challenges

- Interference
- Anomalous Ionosphere

General GBAS Architecture

- Ground Based Augmentation System (GBAS)



- Supports all phases of approach, landing, departure, and surface operations within its area of coverage.

- Ground Subsystem:
  - 4 Reference receivers
  - GBAS Ground Facility/processing unit
  - VHF data broadcast (VDB) transmitter (108.025 -117.975 MHz)

- > 37 km operation radius.

System Advantages

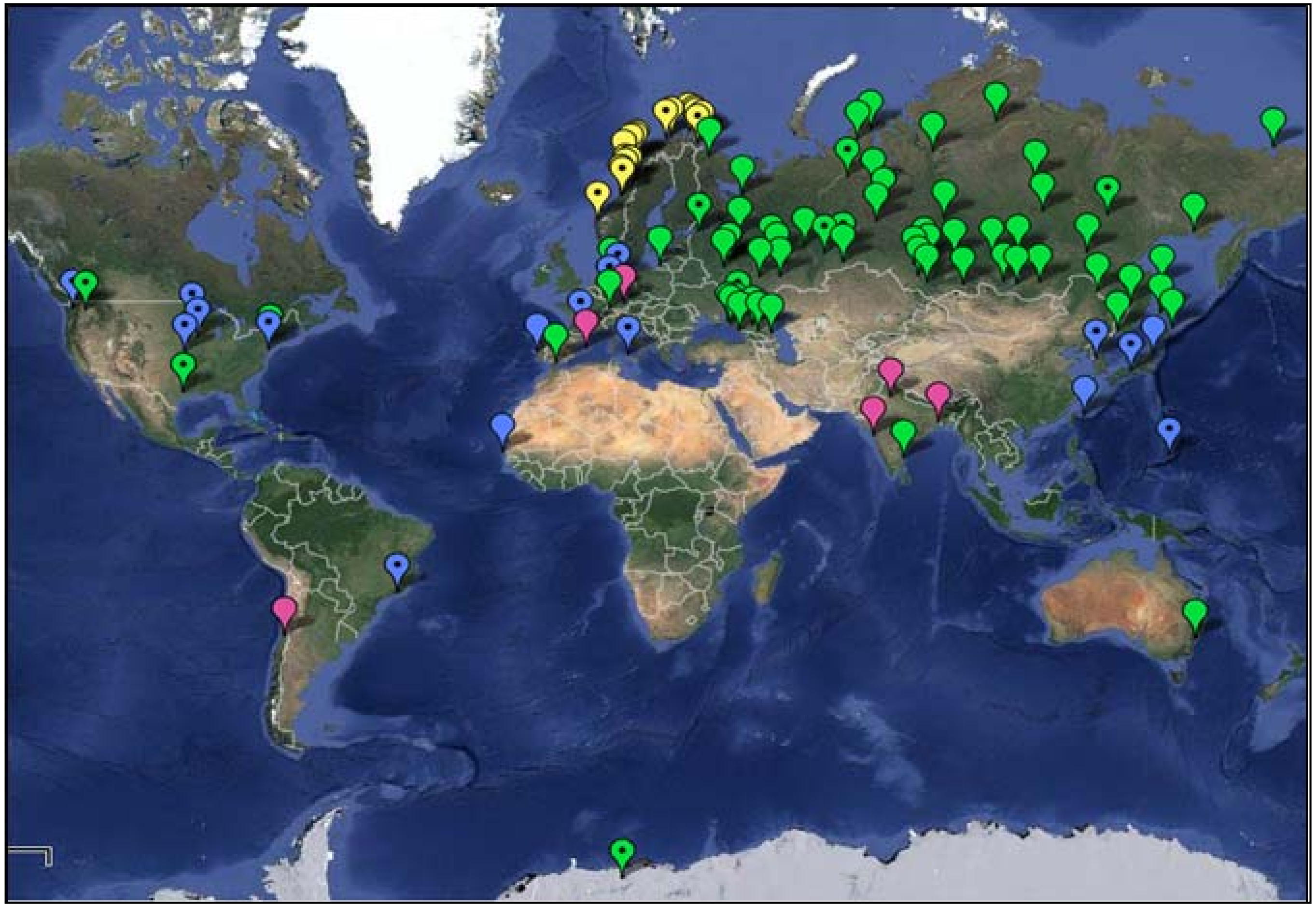
Upper image: courtesy of Indra Navia.
Lower image source: [4].

- Instrument Landing System (ILS) is the most widely used landing system today.
- Requires four installations per runway, and may require substantial work in order to prepare the terrain in front of the antennas as required.

GBAS:

- One GBAS GS can cover all runways on an airport.
- Reduced time between approaches .
- Optimized curved approaches (necessary to create procedures to avoid aircraft flying over specific areas close to airports for reasons of noise over urban areas).
- Curved approaches and reduced time between approaches may reduce fuel consumption in the landing phase.
- Can provide precision approach where ILS cannot due to terrain constraints.

GBAS: Implementation Status



- Operational S-CAT1
- Operational GBAS
- Experimental GBAS
- Planned GBAS

(source: www.flygls.net)

NFR BiA NORGAL – Nordic concept for CAT III GBAS based Automatic Landing (2014-2017)

Partners: Indra Navia, Oslo Lufthavn AS (OSL) , SINTEF and Norwegian Air Shuttle.

Project objective: development and validation of GPS L1 based CAT III GBAS for precision landing operations in the challenging environments (frequent ionosphere disturbances, challenging siting etc.) of the Northern Europe.

Selected project tasks:

- Siting analysis (Gardemoen)
- Integrity monitor algorithm development and verification (focus on the high latitude regions)
- GBAS approach procedure design
- System performance validation

SESAR P15.3.7– Multi GNSS CAT II/III GBAS (2013-2016)

Partners: Eurocontrol, Indra Espacio, Thales, DFS, DSNA, ENAC, NATMIG (Indra Navia and SINTEF), Aena, SELEX, Airbus, Honeywell, ENAV, DLR and NLR as associated partners.

