



Kartverket

# EGNOS performance during ionospheric disturbances at high latitudes

Results from the Arctic Testbed project

*BSS 2016, Trieste*

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# Arctic Testbed

- ESA project lead by Kongsberg Seatex
  - Part of the European GNSS Evolutions Programme (EGEP) of the European Space Agency (ESA)
  - Aiming at possible improvements to EGNOS service at high latitudes



# Arctic Testbed

- Experimentation is performed using a SPEED platform (Support Platform for EGNOS Evolutions & Demonstrations)
  - Based on EGNOS algorithms, extended for next generation of EGNOS
  - Platform adapted for ATB
  - Located at Norwegian Mapping Authority (NMA) premises in Hønefoss, Norway
- Replay and Play mode
  - Play
  - (Fast-)Replay



# Experimentation

Focused on high latitude issues:

- Ionospheric effects at high latitudes
  - Additional stations at high latitudes
  - Alternative dissemination means
  - Maritime services demonstration
  - Interoperability with other SBAS
  - Benefits for Dual Frequency Multi Constellation Users
- 
- Presentation of some preliminary results involving ionospheric issues at high latitudes

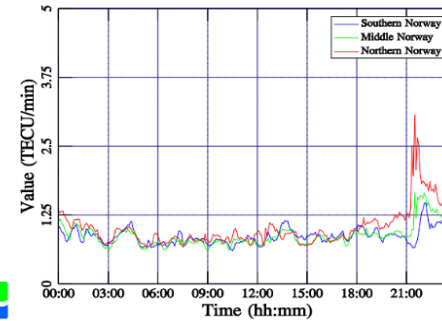




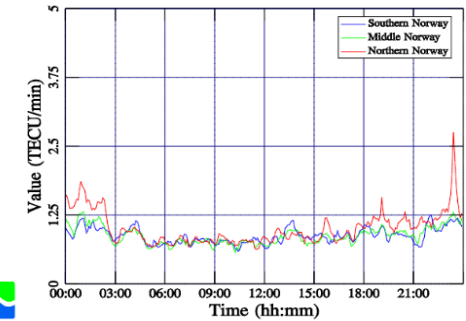
# Experimentation period

- 24th of February – 2nd of March 2014
- 1(-2) days for convergence
- 2 days with low ionospheric activity at high latitudes
- 1 day where EGNOS was severely affected by ionospheric activity
- 3 days where EGNOS was (more moderately) affected by ionospheric activity

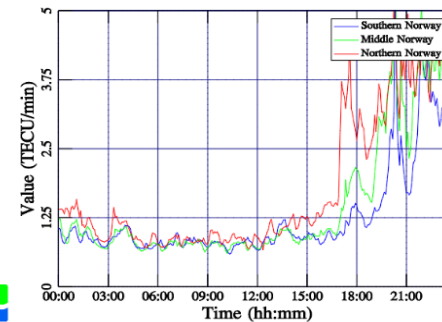
2014-02-25 00:00 to 2014-02-25 23:59 UTC  
Rate of TEC Index at ground



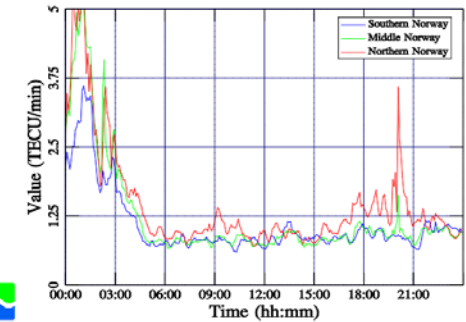
2014-02-26 00:00 to 2014-02-26 23:59 UTC  
Rate of TEC Index at ground



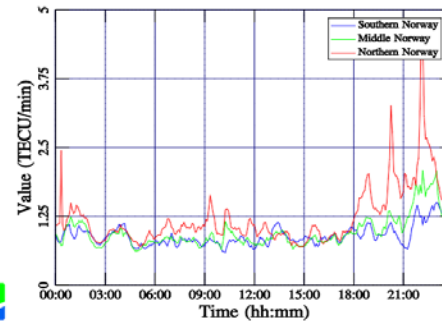
2014-02-27 00:00 to 2014-02-27 23:59 UTC  
Rate of TEC Index at ground



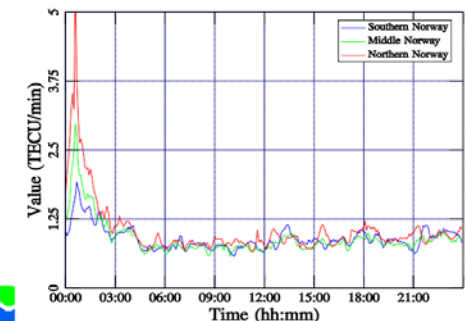
2014-02-28 00:00 to 2014-02-28 23:59 UTC  
Rate of TEC Index at ground



2014-03-01 00:00 to 2014-03-01 23:59 UTC  
Rate of TEC Index at ground

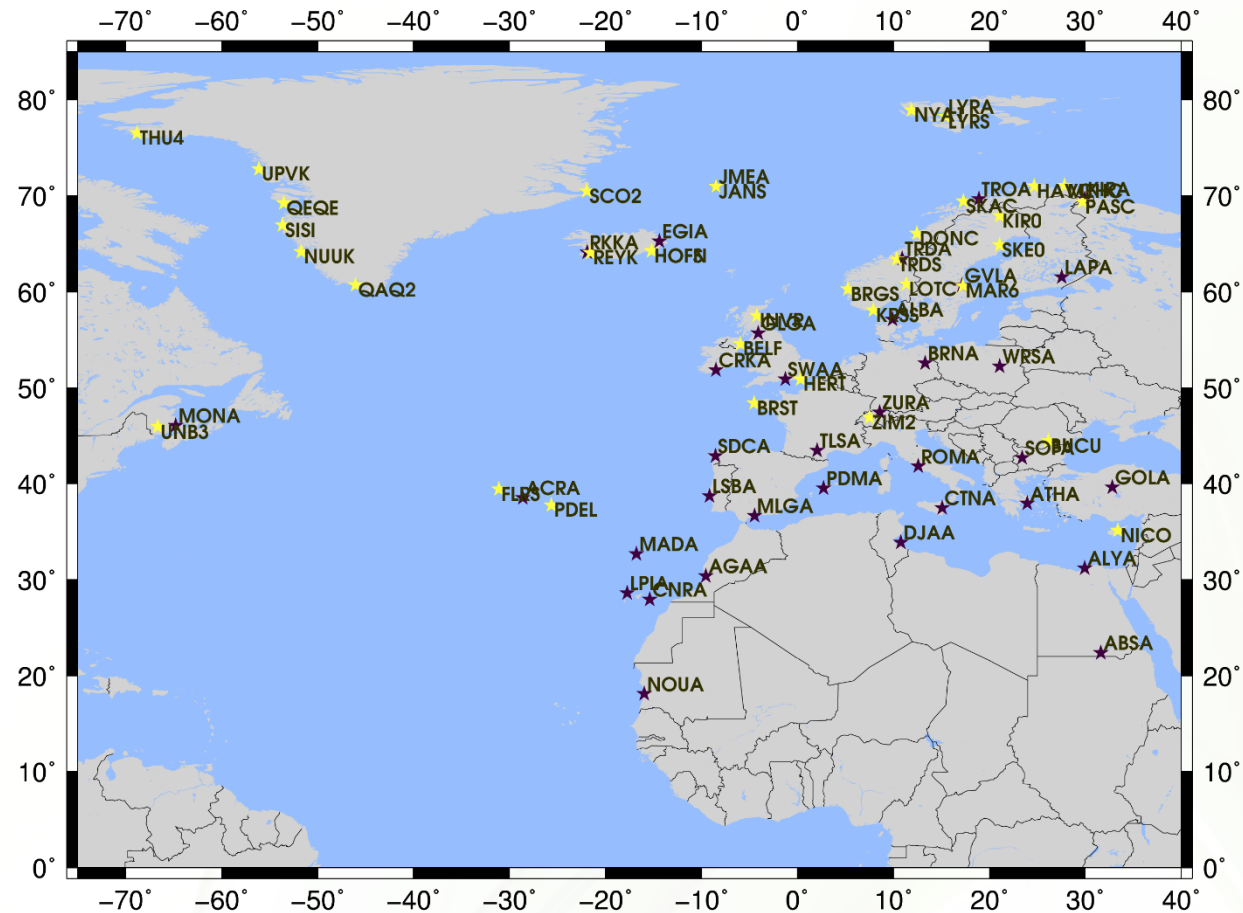


2014-03-02 00:00 to 2014-03-02 23:59 UTC  
Rate of TEC Index at ground



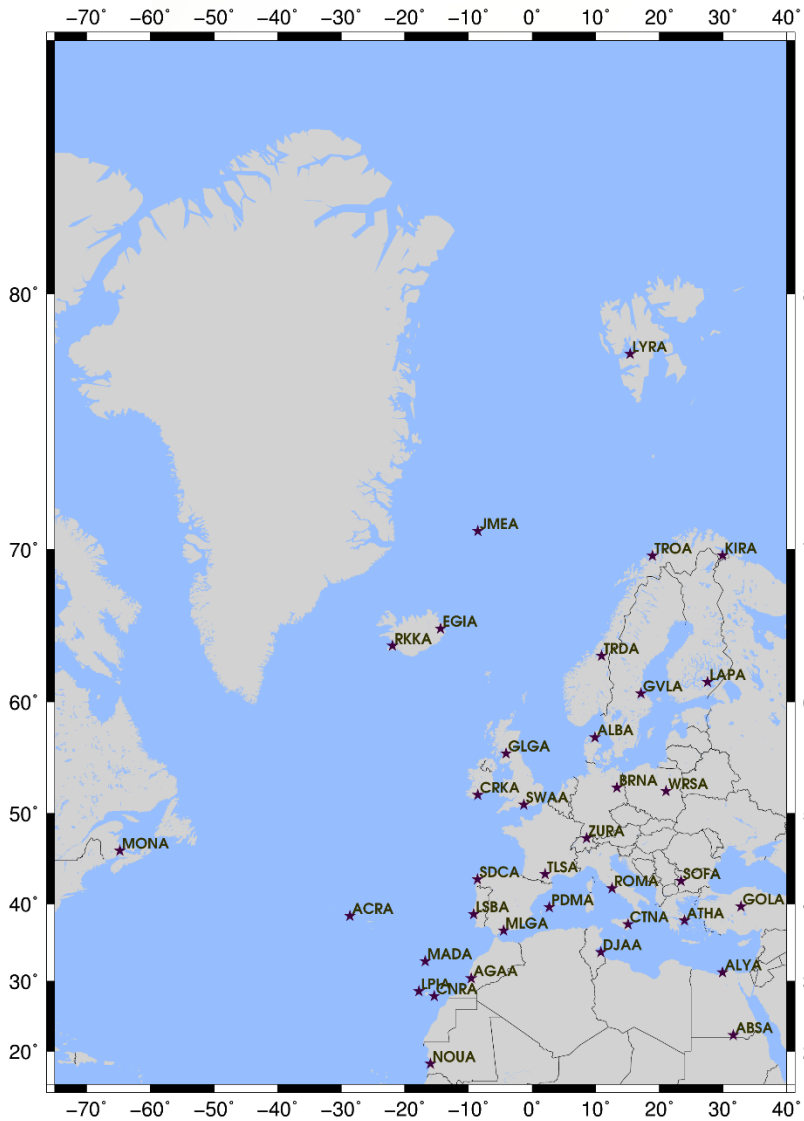
# ATB station network

- EGNOS RIMS stations
- IGS/EUREF stations
- SATREF stations from Norway
- DTU stations from Greenland

