Beregning av DOP langs norsk vei med fjellskygge effekter

10. Okt 2024

Sommerprosjekt av Sindre Havn

Kilde: https://lex.dk/Romsdalen

Globale GDOP verdier

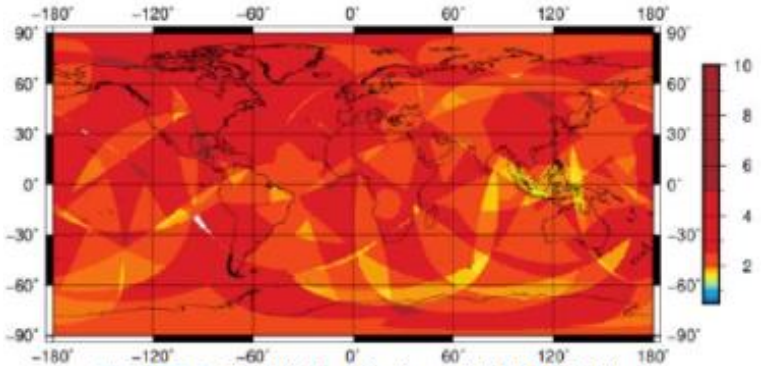


FIGURE 8. Global Distribution of GDOP (Galileo)

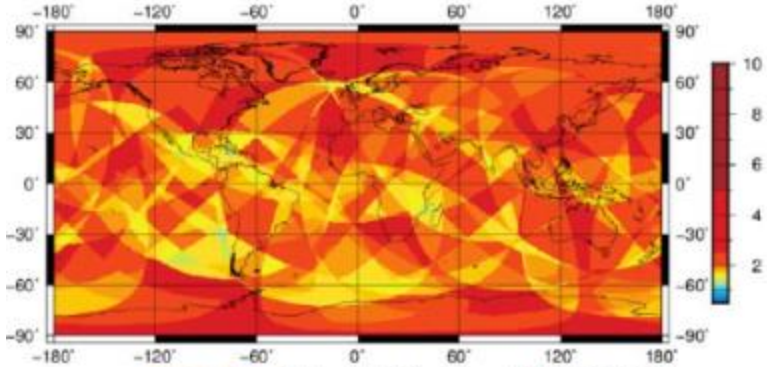


FIGURE 5. Global Distribution of GDOP (GPS)

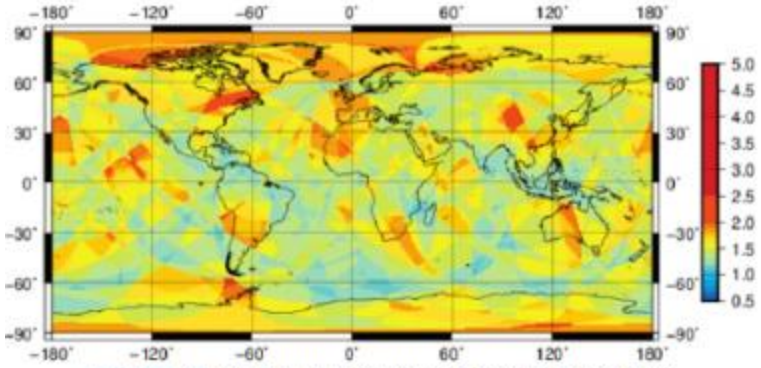


FIGURE 13. Global Distribution of GDOP (GPS+GAL)

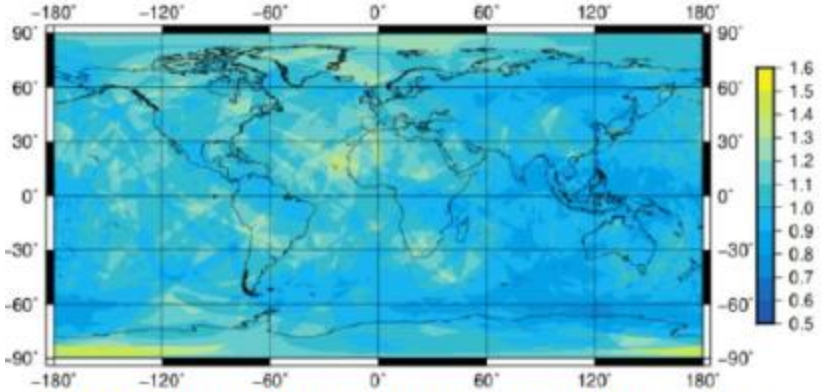
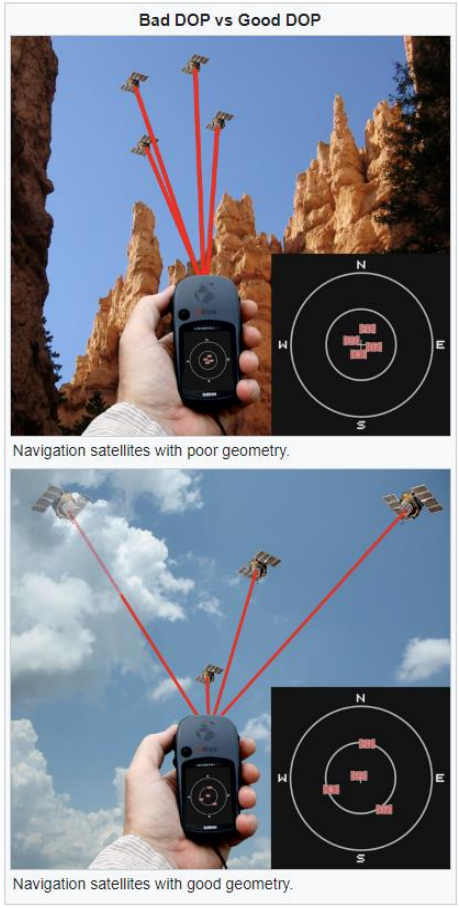