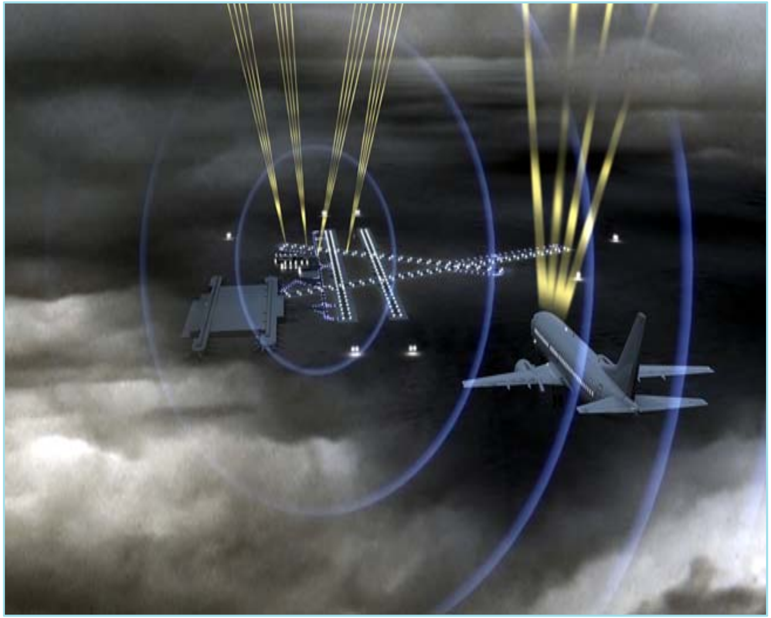


Image source: [2].

Project objective: evolution of single frequency GBAS CAT II/III (GAST-D) based on GPS L1 towards multi-constellation, multi-frequency GBAS.
Core constellations and signals considered: GPS L1 and L5, Galileo E1 and E5a.

Selected activities:

- System architecture and requirements definition (objective - establish baseline SARPS).
- Multi-constellation, multi-frequency processing.
- Ionosphere anomaly characterization and threat model definition (subcontracting the NMA).
- MF MC GBAS ground monitor development.

Challenges: RFI

- A single powerful jamming device can temporarily deny GBAS service for an entire airport or degrade the performance.
- Potential interference sources:
  - in-car GPS/GNSS jamming devices (the so-called personal privacy devices (PPDs)).
  - GPS/GNSS repeaters, spoofers.
  - existing aeronautical navigation systems (e.g. DME and TACAN).
  - etc.

[5].

PPD	Antenna	Freq (GHz)	Power (dBm)
WoolvesFleet GPS L1-L5	1	1.5709	+7.11
	2	1.2004 1.5478 1.7026 1.8965	+8.49 -23.11 -39.52 -40.83
	3	1.2757	+8.39
	4	1.0745 1.1252 1.1758 1.2279 1.2786	-13.20 -8.45 +1.86 +2.36 -15.48

Pure HW Simulation Capabilities

- Spirent HW GNSS Simulator (GPS L1CA, L5, Galileo E1, E5a, E5b and AltBOC)
- RF signal generator from Agilent
- 2 different NovAtel HW receivers used (GPStation 6 and OEM628).
- For OEM628 to acquire as fast as GPSstation 6 required external reference oscillator.