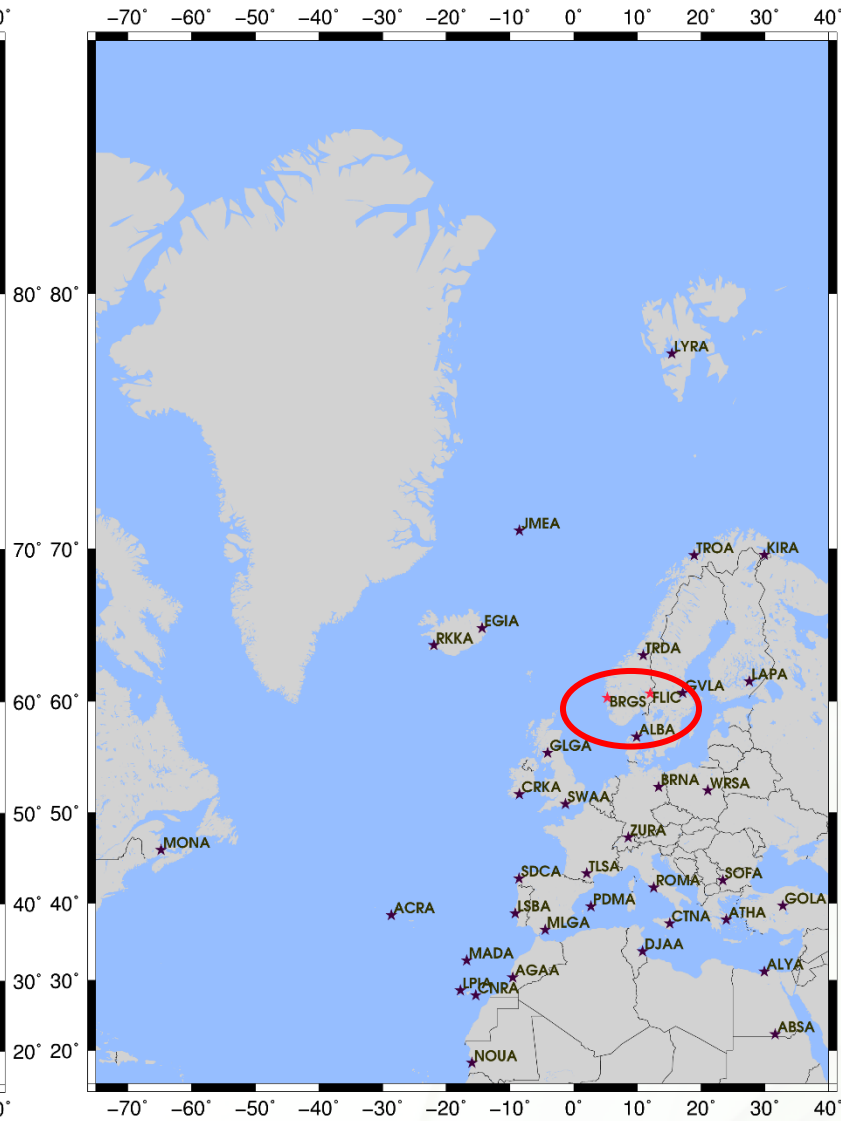




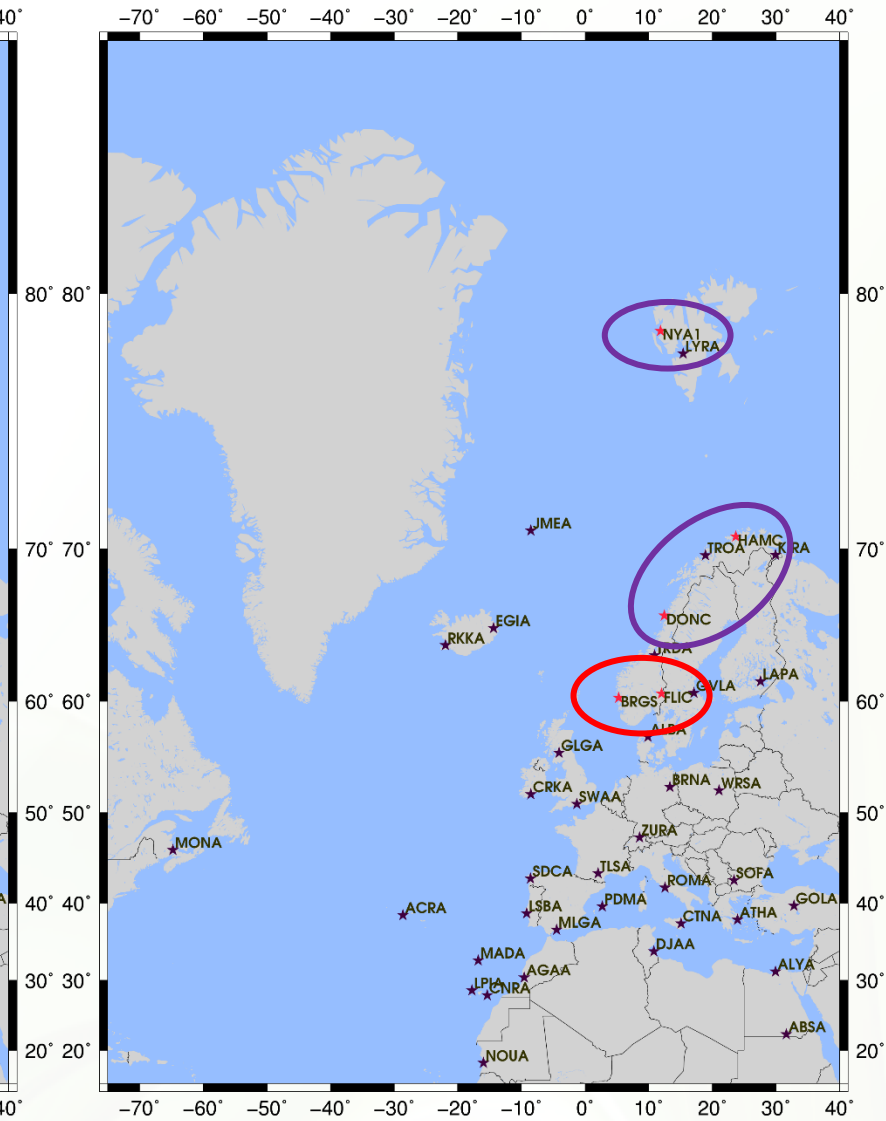
### 37 EGNOS RIMS



### 37 RIMS + 2 ATB stations



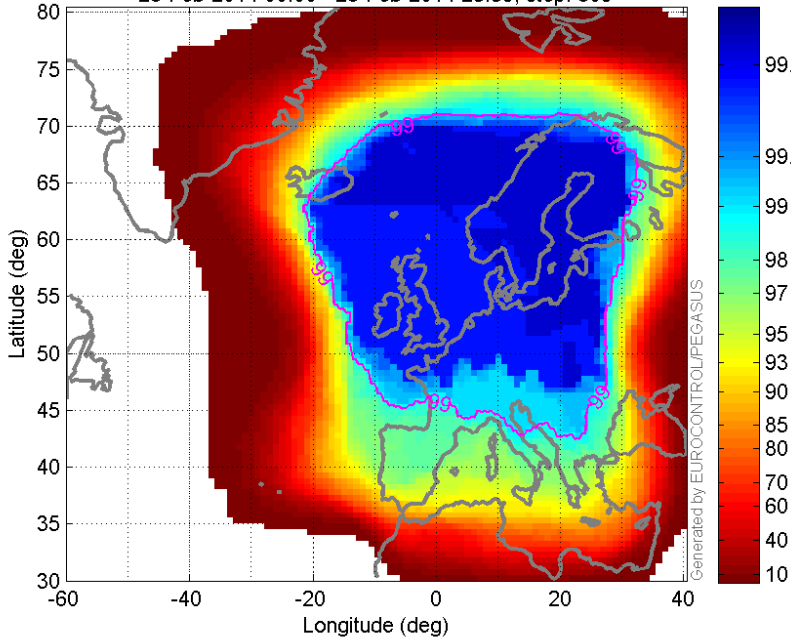
### 37 RIMS + 5 ATB stations



# 37 EGNOS RIMS – APV-1 availability over 24 h

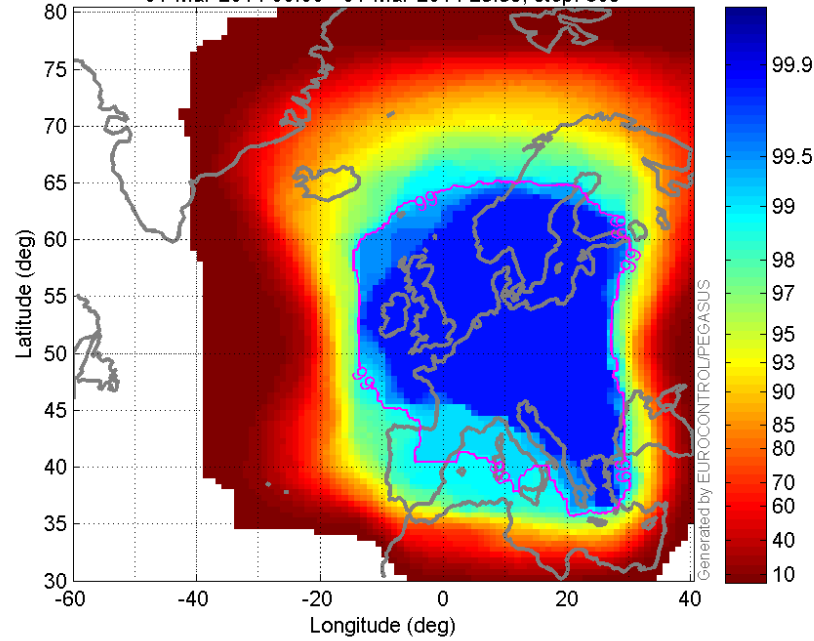
## Quiet ionospheric conditions at high latitudes

Availability APV1 120  
26-Feb-2014 00:00 - 26-Feb-2014 23:59, step: 60s



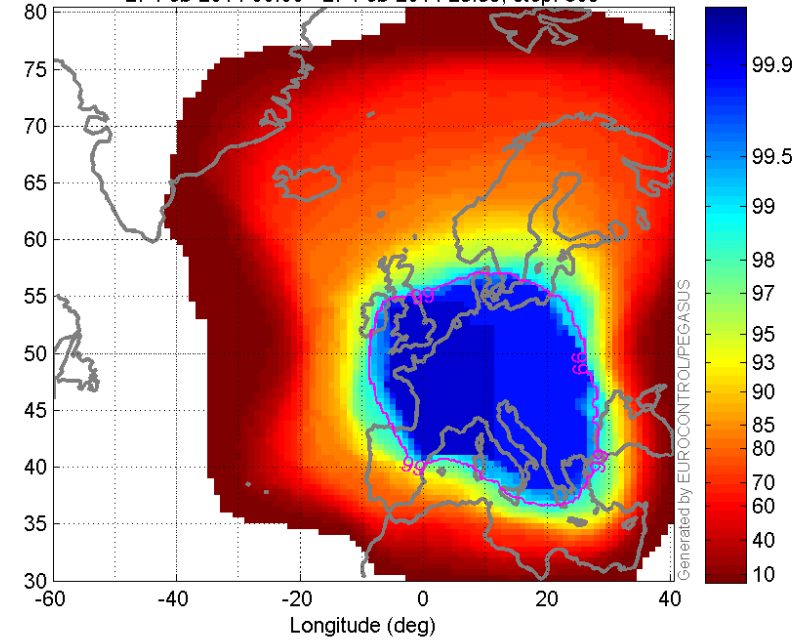
## Disturbed conditions at high latitudes

Availability APV1 120  
01-Mar-2014 00:00 - 01-Mar-2014 23:59, step: 60s



## Severely disturbed conditions at high latitudes

Availability APV1 120  
27-Feb-2014 00:00 - 27-Feb-2014 23:59, step: 60s



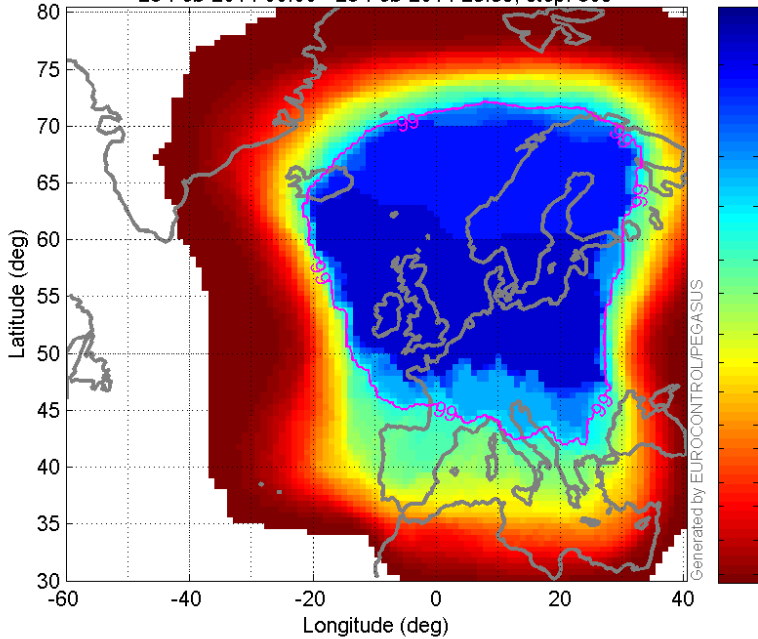


# 2 extra reference stations

Between 60N and 65N

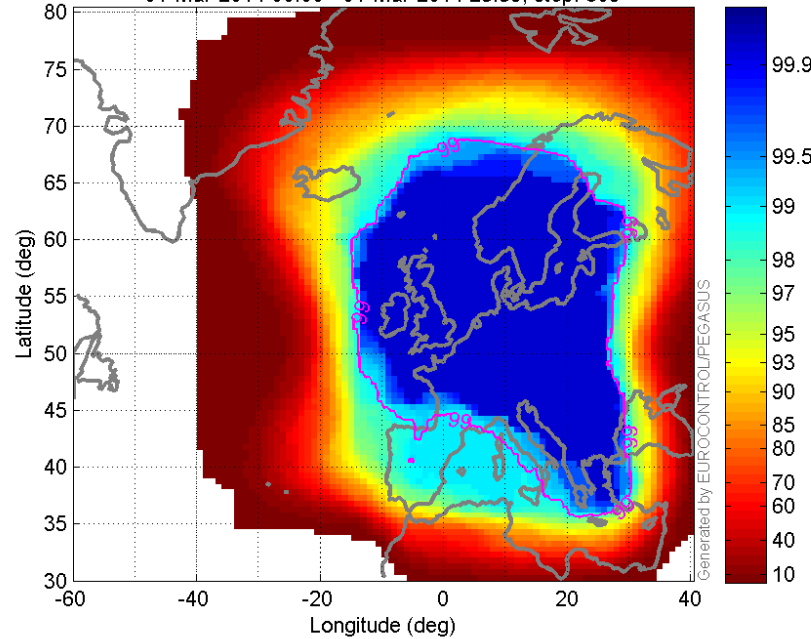
## Quiet ionospheric conditions at high latitudes

Availability APV1 124  
26-Feb-2014 00:00 - 26-Feb-2014 23:59, step: 60s



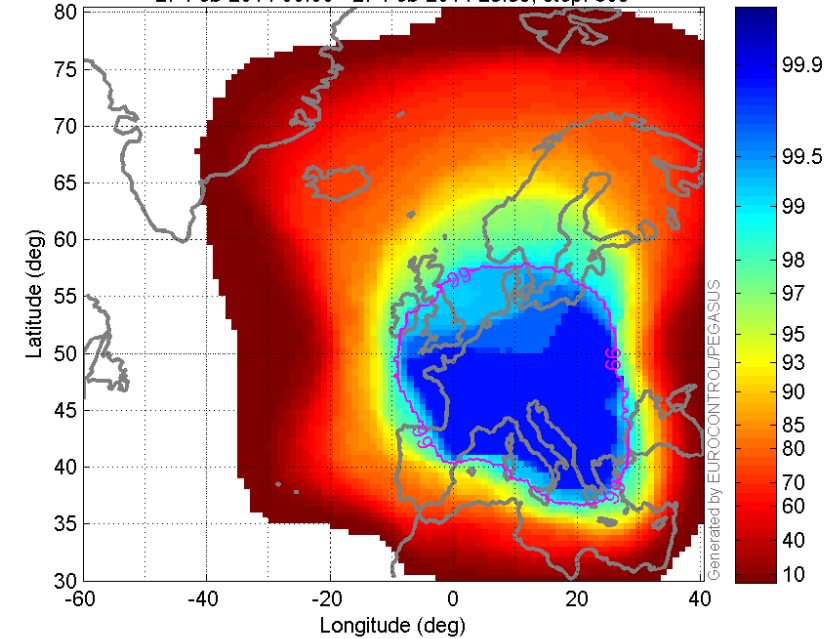
## Disturbed conditions at high latitudes