FIGURE 25. Global Distribution of GDOP (GPS+GLO+BDS+GAL)

Kilde (2019):
https://www.researchgate.net/publication/336358523_Preliminary_Availability_Assessment_of_Multi-GNSS_A_Global_Scale_Analysis

GDOP = satellitt-geometri



Kilde:
https://en.wikipedia.org/wiki/Dilution_of_precision_(navigation)

$$d_{ai} = \frac{a_i - a}{\sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2}}, \quad a = x,\ y,\ or\ z \tag{3.3}$$

$$J = \begin{bmatrix} d_{x1} & d_{y1} & d_{z1} & 1 \\ d_{x2} & d_{y2} & d_{z2} & 1 \\ \vdots & \vdots & \vdots & 1 \\ d_{xn} & d_{yn} & d_{zn} & 1 \end{bmatrix} \tag{3.4}$$

$$Q = [\,J^T\ J]^{-1} = \begin{bmatrix} \sigma_x^2 & \sigma_{xy} & \sigma_{xz} & \sigma_{xt} \\ \sigma_{xy} & \sigma_y^2 & \sigma_{yz} & \sigma_{yt} \\ \sigma_{xz} & \sigma_{yz} & \sigma_z^2 & \sigma_{zt} \\ \sigma_{xt} & \sigma_{yt} & \sigma_{zt} & \sigma_t^2 \end{bmatrix} \tag{3.5}$$

$$GDOP \triangleq \sqrt{trace(Q)} \tag{3.6}$$

and

$$GDOP^2 = HDOP^2 + VDOP^2 + TDOP^2 \tag{3.7}$$

where x_i, y_i, z_i represents the ith satellite position and x, y, z describe the receiver's position.

$$HDOP \triangleq \sqrt{\sigma_x^2 + \sigma_y^2},\ VDOP \triangleq \sqrt{\sigma_y^2},\ \text{and}\ TDOP \triangleq \sqrt{\sigma_t^2}$$

Kilde:
https://trepo.tuni.fi/bitstream/handle/10024/132157/TampierJaraFelipe.pdf?sequence=2

WGDOP = Posisjonsfeil

$$H = \begin{bmatrix} e_{11} & e_{12} & e_{13} & 1 \\ e_{21} & e_{22} & e_{23} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ e_{n1} & e_{n2} & e_{n3} & 1 \end{bmatrix}$$

$$e_{i1} = \frac{\hat{x} - X_i}{\hat{r}_i} \qquad e_{i2} = \frac{\hat{y} - Y_i}{\hat{r}_i} \qquad e_{i3} = \frac{\hat{z} - Z_i}{\hat{r}_i}$$

$$W = \begin{bmatrix} 1/\sigma_1^2 & 0 & 0 & 0 & 0 \\ 0 & 1/\sigma_2^2 & 0 & 0 & 0 \\ 0 & 0 & 1/\sigma_3^2 & 0 & 0 \\ 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 1/\sigma_n^2 \end{bmatrix}$$

$$\hat{r}_i = \sqrt{(\hat{x} - X_i)^2 + (\hat{y} - Y_i)^2 + (\hat{z} - Z_i)^2}$$

$\sigma_i^2 = 1/k_i$, $i = 1,....n$ are variances of measurement errors. According to the formula above, WGDOP is given by the trace of the inverse of the $H^T W H$ matrix:

$$WGDOP = \sqrt{tr(H^T W H)^{-1}} \qquad (3)$$

Kilde:
https://www.researchgate.net/publication/270659318_Weighted_Geometric_Dilution_of_Precision_Calculations_with_Matrix_Multiplication

σ - verdier

Brukt i koden fra github

Data er fra 2022 – nyere satelitter er skutt opp og UERE varierer fra kilde til kilde