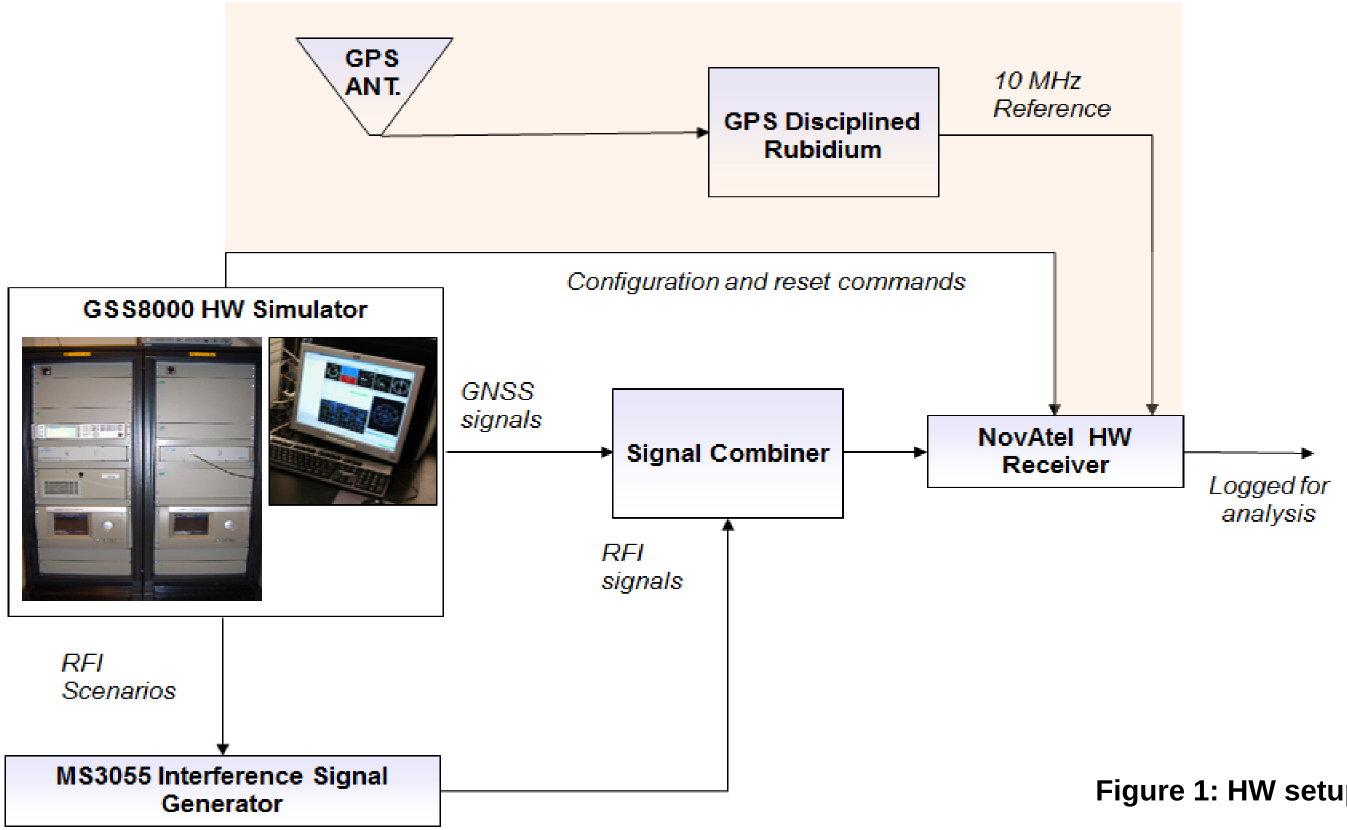


Figure 1: HW setup.

Simulated Sources and Specifications Example

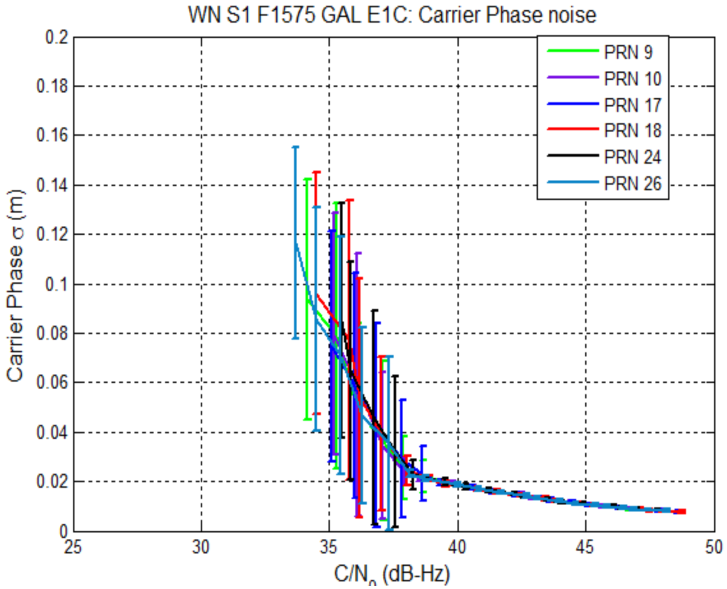
Type of scenario	Shape of modulation function	BW	Power level range in dBm	Chirp rate	Sweep rate	Frequencies
Static	Wideband Noise	24 MHz	-90 to -67 (24 steps)			1575.42 MHz 1176.45 MHz
Static	FM (RAMP, TRIANGLE, SINE)	10 MHz 20 MHz	-92 to -69 (24 steps)	10 kHz		1575.42 MHz 1176.45 MHz
Static	CW noise	1500 Hz	-92 to -69 (24 steps)		50 Hz/s	1575.42 MHz 1575.42+1.023 MHz 1176.45 MHz
Dynamic	Wideband Noise	24 MHz	-75 to -70 (6 steps)			1575.42 MHz 1176.45 MHz
Dynamic	CW noise	1500 Hz	-75 -to-70 (6 steps)		50 Hz/s	1575.42 MHz 1575.42+1.023 MHz 1176.45 MHz
Dynamic	FM (RAMP, TRIANGLE, SINE)	10 MHz 20 MHz	-75 to -70 (6 steps)	10 kHz		1575.42 MHz 1176.45 MHz

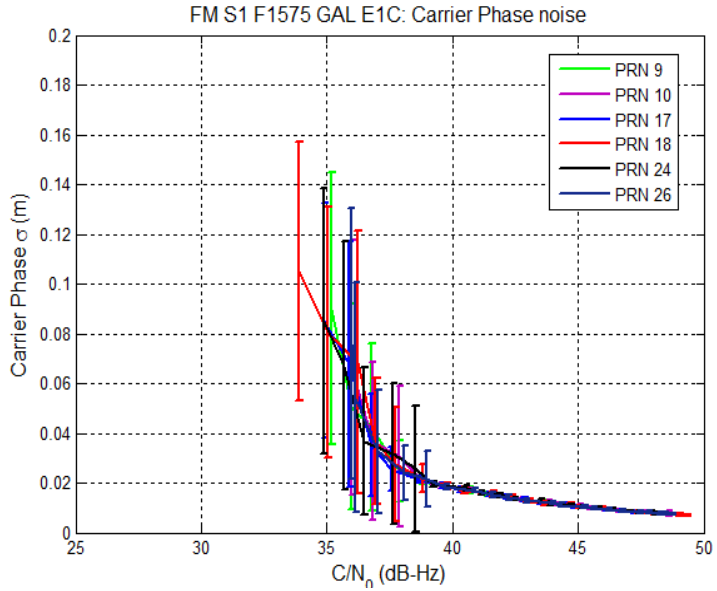
- FM modulation shapes selected to approximate PPDs with single ramp functions
    - Other modulation shapes (e.g. Triangular and Sine) covered for comparison
- CW modulation uses a 50 Hz sweep rate to ensure coverage of a spectral line within the signal envelope