Availability APV1 124  
01-Mar-2014 00:00 - 01-Mar-2014 23:59, step: 60s



## Severely disturbed conditions at high latitudes

Availability APV1 124  
27-Feb-2014 00:00 - 27-Feb-2014 23:59, step: 60s



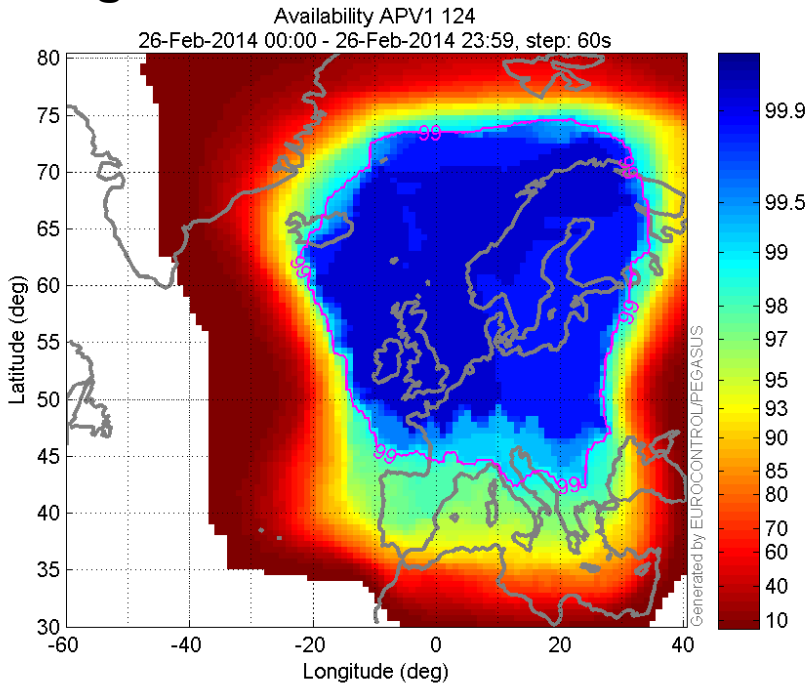
Improvement many places...

..Also with high ionospheric activity for the 99% limit

# 5 extra reference stations

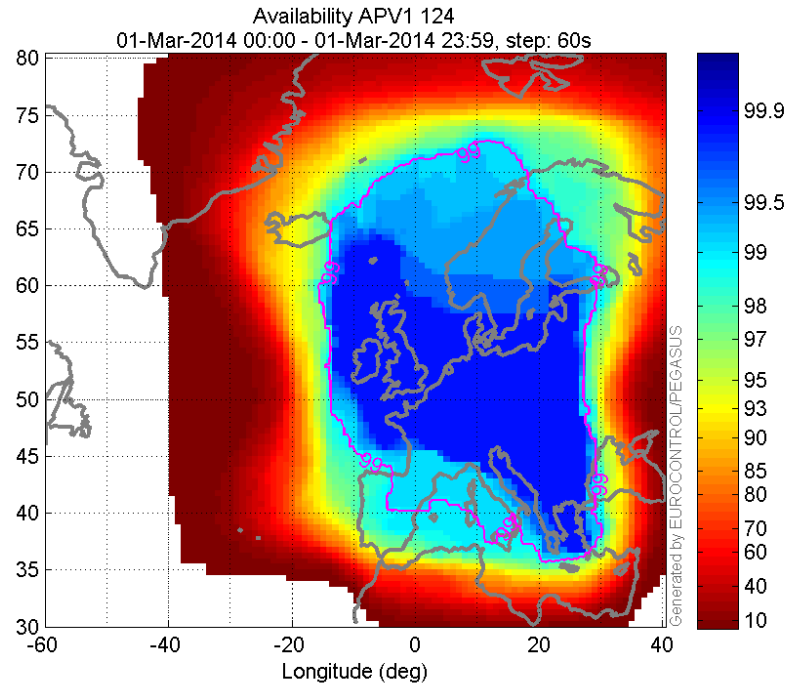
2 between 60N and 65N      1 between 65N and 70N  
1 between 70N and 75N      1 between 75N and 80N

## Quiet ionospheric conditions at high latitudes



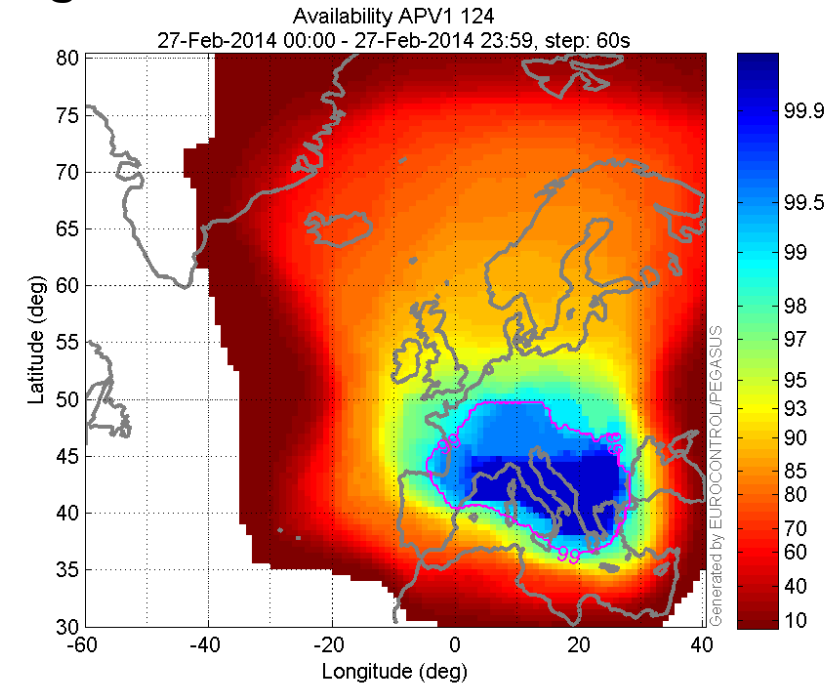
Coverage far north...

## Disturbed conditions at high latitudes



Coverage far north...

## Severely disturbed conditions at high latitudes



Worse in many regions than with fewer stations.

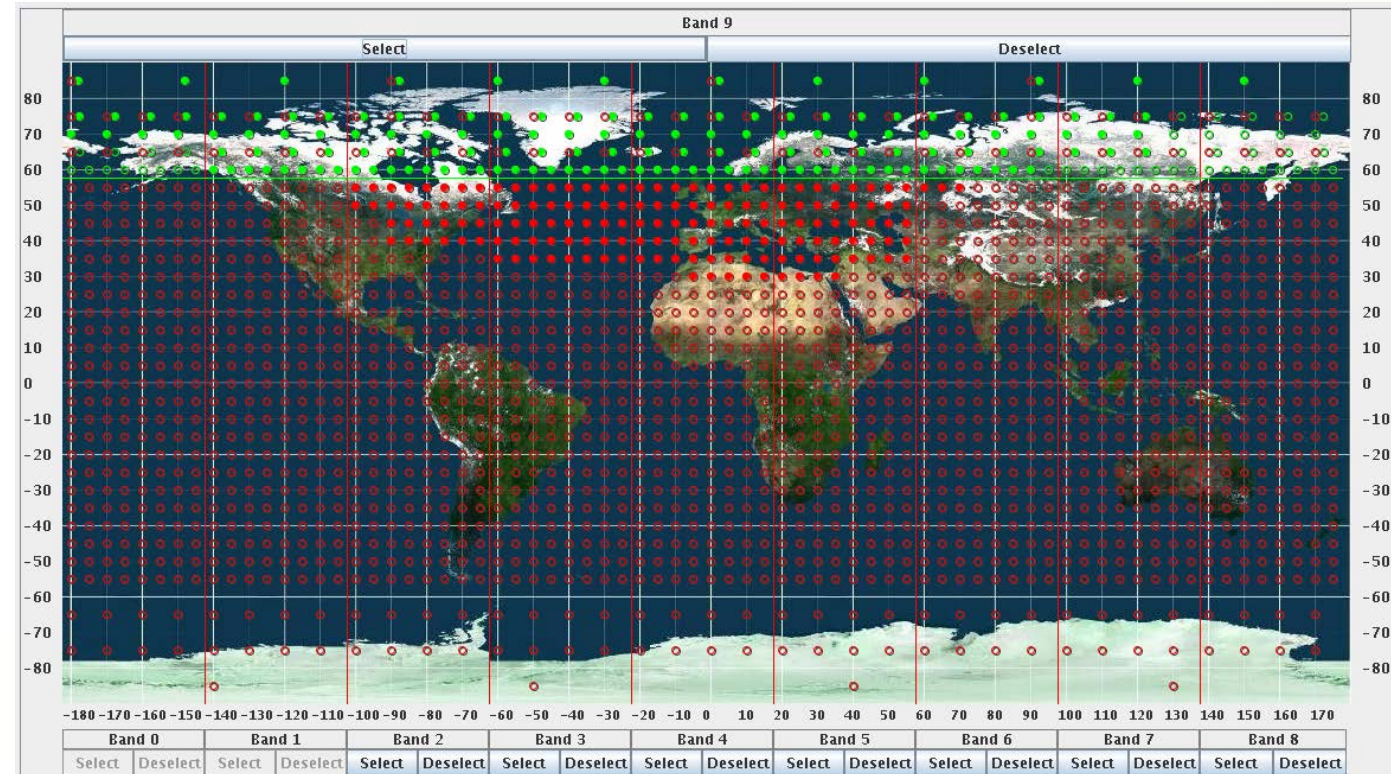


# IGP mask

SBAS provides ionospheric corrections and an ionospheric error bound (GIVE) for a grid of ionospheric grid points (IGPs)

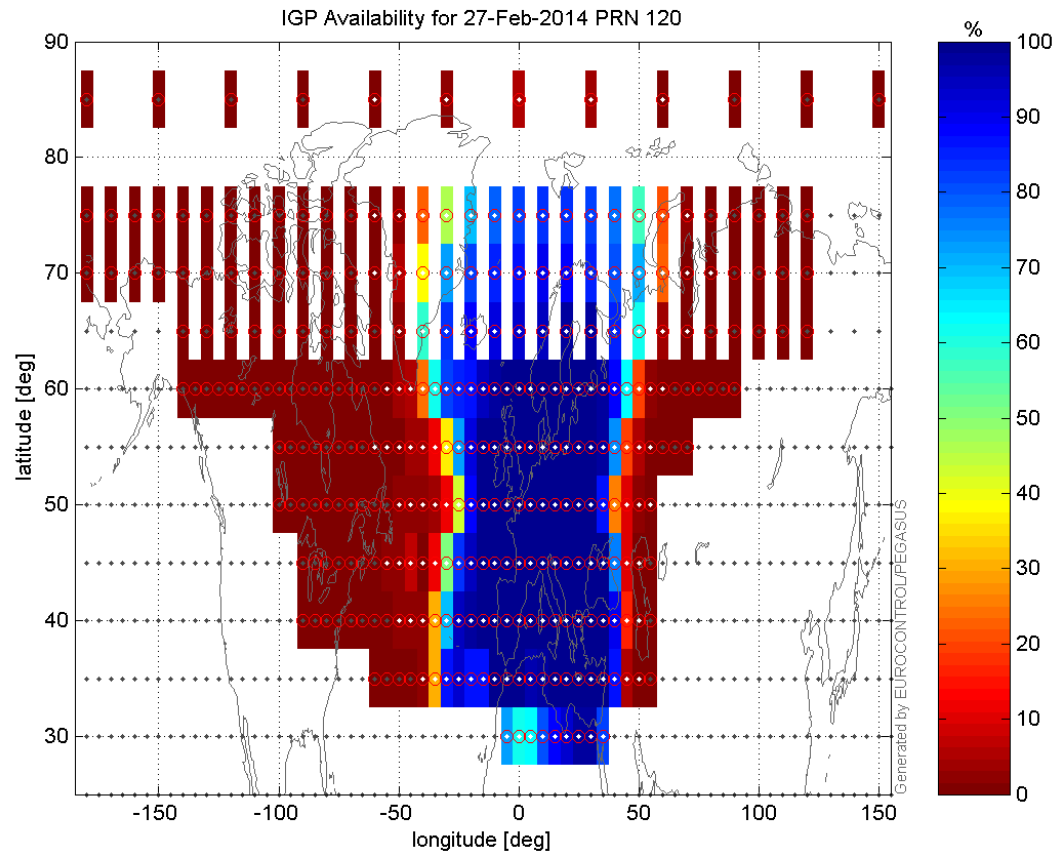
- Ionospheric delay measured for IPP with dual frequency observations
- Interpolation between IPPs provide IGP values transmitted to users
- Users interpolate between IGPs to obtain corrections for single frequency observations

The ionospheric error bound is input to the user's calculation of position error bound. If the position error bound is outside a pre-set limit, the service is said to be not available. Therefore, in particular during an ionospheric storm, the GIVE might be the major factor limiting availability

