

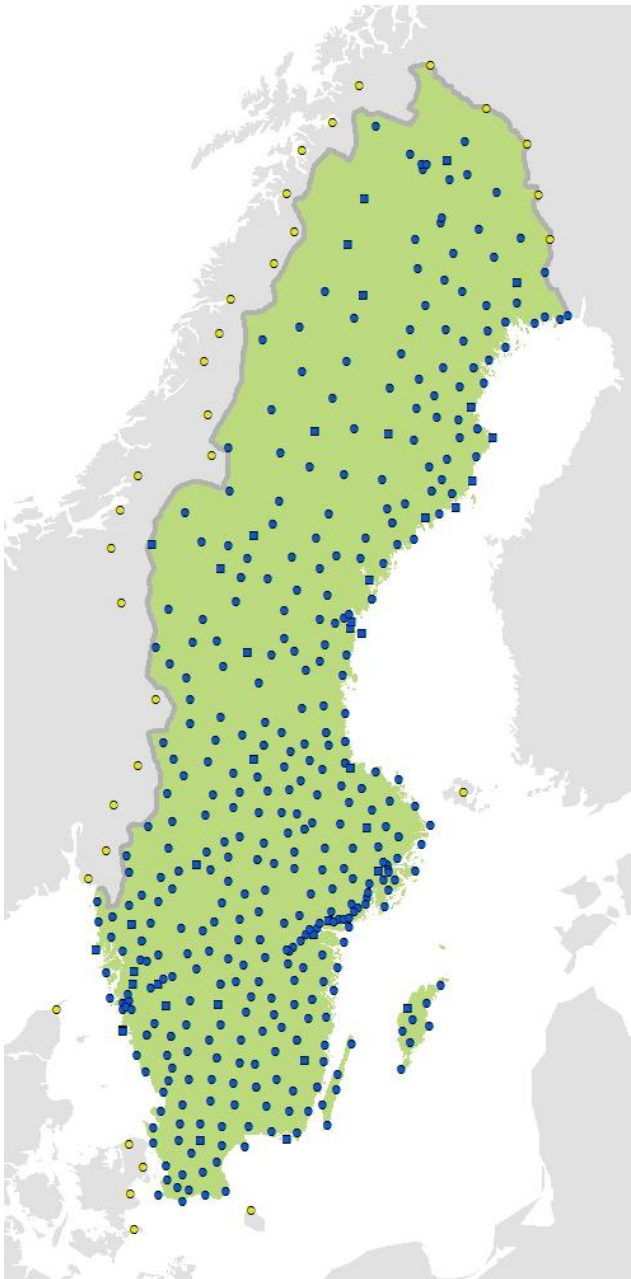
# **Experiences from test measurements with Galileo signals and SWEPOS**

**Swedish Radio Navigation Board seminar  
Stockholm, November 29<sup>th</sup> 2018**

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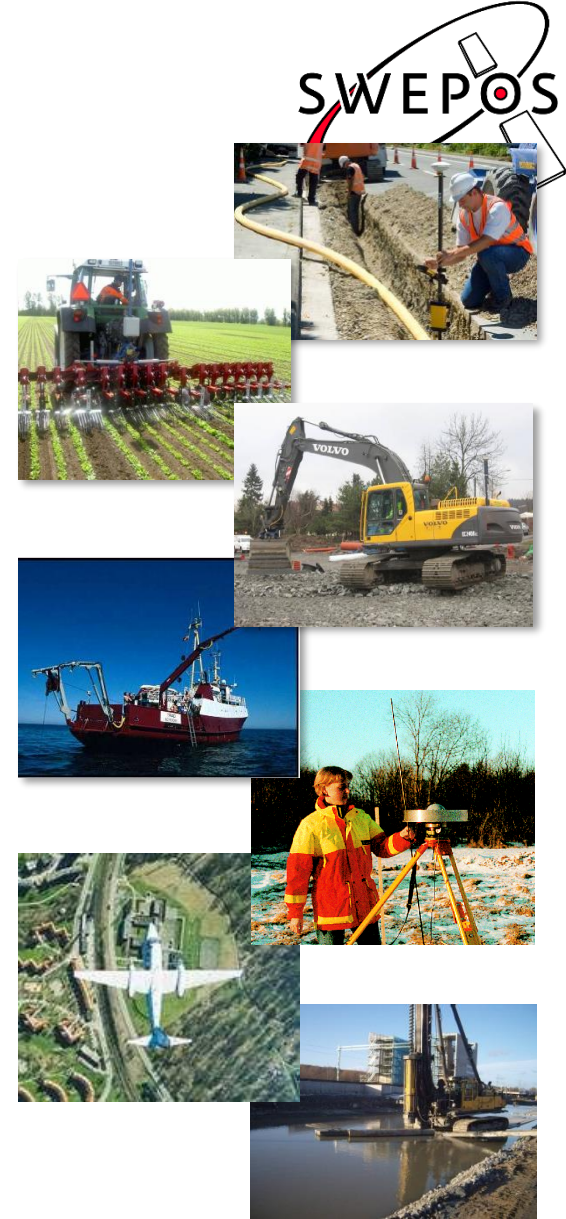
# SWEPOS®