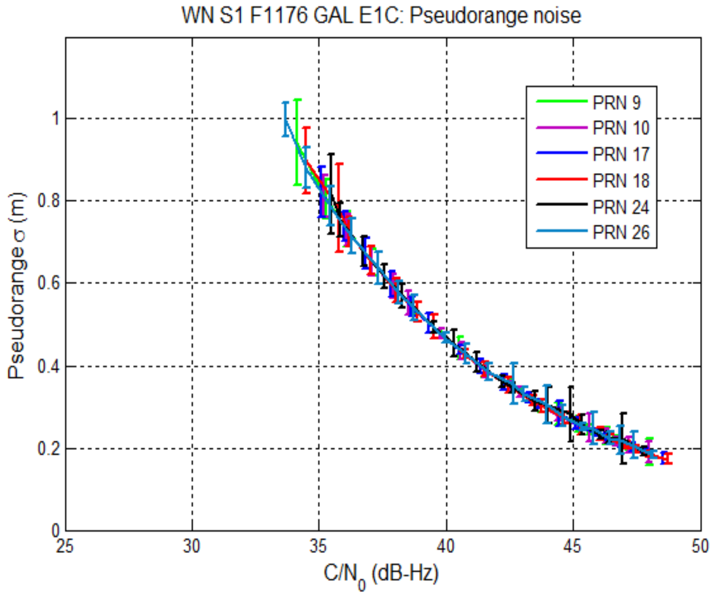
Static Scenario: Carrier Phase and Pseudorange Noise

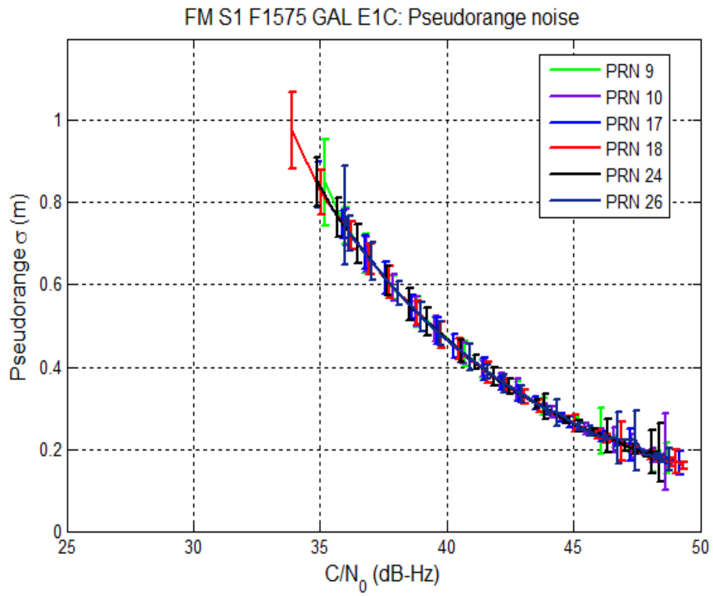
Wideband noise

FM ramp, 20 MHz bandwidth







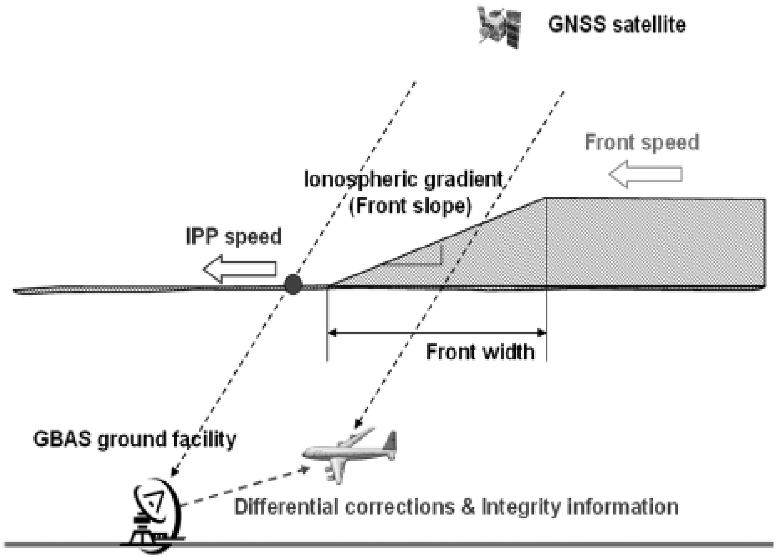


Error bars are established by both averaging over a 30 second long simulation cycle, as well as by repeating each simulation cycle 10 times.

Cycle repetition is done to avoid influence of lost/regained lock transients, etc.

Challenges: Anomalous Ionosphere

Gradient/Spatial Anomaly



- Can manifest as a traveling wave-front of increased TEC over thousands of kilometers
  - Velocity comparable to commercial airliner
  - Misleading corrections – integrity risk

Scintillation

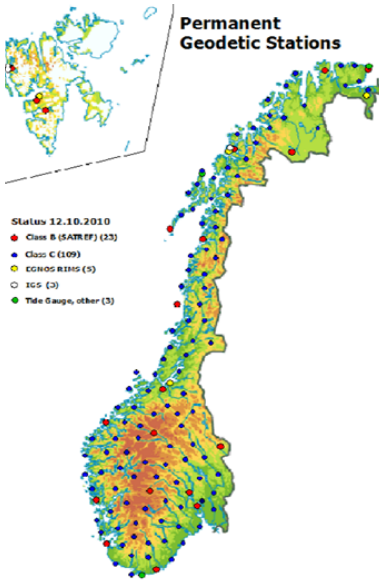
- Effects in different regions follow different physical processes – different typical impacts
  - Polar region can experience both fading and phase scintillation
  - Auroral region can experience strong phase scintillation
  - Mid-Latitude region ideally benign but can experience SED (Storm Enhanced Density)
  - Equatorial region may have very deep amplitude fades
- Several satellites affected – continuity risk