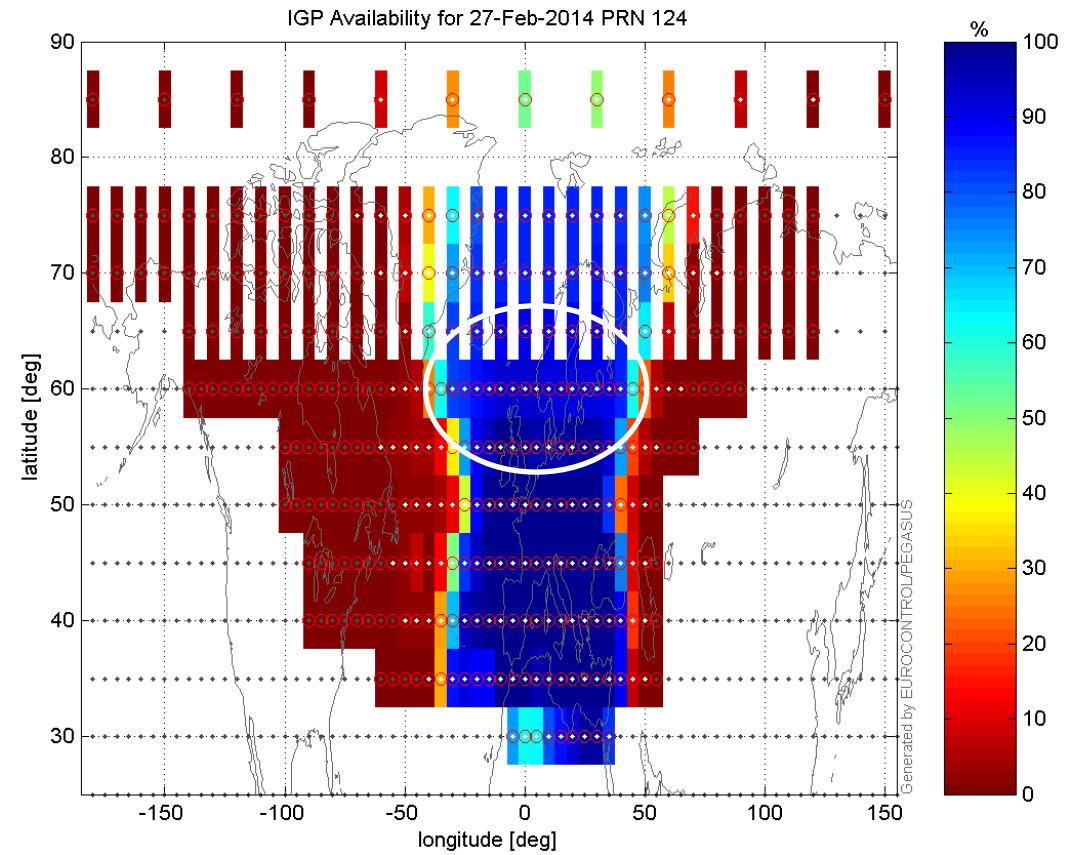


# IGP availability

## 37 EGNOS RIMS



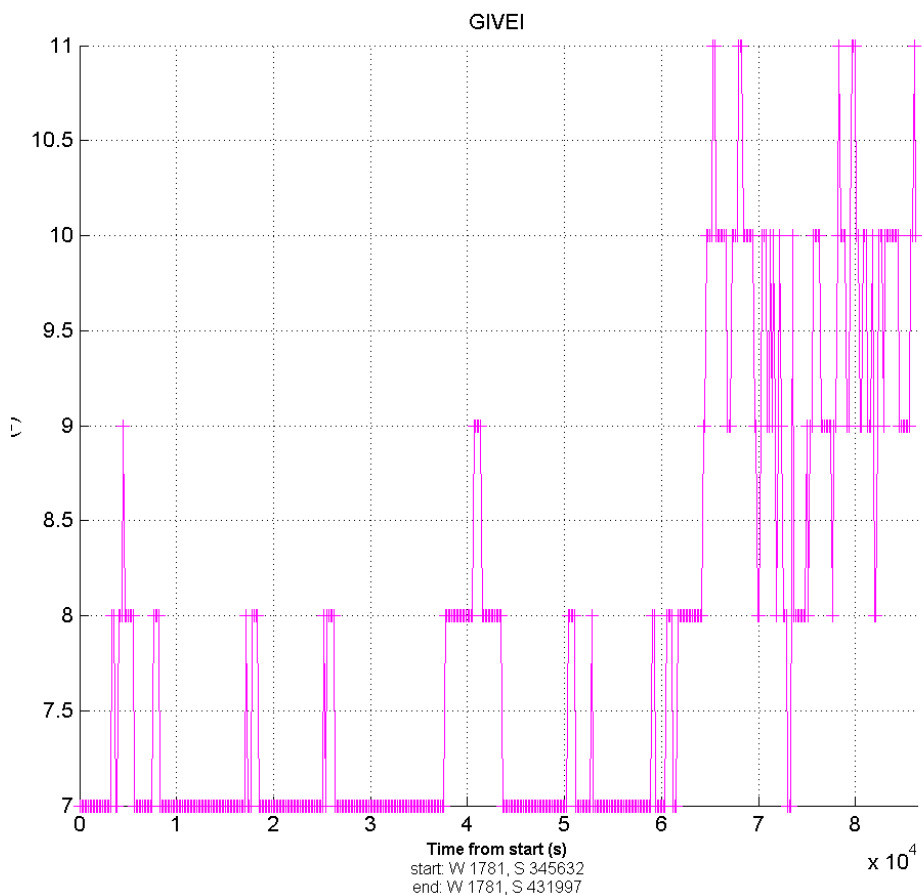
## 37 EGNOS RIMS + 5 extra stations



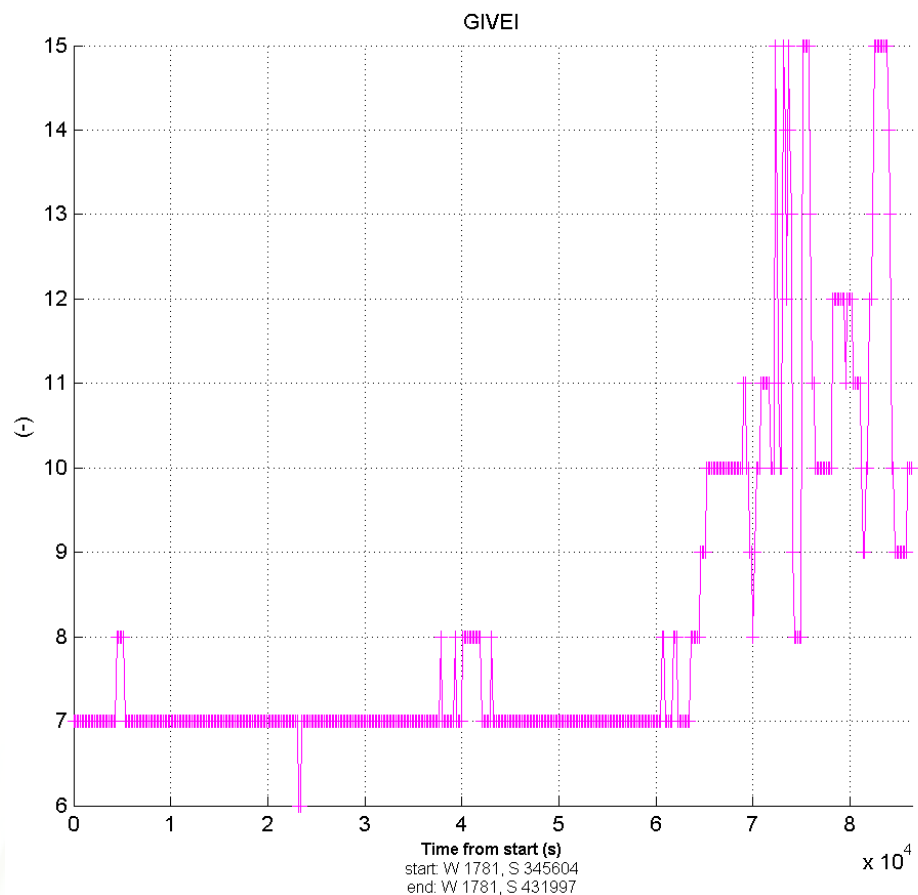


# Single IGP, 55N 10E

## 37 EGNOS RIMS

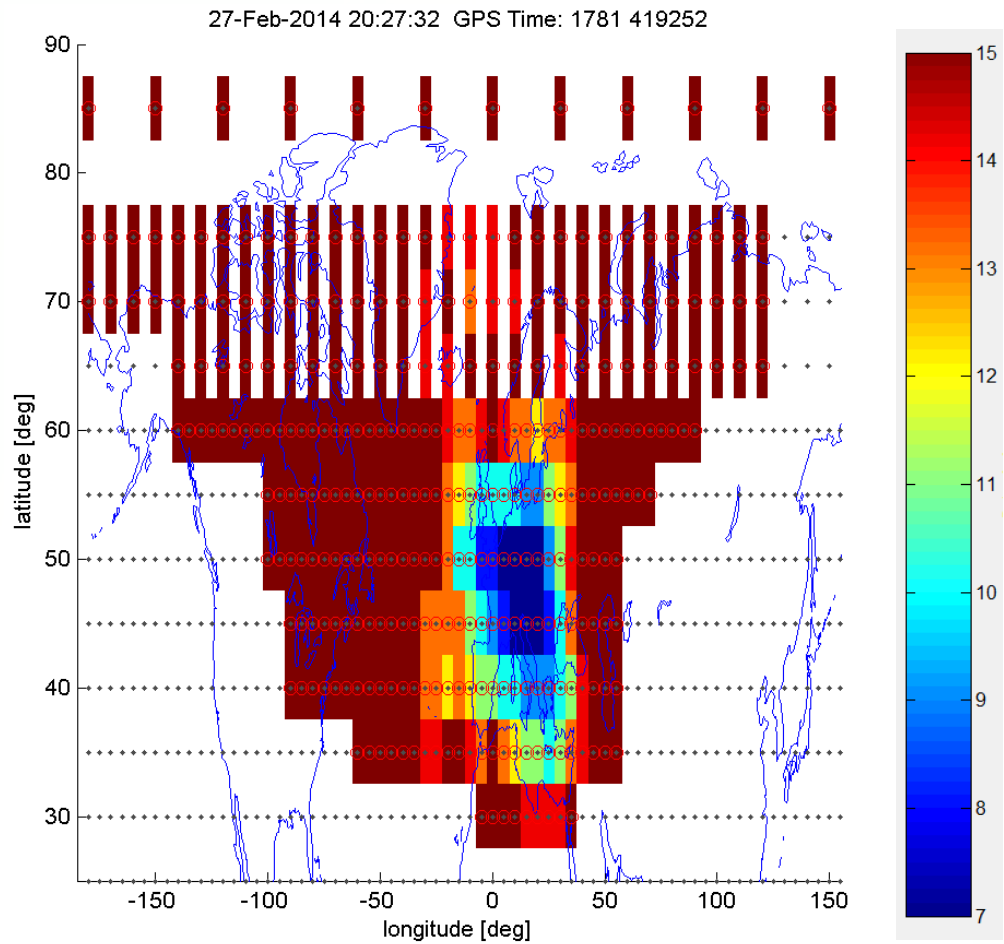


## 37 EGNOS RIMS + 5 extra stations

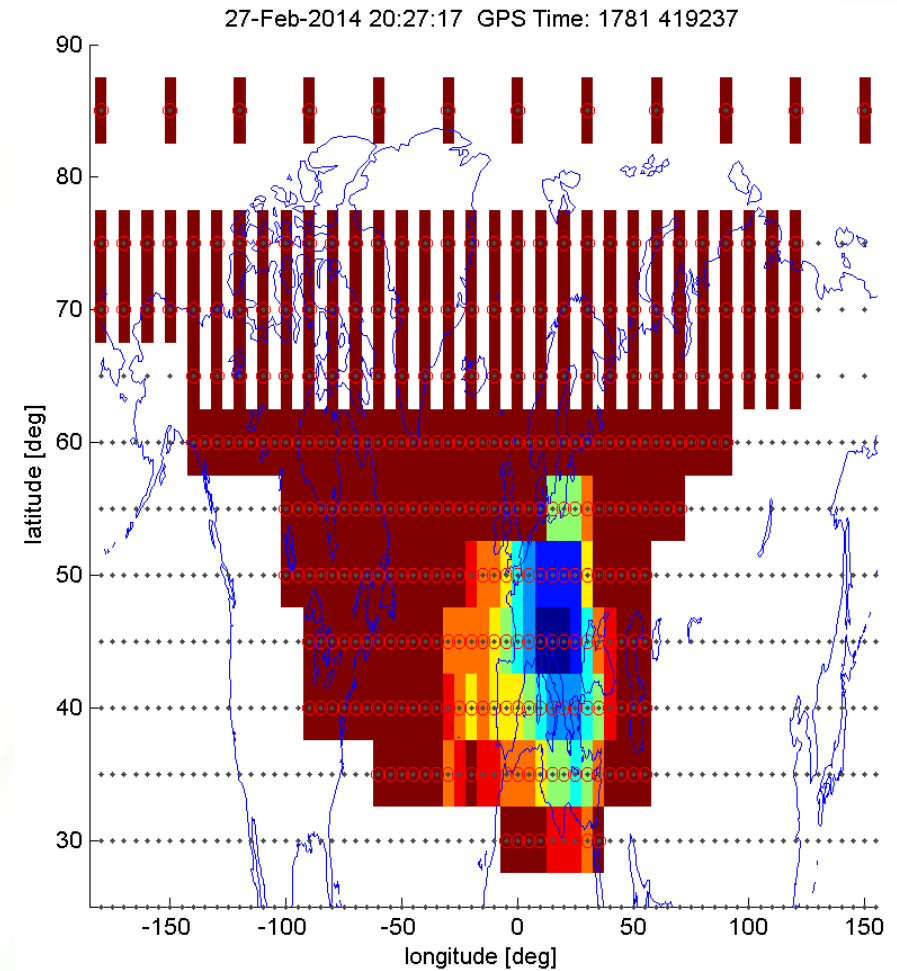