- A national network of permanent reference stations and a part of the national geodetic infrastructure
- Established in cooperation with Onsala Space Observatory/Chalmers and RISE, the Technical Research Institute of Sweden
- 42 class A stations – Mounted on bedrock
- 370 class B stations – Mounted on municipal buildings
- Heterogeneous mix of CORS receiver types
- 5 IGS- and 24 EPN stations



# SWEPOS® services

- Real time services
  - DGNSS service (free of charge)
  - Network RTK service
    - Starts 2004
    - From 2006 GPS and Glonass
    - From 2018 Feb. 1<sup>st</sup> included Galileo
    - More than 4000 users!
- Post processing
  - Automatic calculation service
  - RINEX data
  - Virtual RINEX data
- Project adapted network RTK



# Test Results

# Galileo test measurements with single-station RTK, open area



- Initially through a diploma work by Anna Berggren, Stockholm University
- April 1<sup>st</sup>–15<sup>th</sup> 2016
- Single-station RTK
- 1.2 km to reference station



# Galileo test measurements with single-station RTK



- **Rover:** Trimble R8-3 (other manufacturers not possible by that time)
- **Strategy:** Disconnection from mobile Internet between each measurement
- **Mean value:** Each measurement an average of 10 positions
- **Cut-off angle:** 10 degrees
- **Fixed solution:** If an ambiguity fixed solution was not obtained within 3 minutes, the measurement was considered not successful

# Galileo test measurements with single-station RTK



- Use of signals:
  - **GLONASS:** No satellites were used
  - **GPS:** Some satellites were manually disabled with still good PDOP (5 or 6 GPS satellites were mainly used)
  - **Galileo:** All available satellites were used (0–4)



## Results Stockholm, distance 1.2 km, single-station RTK, open area

GPS + Galileo	Measurements (number)	Successful fixed solutions (%)	Mean value of time to fixed solution (s)	Standard uncertainty horizontally (mm)	Standard uncertainty vertically (mm)	Mean value of PDOP (-)
5 + 0	41	88	28	7	16	4.1
5 + 2	61	93	16	11*	17	3.2
5 + 3	43	100	23	7	15	2.6
5 + 4	7	100	13	8	8	2.2
6 + 0	35	94	10	6	12	3.0
6 + 2	42	98	12	8	14	2.4
6 + 3	27	96	8	5	11	2.2
6 + 4	5	100	8	4	4	2.1

\*8 mm if an outlier of 57 mm is removed



## Further test results Gävle, distance 10.6 km, single-station RTK, open area

GPS + Galileo	Measurements (number)	Successful fixed solutions (%)	Mean value of time to fixed solution (s)	Standard uncertainty horizontally (mm)	Standard uncertainty vertically (mm)	Mean value of PDOP (-)
5 + 0	45	80	44	13	26*	3.4
5 + 2	48	88	30	15	37*	2.7
5 + 3	45	98	43	17	39*	2.5
5 + 4	13	92	30	28*	43*	2.2
6 + 0	37	100	10	15	16	2.5
6 + 2	41	100	15	13	24	2.4
6 + 3	40	95	10	13	26	2.2
6 + 4	12	100	10	13	29	2.0

\*Some large outliers around 10-15 cm

# Test measurements with network RTK started in November 2016 in the Gävle area, open area



- **Rover:** different rover brands used
- **Strategy:** Disconnection from mobile Internet between each measurement
- **Mean value:** Each measurement an average of 10 positions
- **Cut-off angle:** 10 degrees
- **Fixed solution:** If an ambiguity fixed solution was not obtained within 3 minutes, the measurement was considered not successful