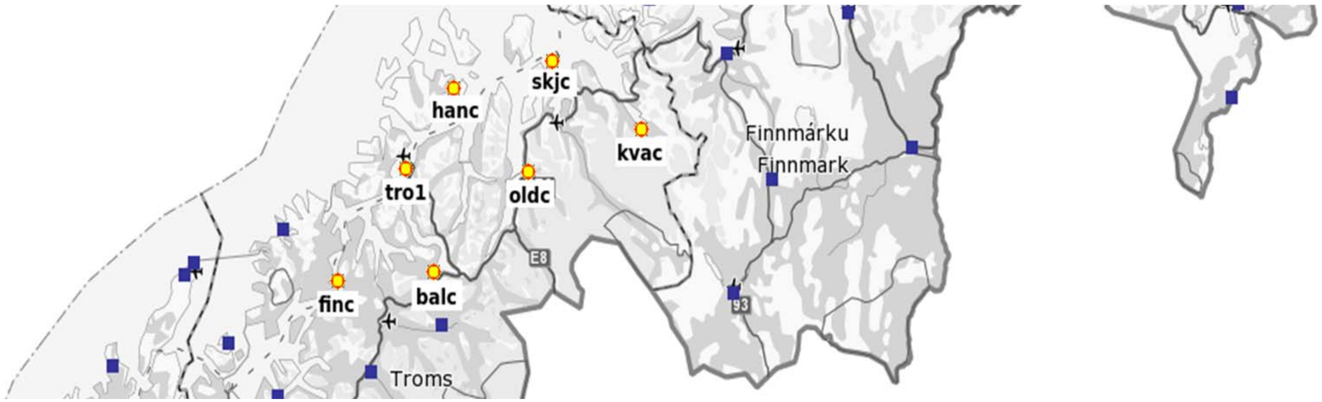
Ionosphere Threat Model Parameter Definition

- Data screening period : 2011-2012
- NMA SATREF network
- Events selected for the preliminary analysis:

List of days processed for parameter determination

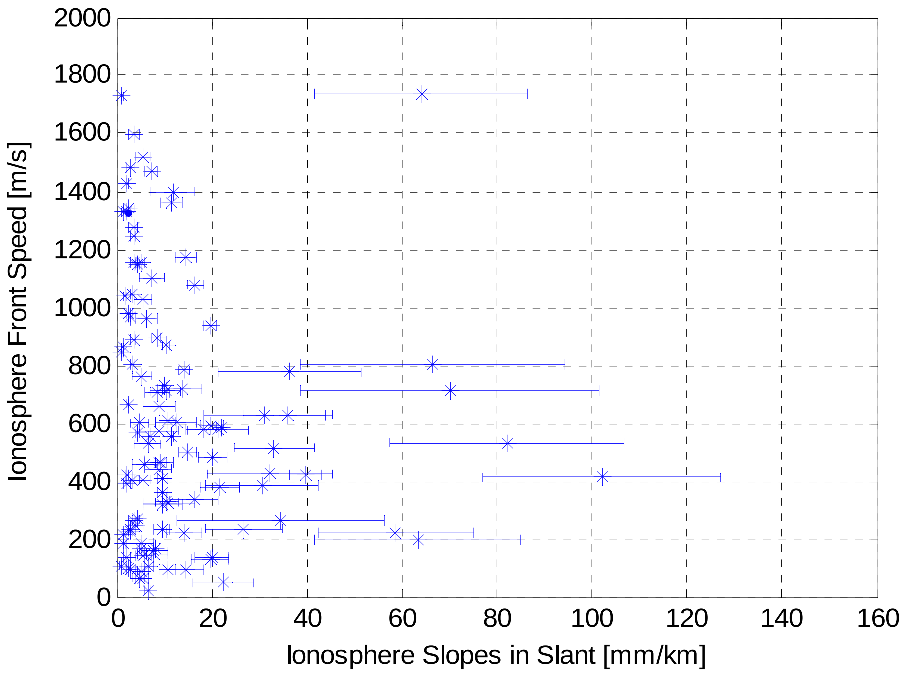
Dates	Geomagnetic storm class	Comments
2011-10-24 - 2011-10-25	G2	Strong. Very strong night-time TEC enhancement.
2011-09-26 - 2011-09-29	G2	Strong. Multiple storm events.
2011-08-05 - 2011-08-06	G3	Strong.

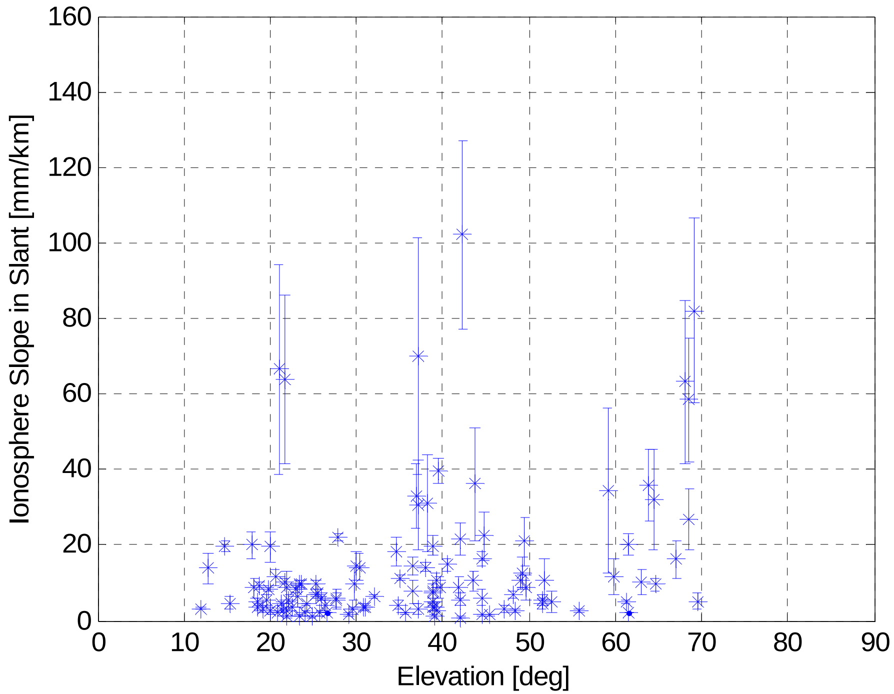




A cluster of receivers in the vicinity of Tromsø (at approximately 70 degrees North) were selected for the analysis.