# GIVEI for each IGP at one epoch

37 EGNOS RIMS



EGNOS RIMS + 5 extra

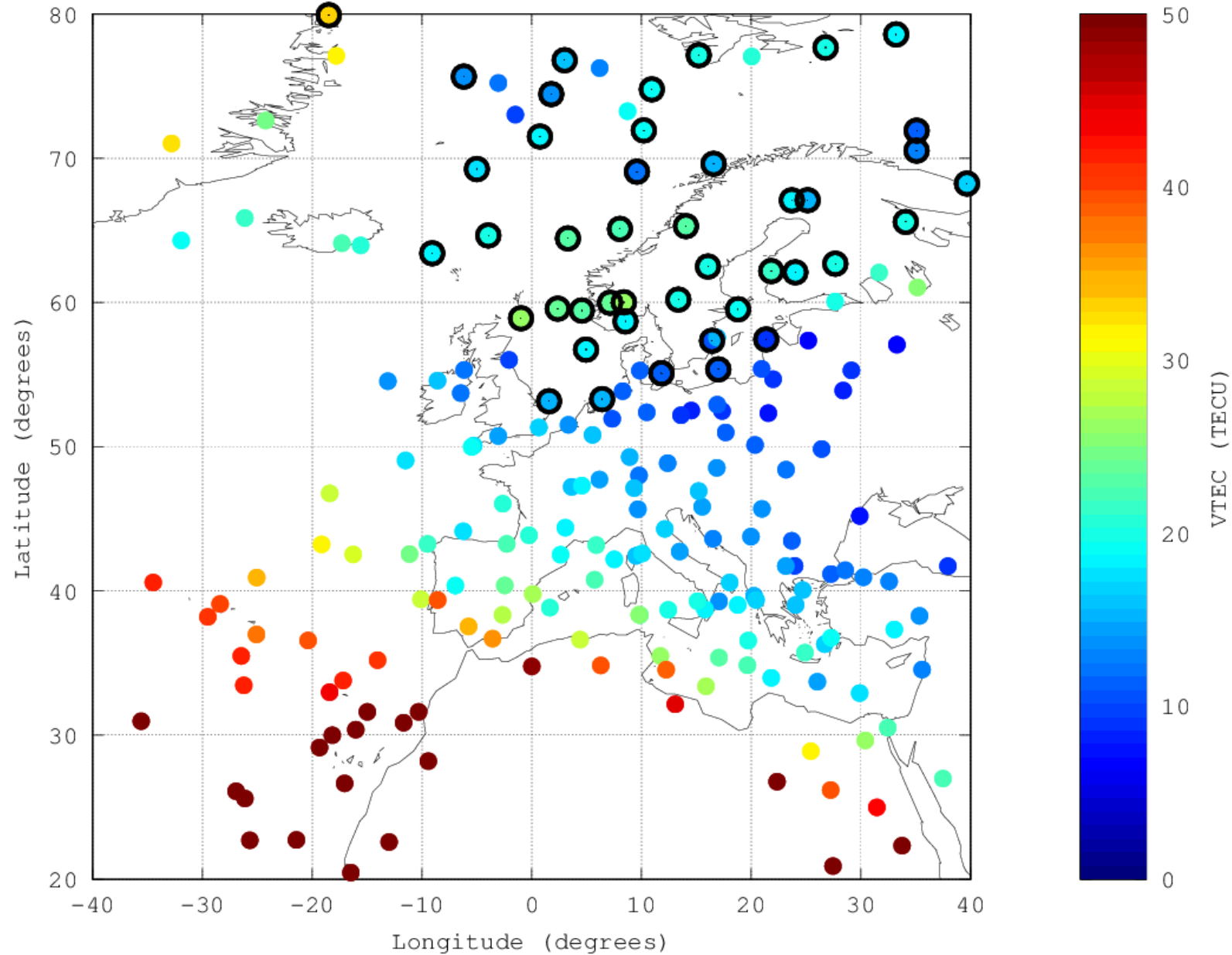


IPPs, 2014-02-27 20:27:01 UT

Run with 5 additional stations

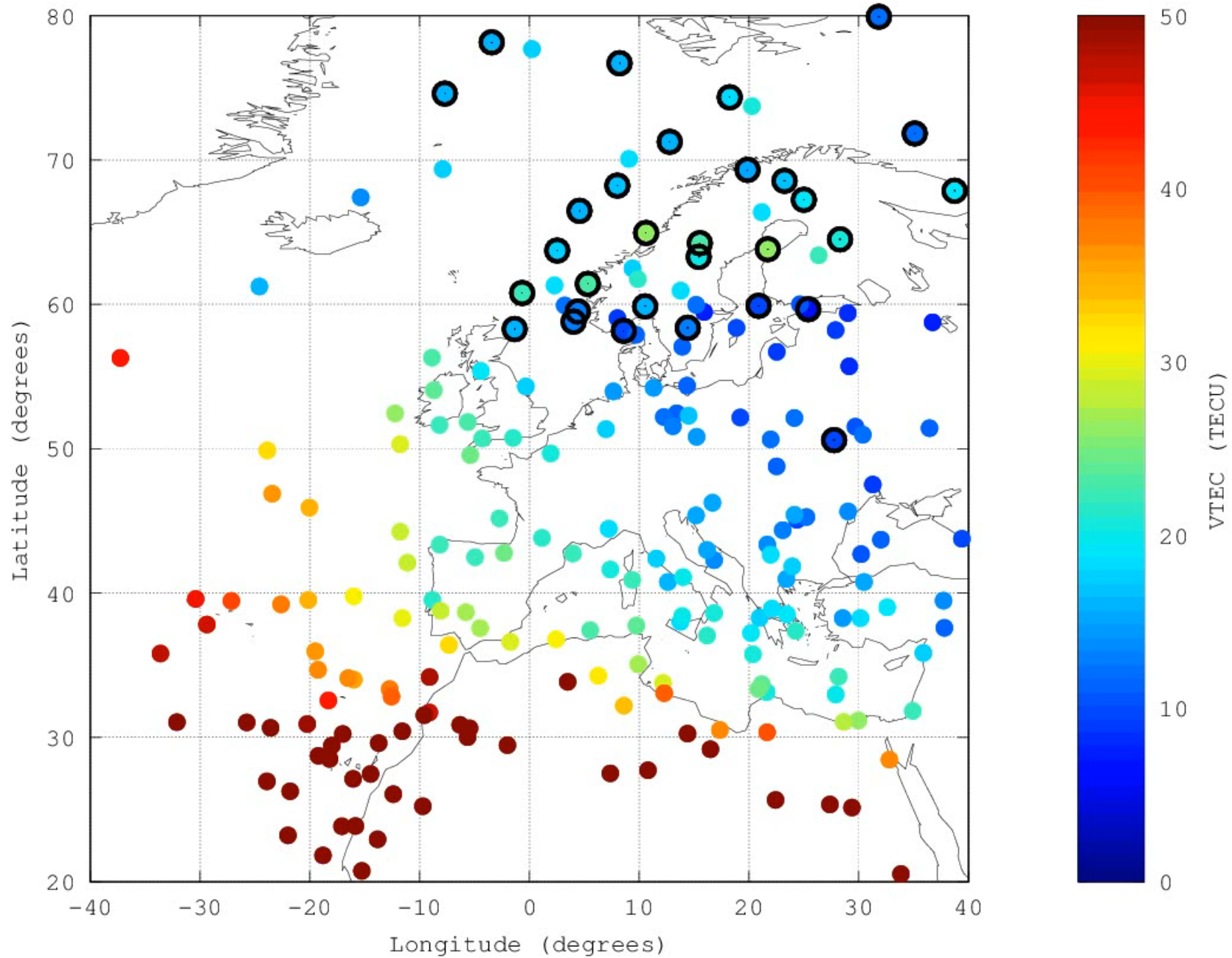
Raw VTEC data for ionospheric  
pierce points

Black circles indicate  
IPPs seen by the additional  
stations



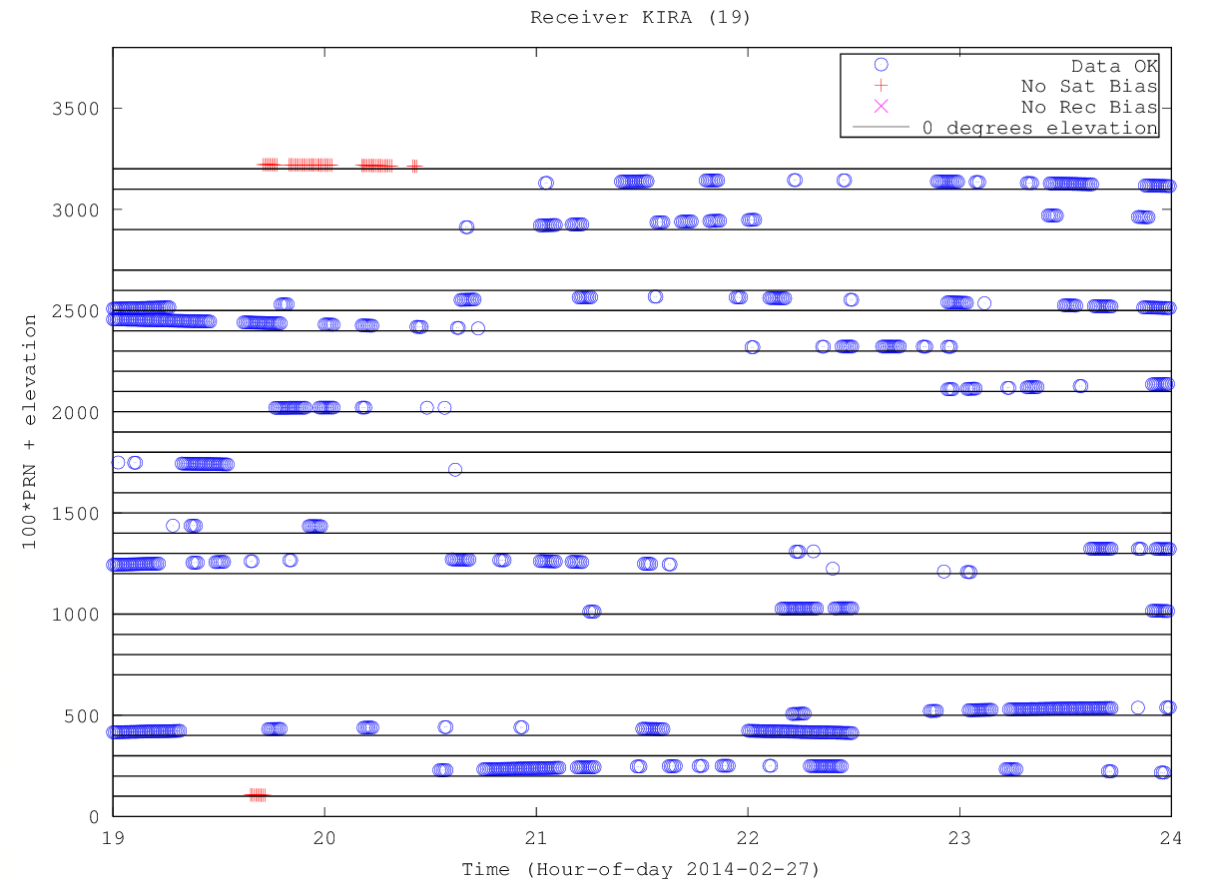
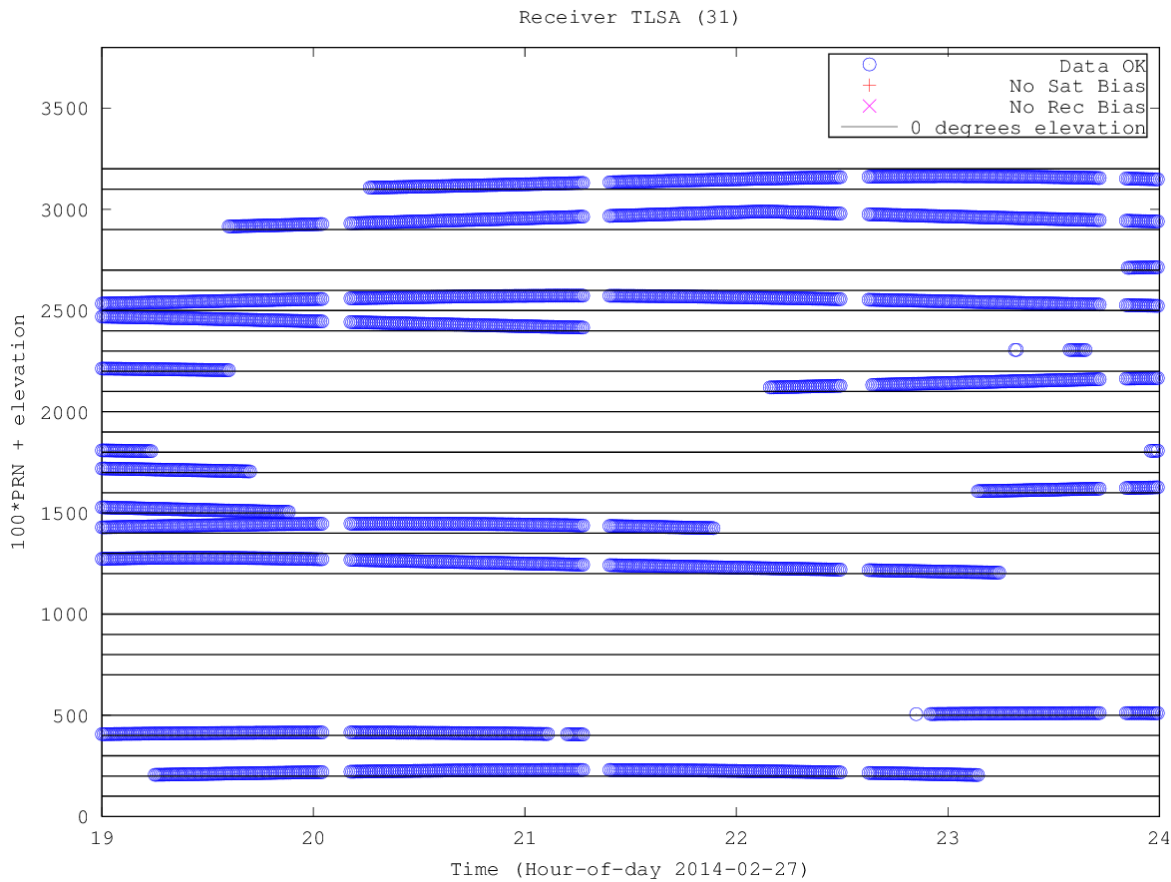