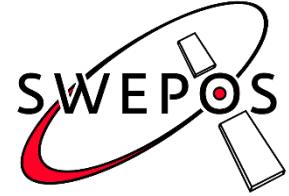
## Galileo test measurements with network RTK



- Use of signals:
  - **GLONASS:** No satellites were used
  - **GPS:** Some satellites were manually disabled with still good PDOP (5 or 6 GPS satellites were mainly used)
  - **Galileo:** All available satellites were used (0–5)



Nov 2016 – Jan 2017  
GPS + Galileo (11)

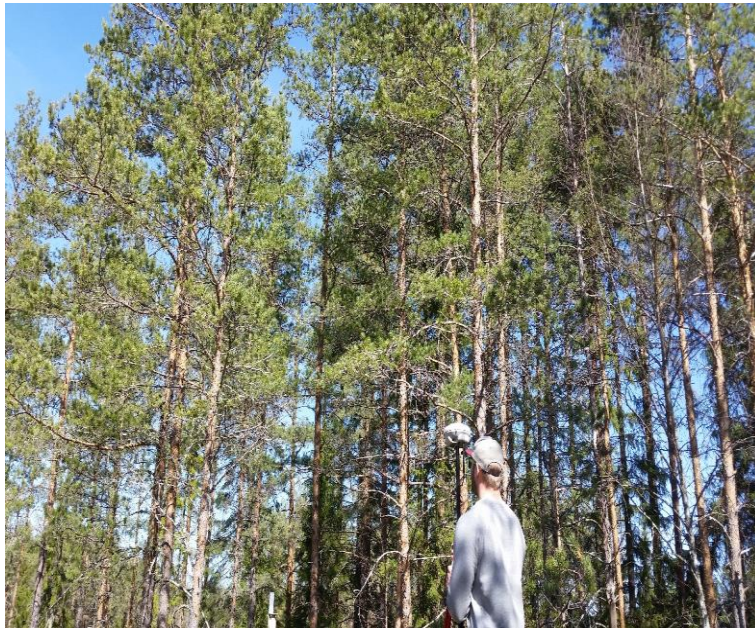


## Network RTK Gävle, rover brand #2, open area

GPS + Galileo	Measurements (number)	Successful fixed solutions (%)	Mean value of time to fixed solution (sec)	Standard uncertainty horizontally (mm)	Standard uncertainty vertically (mm)	Mean value of PDOP (-)
<b>5 + 0</b>	29	93	10	10	10	3,6
<b>5 + 2</b>	57	91	8	12	12	3,2
<b>5 + 3</b>	62	100	11	6	11	2,5
<b>5 + 4</b>	131	100	3	7	12	2,5
<b>5 + 5</b>	46	100	6	9	13	2,8
<b>6 + 0</b>	54	96	9	7	15	3,5
<b>6 + 2</b>	0	-	-	-	-	-
<b>6 + 3</b>	56	100	2	4	13	2,9
<b>6 + 4</b>	89	100	2	7	11	2,4
<b>6 + 5</b>	14	93	15	10	14	2,5



# More Galileo test measurements with network RTK. Students, Stefan Johansson and Petter Tysk, HiG Spring 2017



- **Rover:** different rover brands used
- **Strategy:** Disconnection from mobile Internet between each measurement
- **Mean value:** Each measurement an average of 10 positions
- **Cut-off angle:** 15, 25 and 35 degrees
- **Fixed solution:** If an ambiguity fixed solution was not obtained within 2 minutes, the measurement was considered not successful
- **Environment:** Forested and urban areas



## More Galileo test measurements with network RTK



- Use of signals:
  - **GLONASS:** All available satellites were used
  - **GPS:** All available satellites were used
  - **Galileo:** All available satellites were used (0–6)

# Network RTK, Gävle/Mårtsbo, 6 different measuring points, Forest area

GPS+Glonass <b>G+G</b>	Satellites average	Successful fixed solutions	Mean value of time to fixed solution	Standard uncertainty horizontally	Standard uncertainty vertically	Mean value of PDOP
(cut-off)	(numbers)	(%)	(sec)	(mm)	(mm)	(-)
<b>15°</b>	6+6	100	30	15	21	2,5
<b>25°</b>	5+4	80	14	8	14	3,8
<b>35°</b>	4+3	61	62	2	42	5,8