Preliminary Results (1/2)





Summary of the observed parameter ranges:

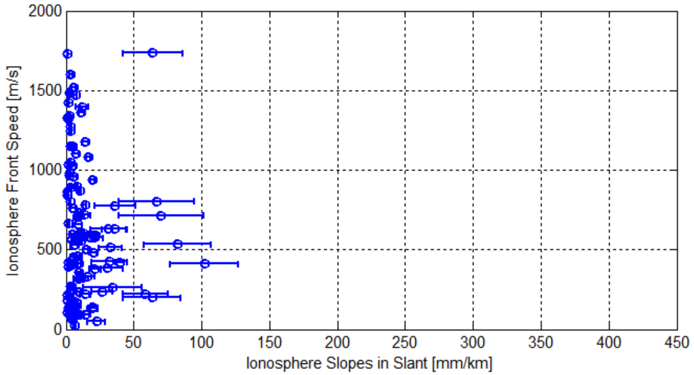
Elevation	Speed	Width	Slope (slant)	D (max. iono delay)
≥ 12°	25 – 1737 m/s	10 – 630 km	0.1 – 102 mm/km	0.1 – 3 m

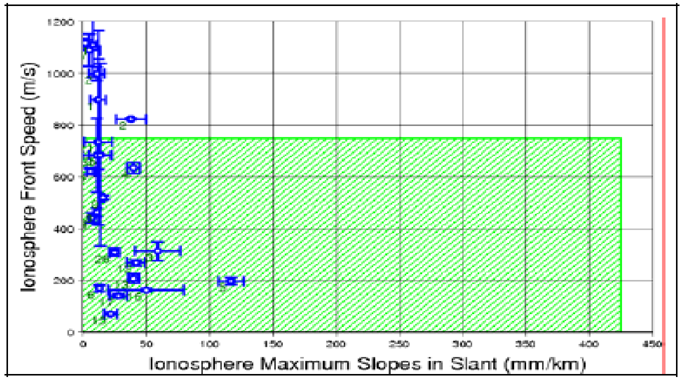
- 35 % of the observations are showing max iono delay ≤ 0.5 m

Preliminary Results (2/2)

Results for Norway compared to the front events observed over Germany [3] along with the CONUS parameter domain.

- All observations of anomalous ionospheric gradients fall within the bounds of the FAA-certified GBAS ionosphere threat model.





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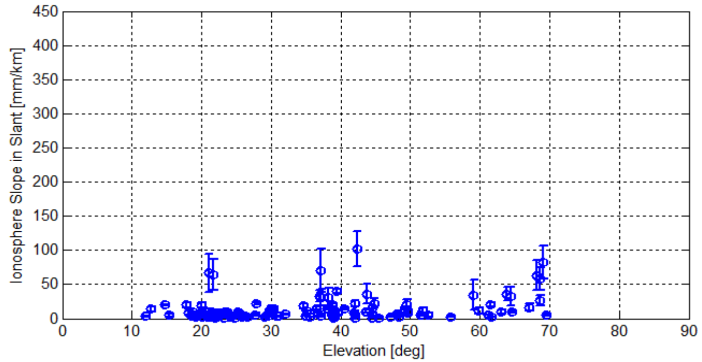