IPPs, 2014-02-27 19:32:31 UT



# IPP data availability

## South vs North

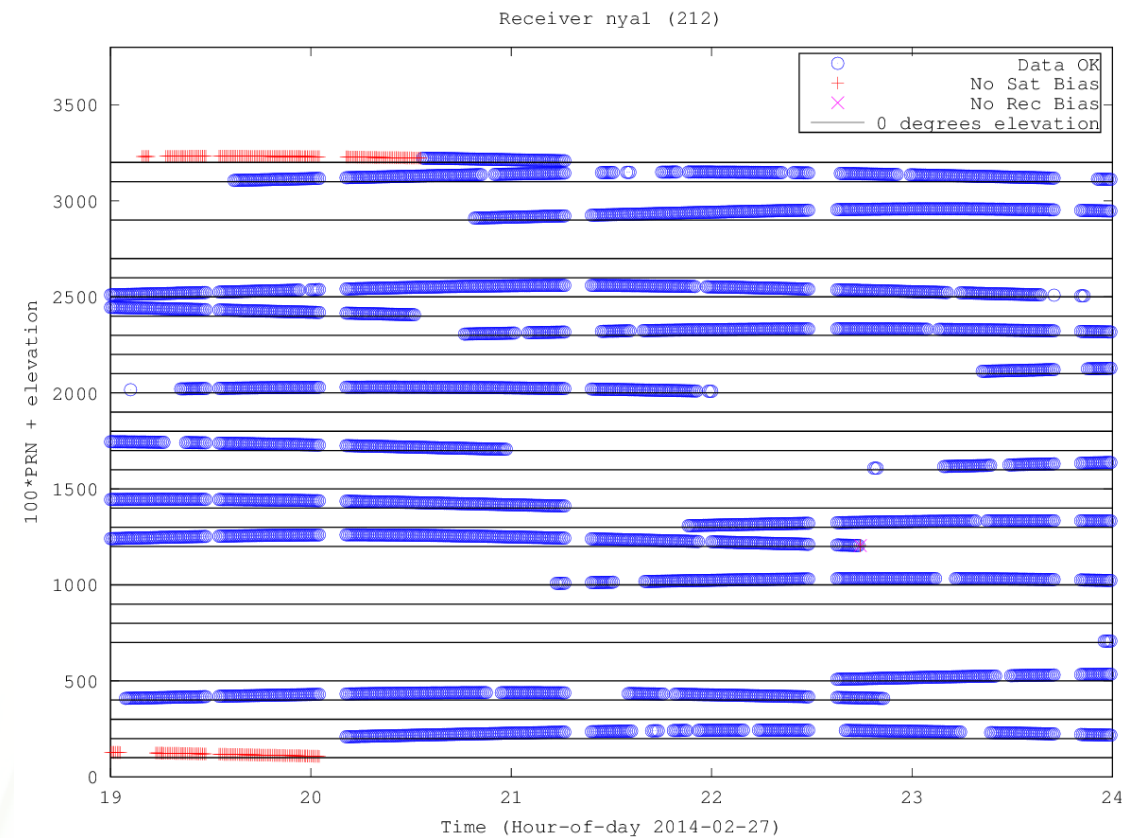
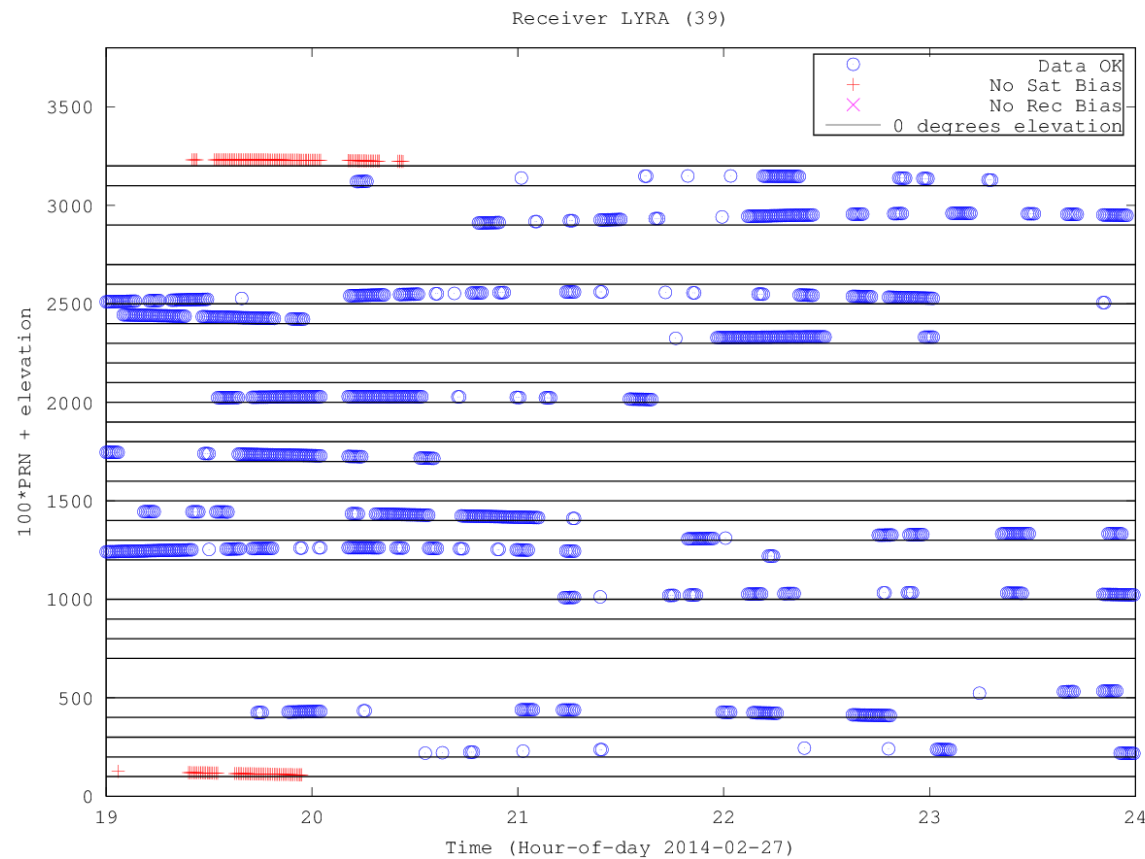


NOTE: Gaps for all satellites are due to the data collection tool and are not actual gaps

# IPP data availability

## RIMS vs non-RIMS

Approximately same place (Svalbard)





# Summary

**Addition of reference stations when the ionospheric effects on the system are low or medium:**

- Better APV-1 availability the more reference stations

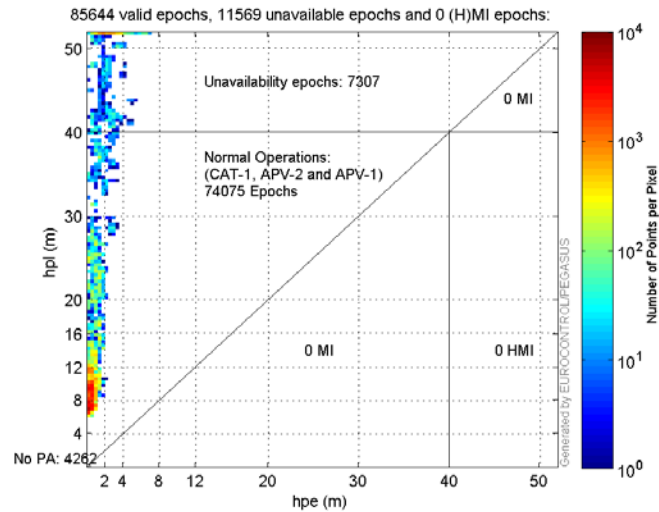
**Addition of reference stations when the ionosphere is strongly affecting the system:**

- More IPPs seems to lead to IGPs not monitored in the central coverage area
- More IPPs observed with higher VTEC values
- Decrease of the area inside the 99% limit of APV-1 availability
- However, an increase in availability at the northern limits of the service area
  
- EGNOS RIMS have significantly more gaps in the satellite availability (for VTEC/GIVE) at high latitudes than the additional stations
  
- EGNOS prioritizes integrity -> availability and accuracy might be degraded

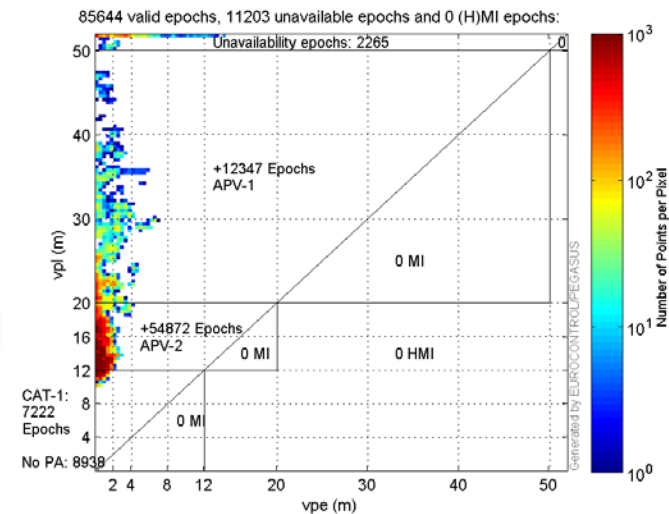
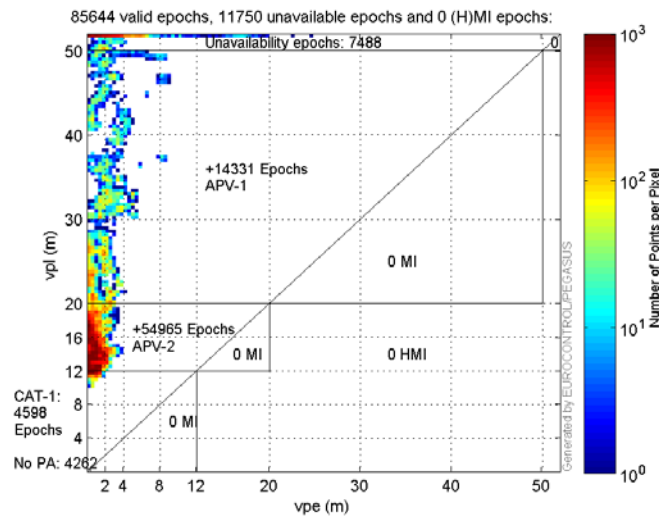
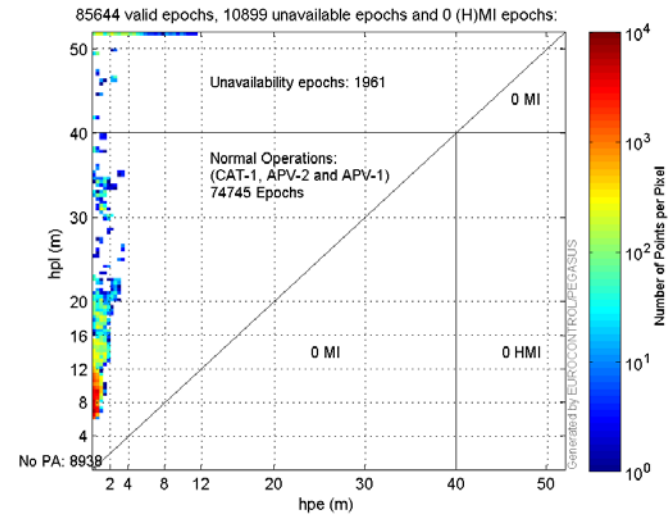
# Backup slides..