GNSS	BDS	GPS	GLONASS	Galileo
SISE (m)	0.7	1.0	2.3	0.8
UEE (m)	1.6	1.6	1.6	1.6
UERE (m)	1.7	1.9	2.8	1.8

Kilde: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9002469/

Alternativ SISRE data I rapport (2024): https://www.sciencedirect.com/science/article/abs/pii/S0273117724000954

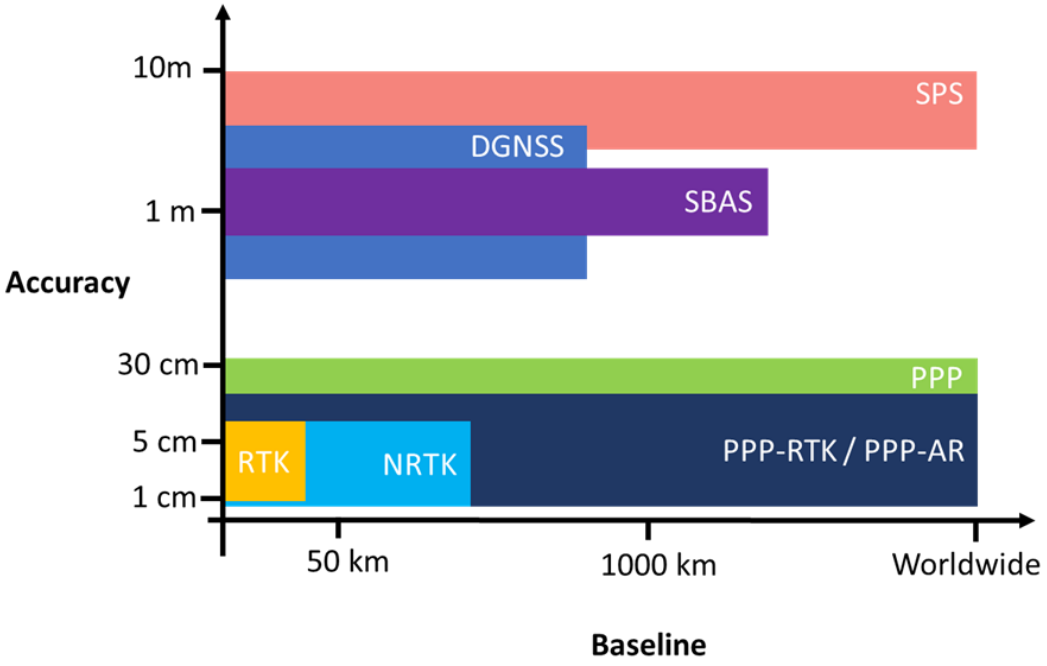
$$W = \mathbf{R}^{-1} = \begin{pmatrix} 1/\sigma_{y_1}^2 & & \\ & \ddots & \\ & & 1/\sigma_{y_n}^2 \end{pmatrix} \quad (6)$$

https://gssc.esa.int/navipedia/index.php?title=Best_Linear_Unbiased_Minimum-Variance_Estimator_(BLUE)

where $\sigma_{y_i}^2$ comes from the uncertainty of the different error sources (satellite clocks, ephemeris, ionosphere, troposphere, multipath and receiver noise):

$$\sigma_{y_i}^2 \equiv \sigma_{UERE_i}^2 = \sigma_{clk_i}^2 + \sigma_{eph_i}^2 + \sigma_{iono_i}^2 + \sigma_{tropo_i}^2 + \sigma_{mp_i}^2 + \sigma_{noise_i}^2 \quad (7)$$

Posisjonerings metoder



Application	Land Survey	Machine Guidance	Natural Resources	Natural Hazards	Marine Navigation	Air Navigation
Category	RTK		PPP		DGPS/WAAS /SPS/SPP	
Coverage	Regional		Global		Coastal/Continental	
Purpose	Positioning		Monitoring		Navigation	
Communications	Terrestrial				Satellite	
Corrections	Commercial				Public	
Performance	Accuracy		Reliability		Integrity	
Method	Differential		Undifferenced		Differential	
Observable	Carrier phase		Carrier Phase		Pseudorange	
Precision	CENTIMETRE				METRE	

20 100 200 500

Reference Station Spacing (km)

Kilde: https://garrett.seepersad.org/post/positioning_techniques/

Kilde: https://cgrsc.ca/resources/gnss-augmentation/

Beste kilder på å forklare (W)GDOP:

- https://snl.no/DOP_-_satellittgeometri
- https://www.researchgate.net/publication/258400682_Calculation_of_Weighted_Geometric_Dilution_of_Precision
- https://gssc.esa.int/navipedia/index.php?title=Best_Linear_Unbiased_Minimum-Variance_Estimator_(BLUE)
- https://gssc.esa.int/navipedia/index.php?title=Parameters_adjustment

Videre korrigering av DOP?