GPS+Glo+Gal <b>G+G+G</b>	Satellites average	Successful fixed solutions	Mean value of time to fixed solution	Standard uncertainty horizontally	Standard uncertainty vertically	Mean value of PDOP
(cut-off)	(numbers)	(%)	(sec)	(mm)	(mm)	(-)
<b>15°</b>	5+5+2	100	14	12	41	2,2
<b>25°</b>	5+4+2	98	34	21	51	3,4
<b>35°</b>	4+3+2	79	26	23	47	4,7

## Network RTK, Gävle, 5 different measuring points, Urban areas

GPS+Glonass <b>G+G</b>	Satellites average	Successful fixed solutions	Mean value of time to fixed solution	Standard uncertainty horizontally	Standard uncertainty vertically	Mean value of PDOP
(cut-off)	(numbers)	(%)	(sec)	(mm)	(mm)	(-)
<b>15°</b>	5+6	100	12	7	20	2,7
<b>25°</b>	6+5	95	11	18	25	2,6
<b>35°</b>	4+3	60	42	15	23	3,9

GPS+Glo+Gal <b>G+G+G</b>	Satellites average	Successful fixed solutions	Mean value of time to fixed solution	Standard uncertainty horizontally	Standard uncertainty vertically	Mean value of PDOP
(cut-off)	(numbers)	(%)	(sec)	(mm)	(mm)	(-)
<b>15°</b>	5+6+2	100	12	10	21	2,4
<b>25°</b>	6+5+2	100	13	11	14	2,4
<b>35°</b>	4+3+2	91	14	9	26	4,7

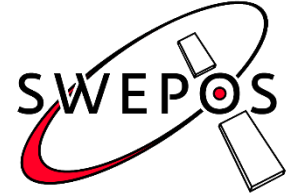
# Network RTK, Gävle/Rörberg, continuous readings with one observation/second October 2018



- **Rover:** Leica
- **Strategy:** Continuous readings with one observation/second, 3 hour measurement
- **Cut-off angle:** 13 and 25 degrees
- **Fixed solution:** Check all data after 3 hours of measurement
- **Environment:** Forested areas

October 2018

GPS + Glonass vs GPS + Glonass + Galileo (17)



## Network RTK, Gävle/Rörberg, continuous readings with one observation/second, Forest area

GPS+Glonass <b>G+G</b> (vinkel)	Satellites average (numbers)	Successful fixed solutions (%)	Standard uncertainty horizontally (mm)	Standard uncertainty vertically (mm)	Mean value of PDOP (-)	Mean value of time to fixed solution (sec)
<b>13°</b>	9+6	97	17	21	1,5	17
<b>25°</b>	7+4	97	26	38	2,4	18

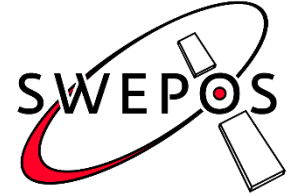
GPS+Glo+Gal <b>G+G+G</b> (vinkel)	Satellites average (numbers)	Successful fixed solutions (%)	Standard uncertainty horizontally (mm)	Standard uncertainty vertically (mm)	Mean value of PDOP (-)	Mean value of time to fixed solution (sec)
<b>13°</b>	9+5+3	97	22	30	1,5	30
<b>25°</b>	7+4+3	99,9	23	28	2,1	14

(Outliers limit 100mm)



October 2018

GPS + Glonass vs GPS + Glonass + Galileo (17)



## Network RTK, Gävle, continuous readings with one observation/second, Forest area

GPS+Glonass <b>G+G</b> (vinkel)	Satellites average (numbers)	Successful fixed solutions (%)	Standard uncertainty horizontally (mm)	Standard uncertainty vertically (mm)	Mean value of PDOP (-)	Mean value of time to fixed solution (sec)
<b>13°</b>	9+5	99	17	25	1,5	17
<b>25°</b>	8+3	92	20	32	2,3	22