# ESA Stanford diagram

## 37 EGNOS RIMS

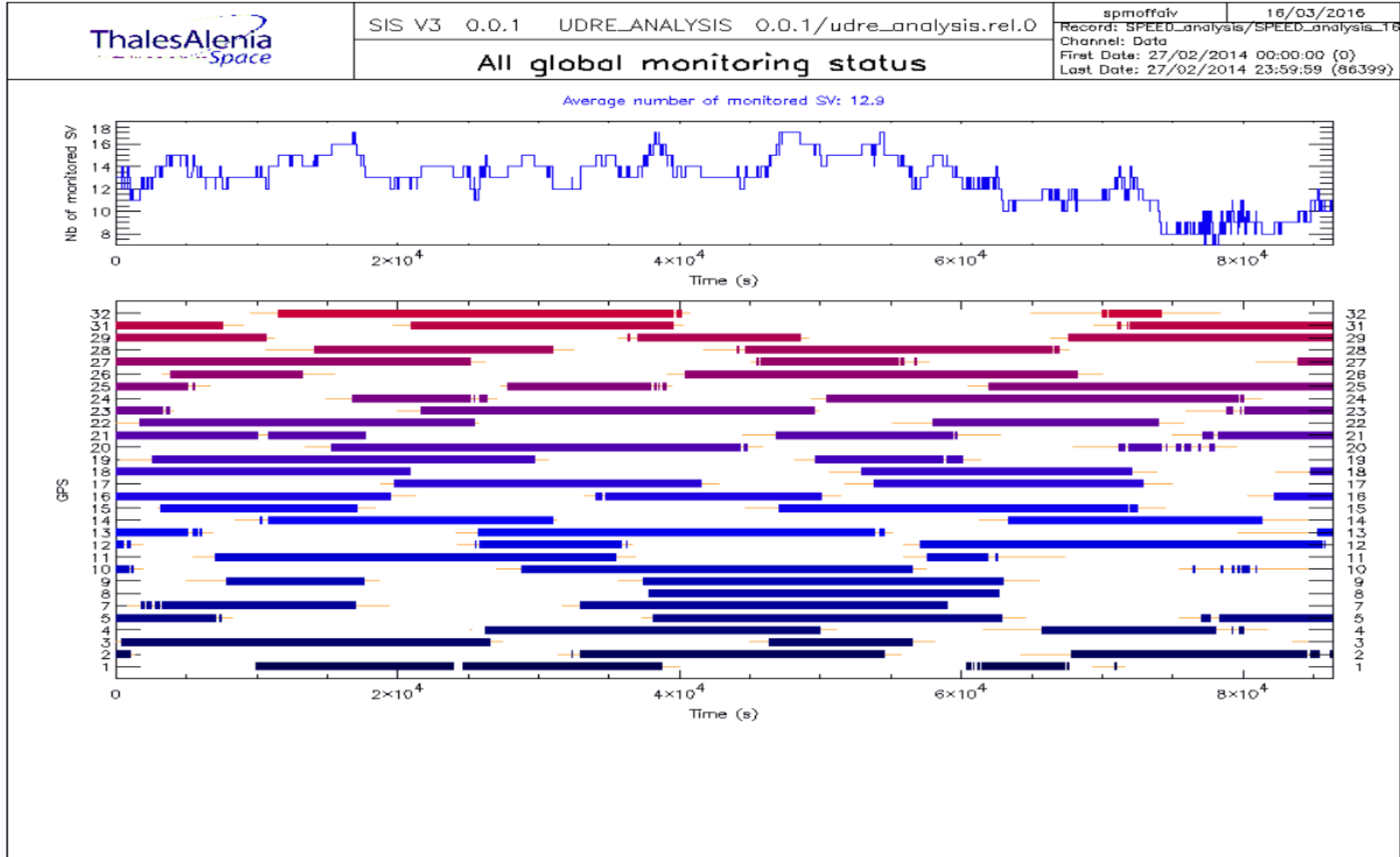


## 37 EGNOS RIMS + 5 extra stations



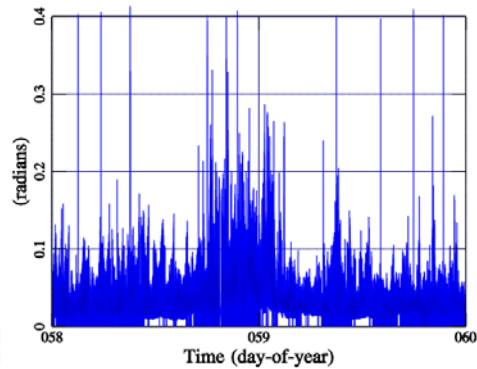


# Satellite monitoring status

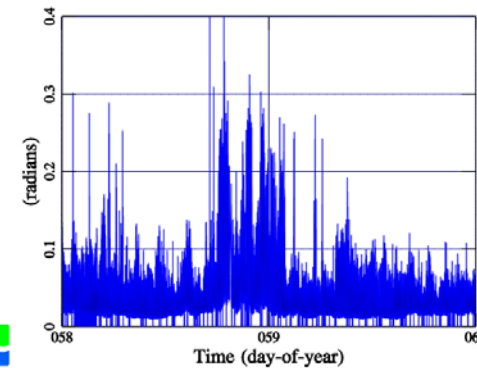


# Sigma Phi time-series examples

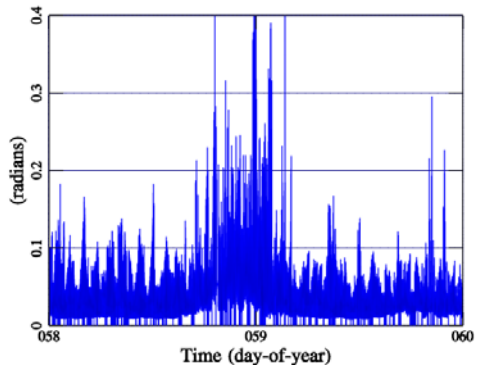
2014-02-27 00:00 to 2014-03-01 00:00 UTC  
hon2, SigmaPhi, GPS L1C



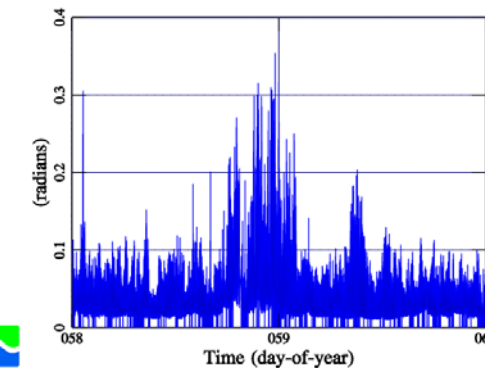
2014-02-27 00:00 to 2014-03-01 00:00 UTC  
hop2, SigmaPhi, GPS L1C

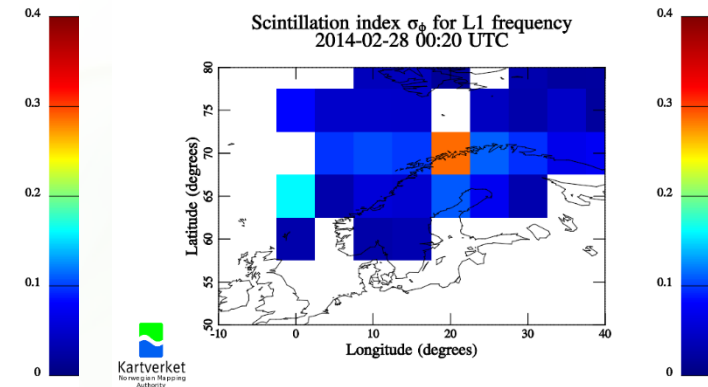
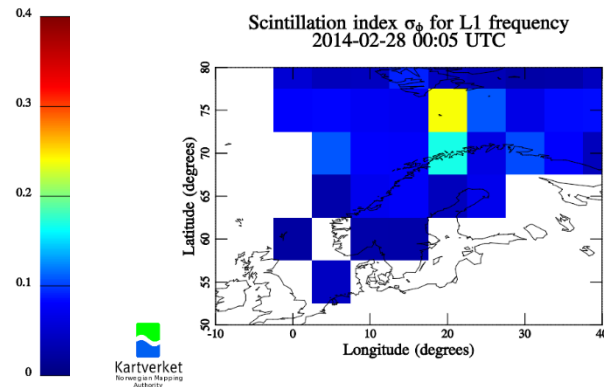
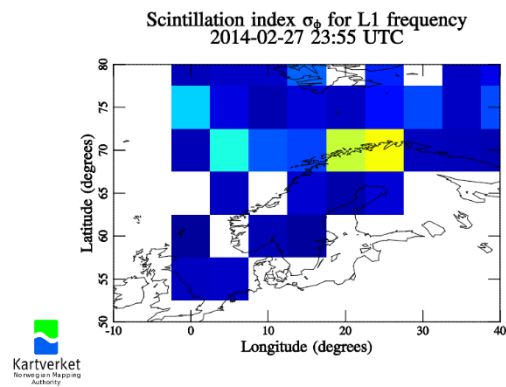
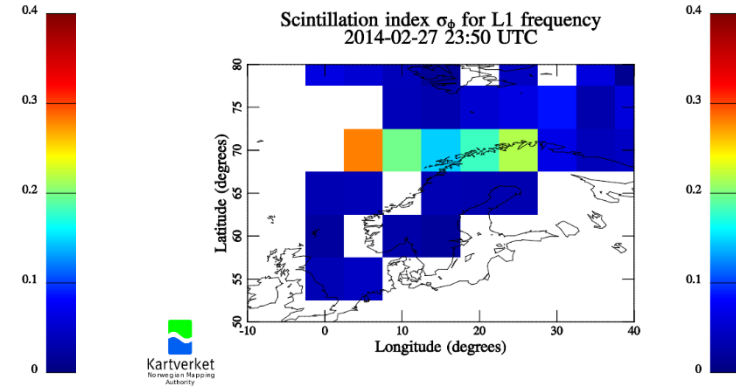
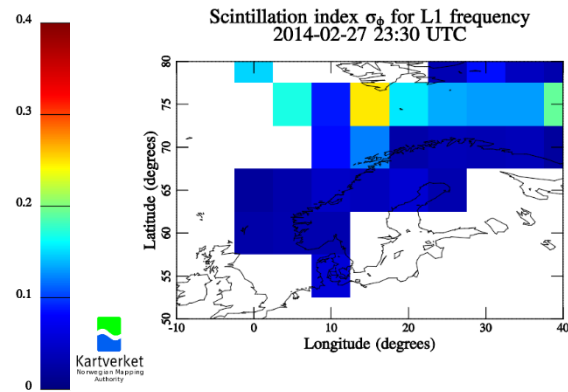
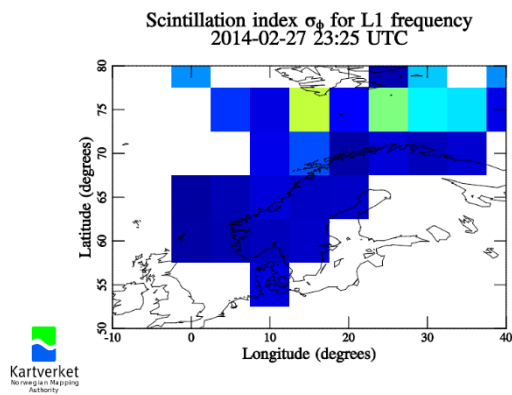


2014-02-27 00:00 to 2014-03-01 00:00 UTC  
hon2, SigmaPhi, GLO L2C (Scaled to GPS L1)



2014-02-27 00:00 to 2014-03-01 00:00 UTC  
hop2, SigmaPhi, GLO L2C (Scaled to GPS L1)

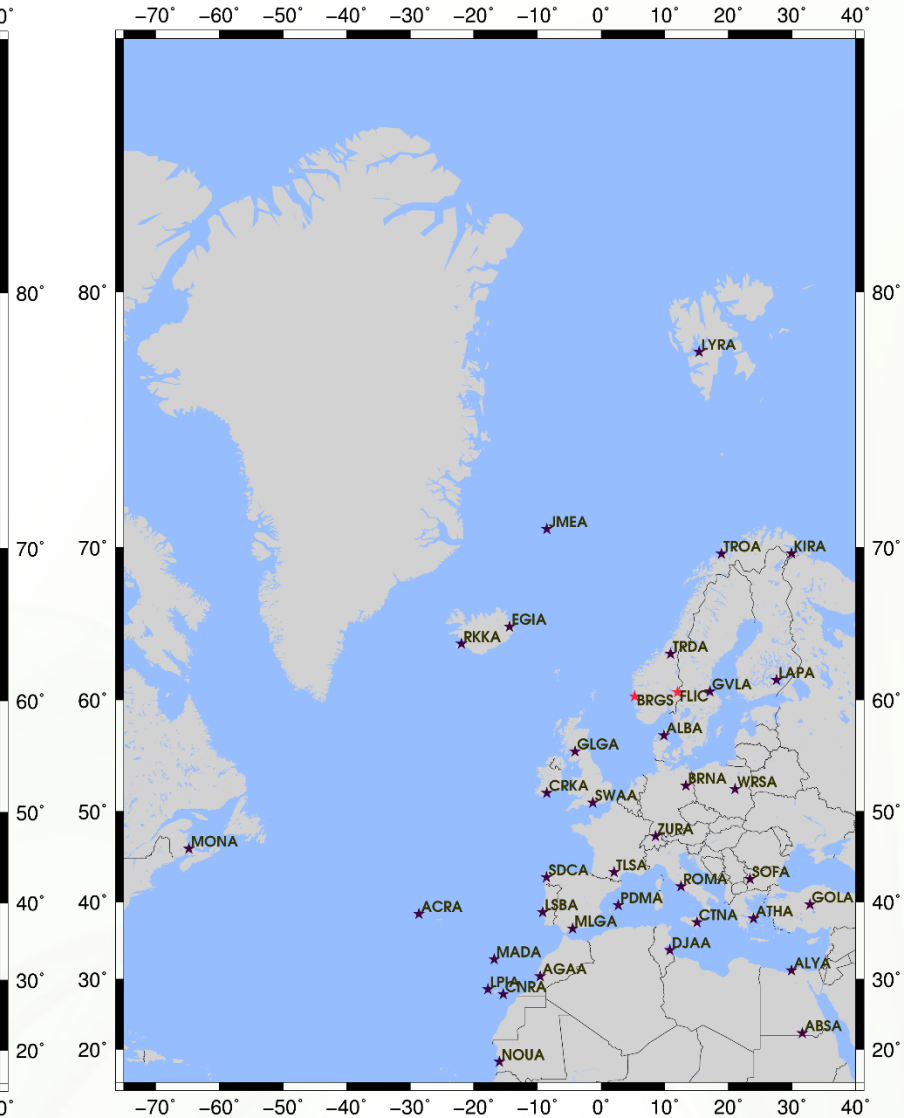
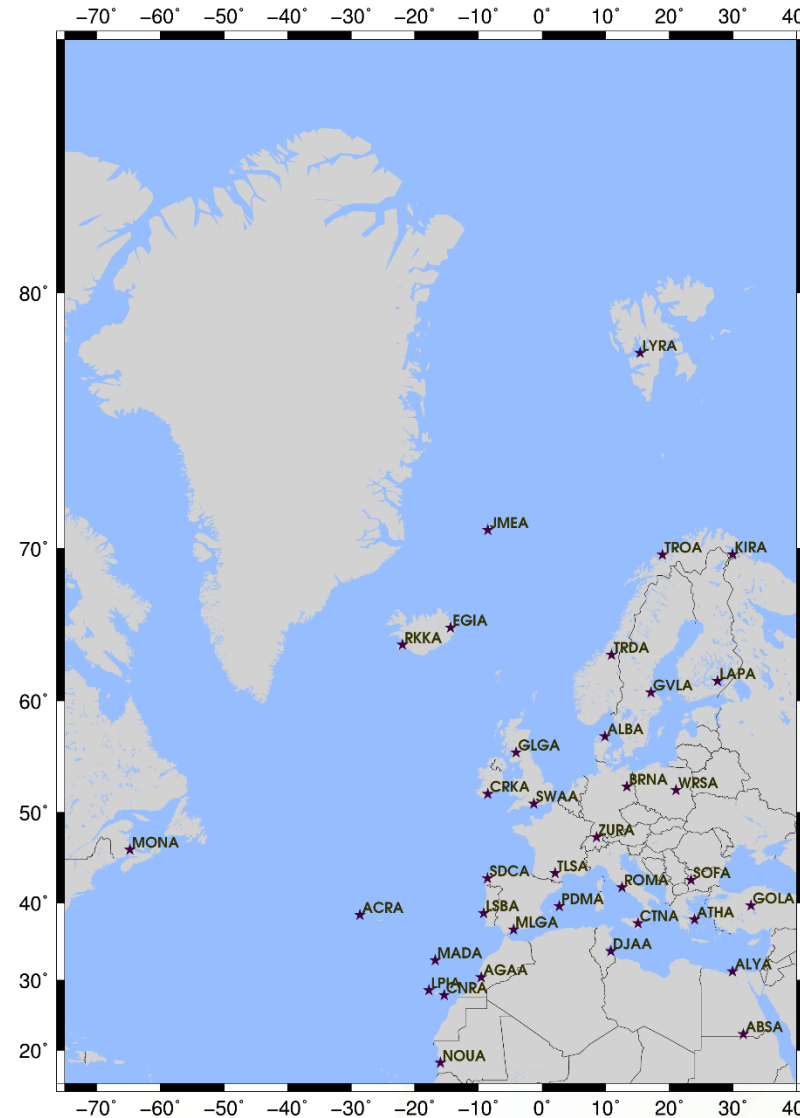