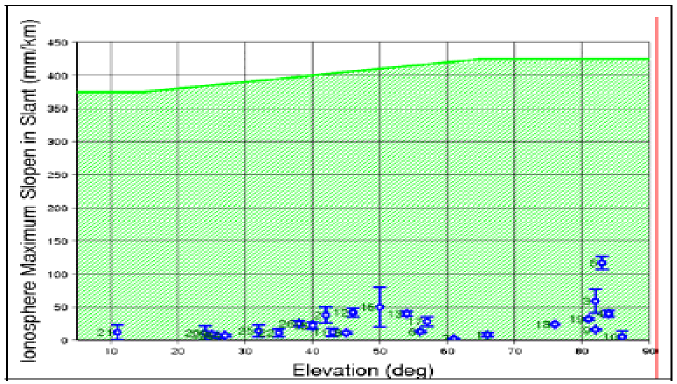

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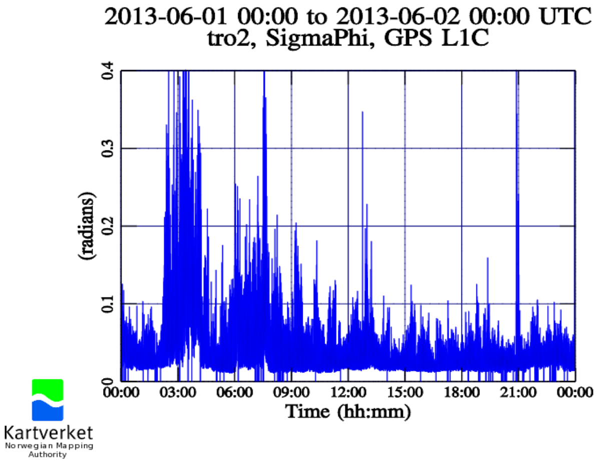
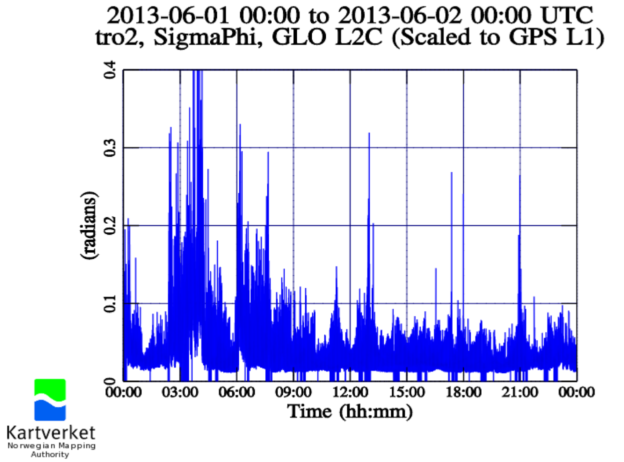
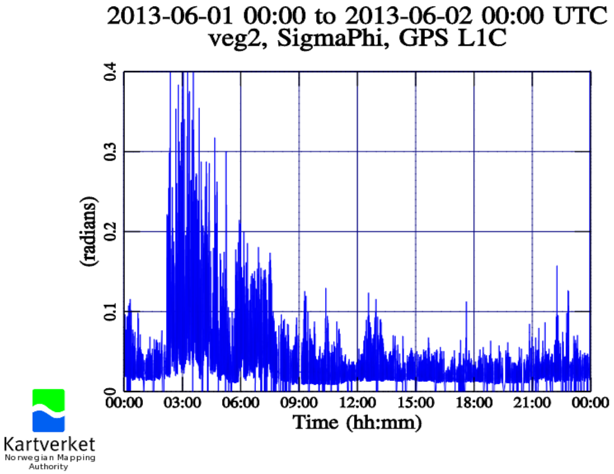
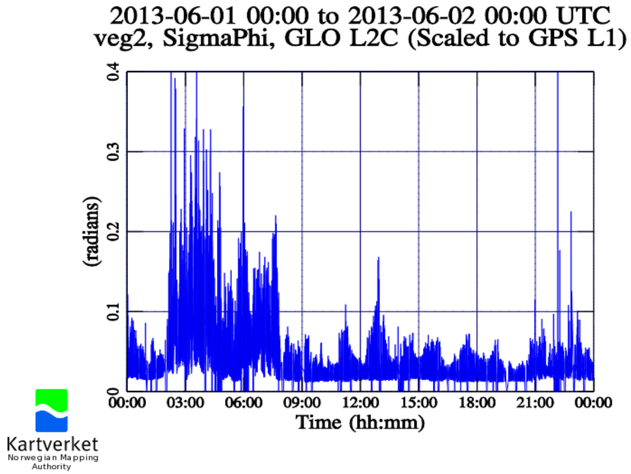
Phase Scintillation Characterization







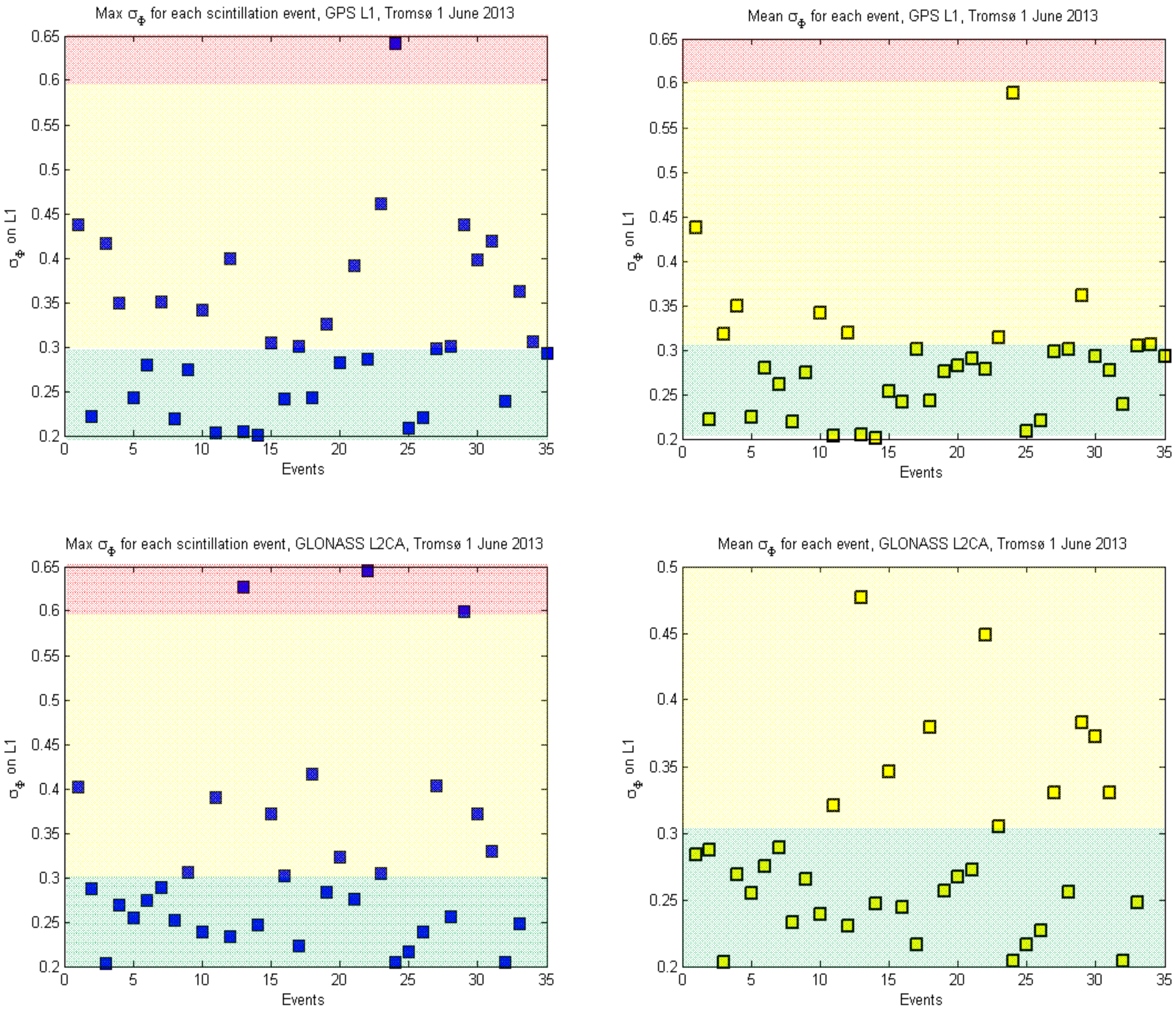


Phase scintillation (σ_φ) observed by satellites in view at Tromsø and Vega scintillation monitoring stations of the NMA network (GPS L1 and GLO L2C).