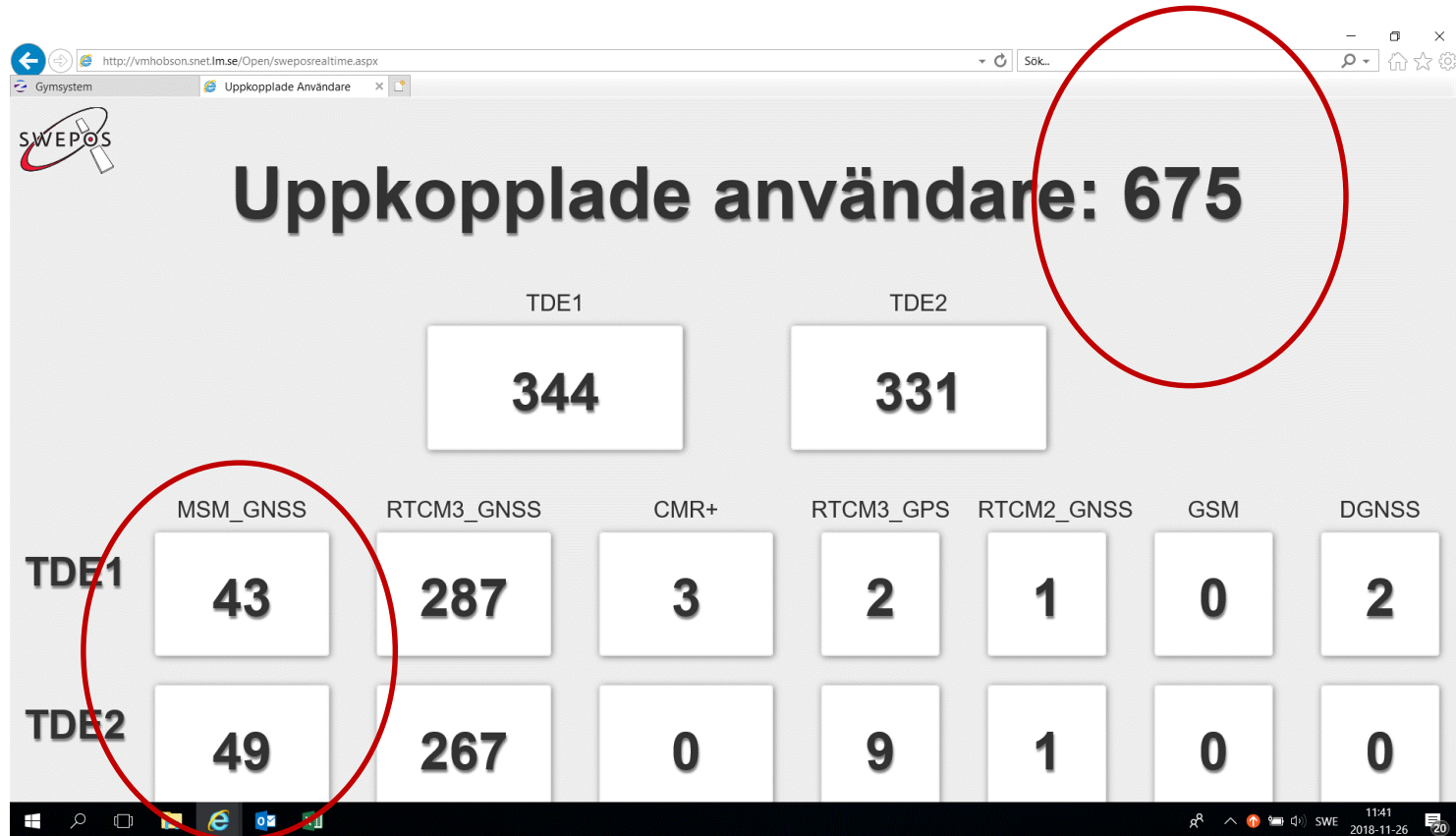
GPS+Glo+Gal <b>G+G+G</b> (vinkel)	Satellites average (numbers)	Successful fixed solutions (%)	Standard uncertainty horizontally (mm)	Standard uncertainty vertically (mm)	Mean value of PDOP (-)	Mean value of time to fixed solution (sec)
<b>13°</b>	9+5+4	95	18	25	1,5	34
<b>25°</b>	8+3+2	99	18	21	2,2	23

(Outliers limit 100mm)

## Conclusions

- The test measurements show small variations in position uncertainty depended on if Galileo satellites are added to GPS and Glonass satellites or not.
- The test measurements indicate improvements in availability if Galileo satellites are added to GPS and Glonass satellites compared with no Galileo satellites
  - More fixed solutions and maybe shorter initialisation time
  - Perhaps more in tough environment and with higher cut-off angle

# SWEPOS users



Thank you for your  
attention!

Any questions?

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