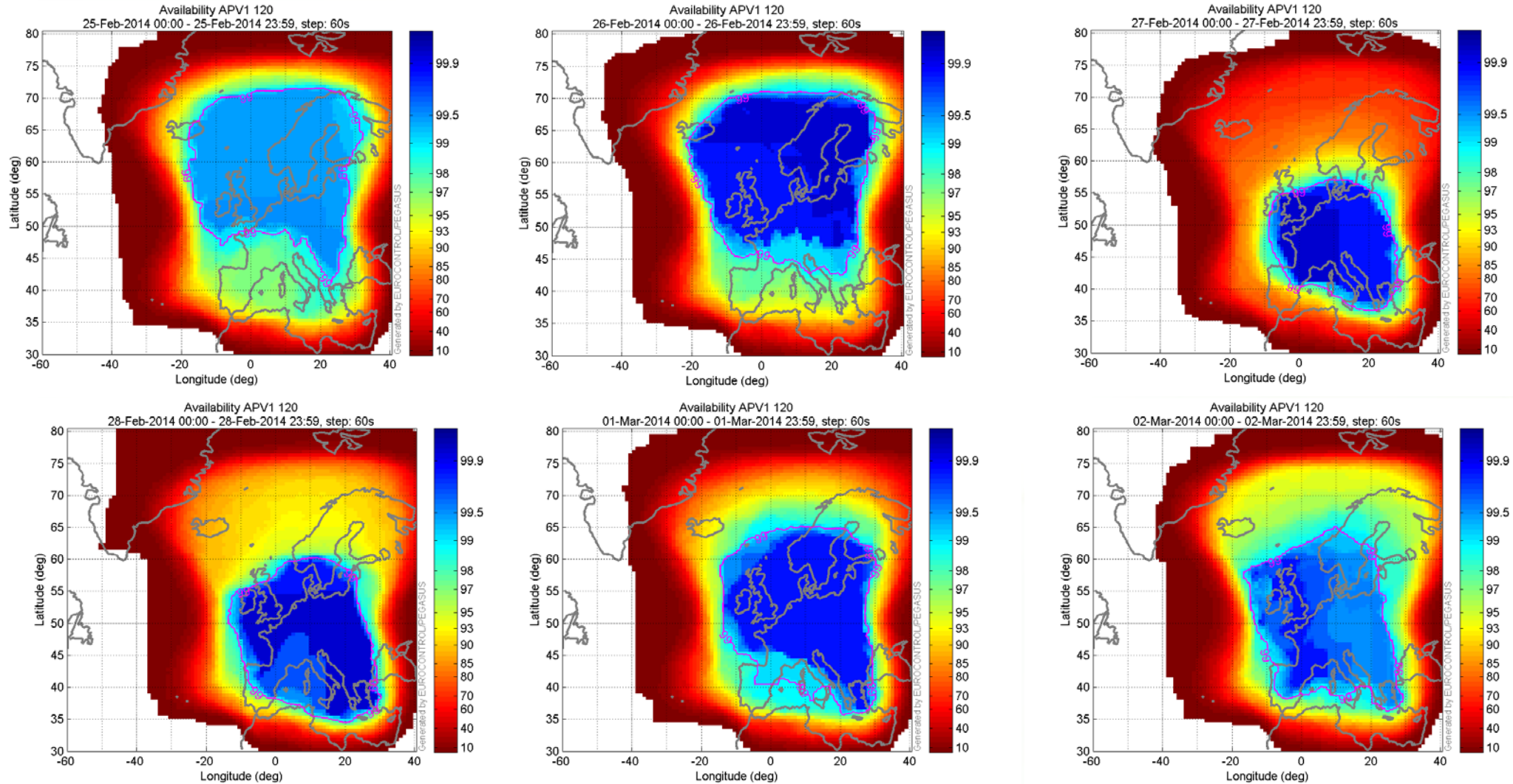
# EGNOS RIMS + extra stations

- 37 EGNOS RIMS
- 2 additional stations at ~60 degrees north

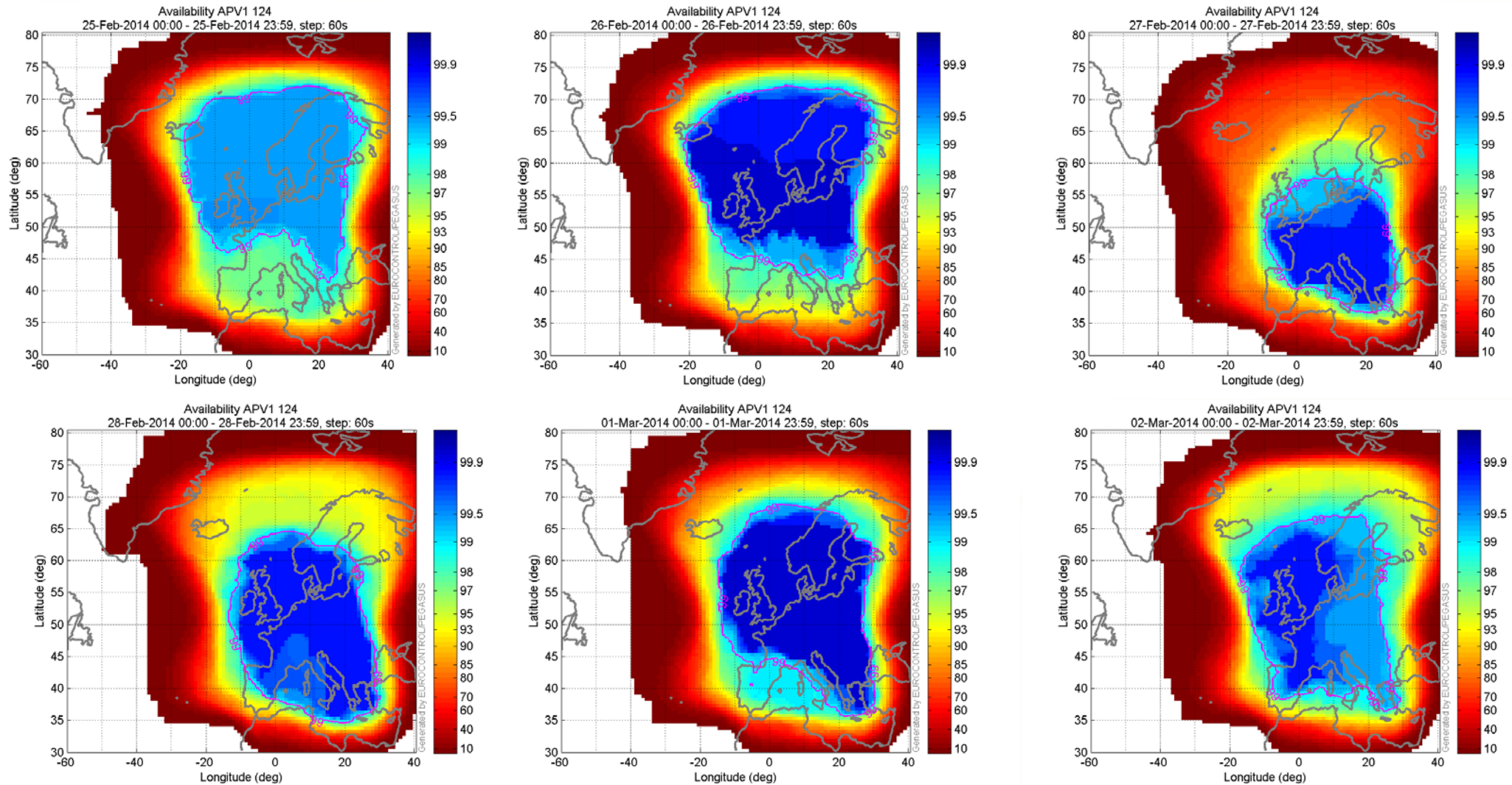


# 37 EGNOS RIMS

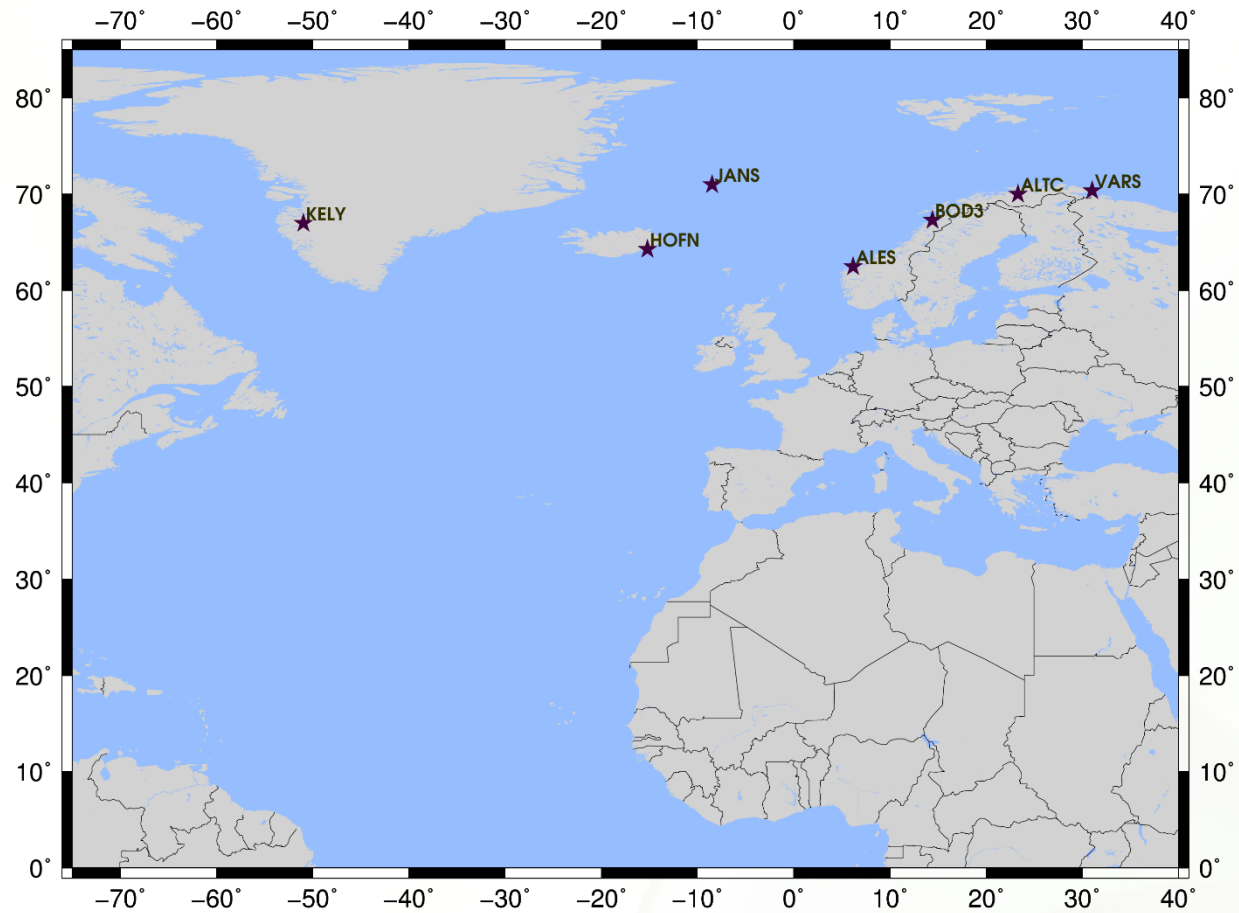
## APV-1 availability over 24h



# 37 RIMS + 2 extra stations



# Monitor stations



7 monitor stations at high latitudes



## Availability with 2 extra stations

DOY	Date	ales	bod3	altc	vars	jans	hofn	kely
56	25.02.2014	99.55	99.55	99.55	94.23	96.63	99.55	0.00
57	26.02.2014	100.00	100.00	99.80	93.45	96.98	100.00	0.00
58	27.02.2014	96.06	84.49	77.51	68.83	70.22	75.77	0.00
59	28.02.2014	99.80	94.93	93.24	87.75	93.10	93.08	0.00
60	01.03.2014	100.00	99.79	93.64	80.89	88.28	96.95	0.00
61	02.03.2014	100.00	98.84	95.37	92.10	95.44	97.98	0.00

## Diff with and without 2 extra stations

DOY	Date	ales	bod3	altc	vars	jans	hofn	kely
56	25.02.2014	-0.01	-0.01	-0.01	0.46	0.53	-0.01	0.00
57	26.02.2014	0.00	0.00	0.19	0.41	0.52	0.00	0.00
58	27.02.2014	10.76	5.79	3.96	2.24	1.46	0.20	0.00
59	28.02.2014	5.32	2.32	2.39	2.49	4.44	3.34	0.00
60	01.03.2014	0.38	2.13	3.36	1.18	2.95	2.08	0.00
61	02.03.2014	1.01	1.04	0.15	0.11	0.44	1.89	0.00

## Accuracy HPE95%

DOY	Date	ales	bod3	altc	vars	jans	hofn	kely
56	25.02.2014	0.7	1.2	1.6	2.4	2.1	0.9	*
57	26.02.2014	1.1	1.1	1.5	2.0	2.5	1.3	*
58	27.02.2014	1.6	2.4	2.9	2.8	2.5	3.3	*
59	28.02.2014	1.1	1.4	1.3	1.9	1.9	1.7	*
60	01.03.2014	0.9	1.6	1.8	2.7	2.3	1.7	*
61	02.03.2014	1.0	1.2	2.2	2.4	3.2	1.6	*

## Accuracy VPE95%

DOY	Date	ales	bod3	altc	vars	jans	hofn	kely
56	25.02.2014	1.5	2.1	2.9	4.0	3.2	2.2	*
57	26.02.2014	1.8	2.3	3.7	4.5	4.2	2.0	*
58	27.02.2014	2.3	3.8	4.1	4.3	4.7	4.3	*
59	28.02.2014	2.0	2.7	2.9	4.1	2.9	2.7	*
60	01.03.2014	1.7	2.9	2.8	4.0	3.8	2.9	*
61	02.03.2014	1.7	2.2	2.8	3.4	4.4	2.2	*