σ_φ	
0.6	strong
0.3	moderate
0.2	weak
0.05	very weak

Amplitude scintillation also monitored as – only weak events observed ($S_4 \leq 0.3$).

Event Statistics (Tromsø, 01.06.2013)

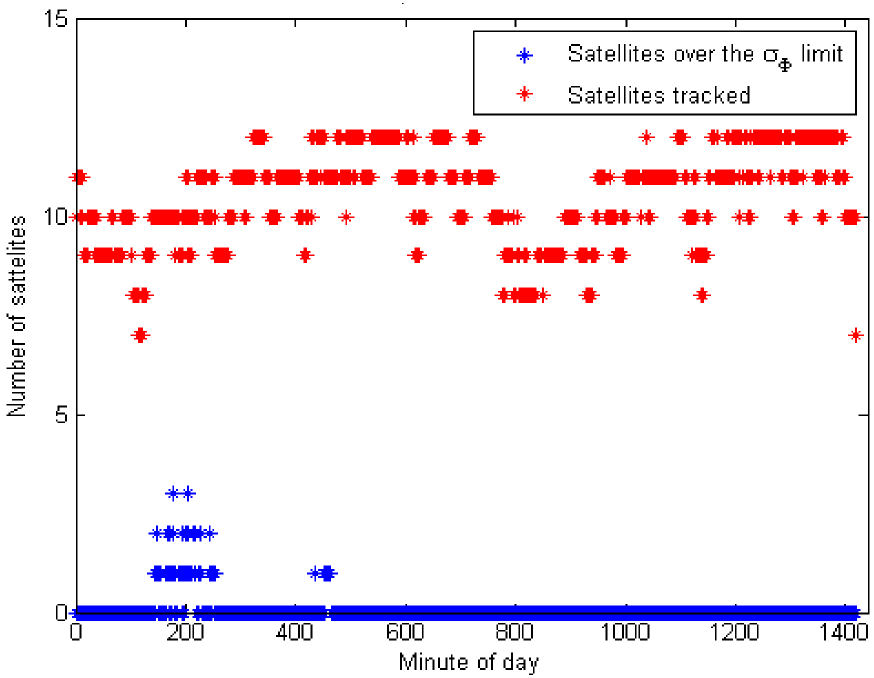


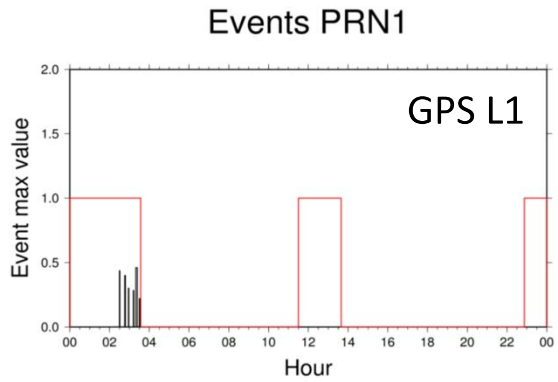
Maximum and mean σ_φ values for each event:

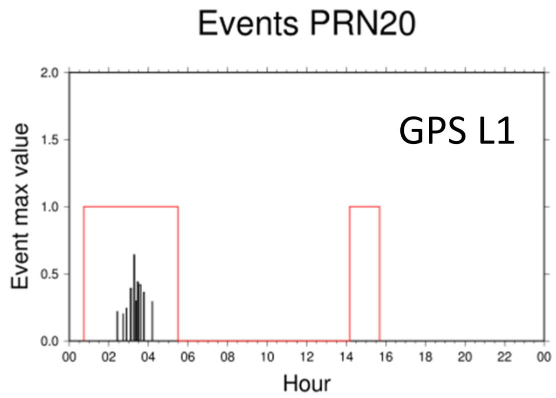
- An event is here defined as σ_φ above the limit for two consecutive epochs.
- σ_φ limit: 0.2 rad
- If a new event is found it is interpreted as part of the same event if less than 1 minute has passed since the end of the previous event.

Frequency of Event Occurrence per PRN and Number of Satellites Affected

GPS L1, Tromsø, 01.06.2013







- Red boxes (images on the right) show period of satellite visibility

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[2]. SESAR JU: "SESAR makes Progress on Precision Landing in Low Visibility", available at: http://www.sesarju.eu/newsroom/all-news/sesar-makes-progress-precision-landing-low-visibility

[3]. C. Mayer, B. Belabbas, N. Jakowski, M. Meurer and W. Dunkel (2009) "Ionosphere Threat Space Model Assessment for GBAS", Proceedings of GNSS09 (Savannah, GA, 22-25 Sep), The Institute of Navigation.

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[5]. Andalsvik Y. L., Jacobsen K. S., Sokolova N., Morrison, A. and M. Stakkeland, (2014) SESAR 15.3.7: Anomalous Ionosphere Characterization. 15th International GBAS Working Group meeting, 3-6 June 2014, Eurocontrol Experimental Centre, Bretigny-sur-Orge, France.

[6]. Andalsvik Y. L., Sokolova, N. Morrison, A., and M. Stakkeland, (2014) Scintillation Analysis: Phase Effects in High Latitude Regions. Landing and Take-Off Focus Group meeting 24 (LATO/24), 8th of April, 2014, London, UK.