Dersom man vil garantere inverterbar matrise
i databehandling (bruke kovariansene videre)
=> Symmetrisk matrise

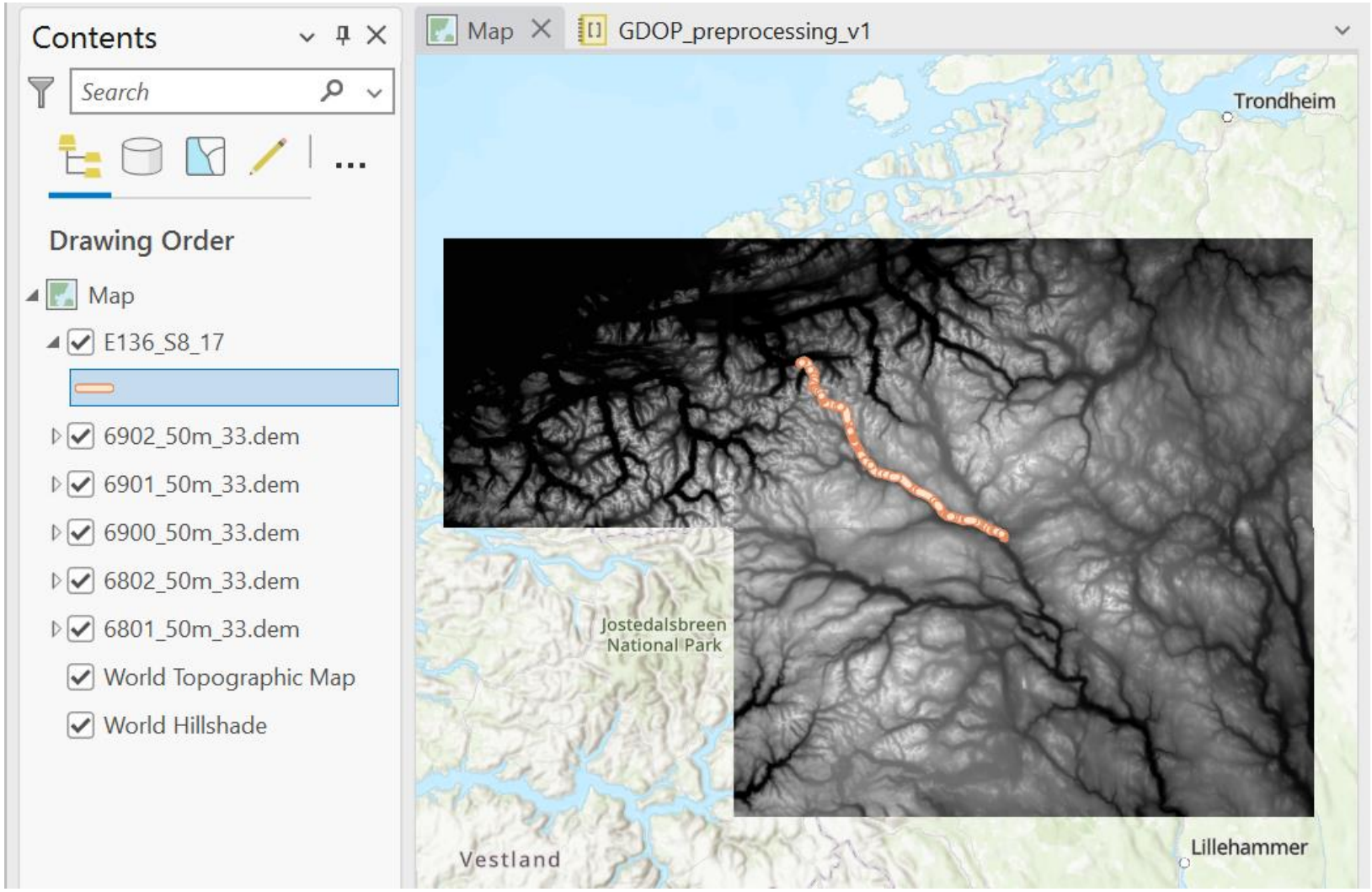
By combing GDOP with weighted scheme, WGDOP can be expressed as Equation (3). In order to guarantee the matrix $H^T WH$ is a symmetric one in later operation, we refreshed the formulation above:

$$WGDOP = \sqrt{tr(H^T WH)^{-1}} = \sqrt{tr(H^T W^{\frac{1}{2}} W^{\frac{1}{2}} H)^{-1}} = \sqrt{tr(W^{\frac{1}{2}} HH^T W^{\frac{1}{2}})^{-1}} \quad (4)$$

Kilde:
https://www.researchgate.net/publication/270659318_Weighted_Geometric_Dilution_of_Precision_Calculations_with_Matrix_Multiplication

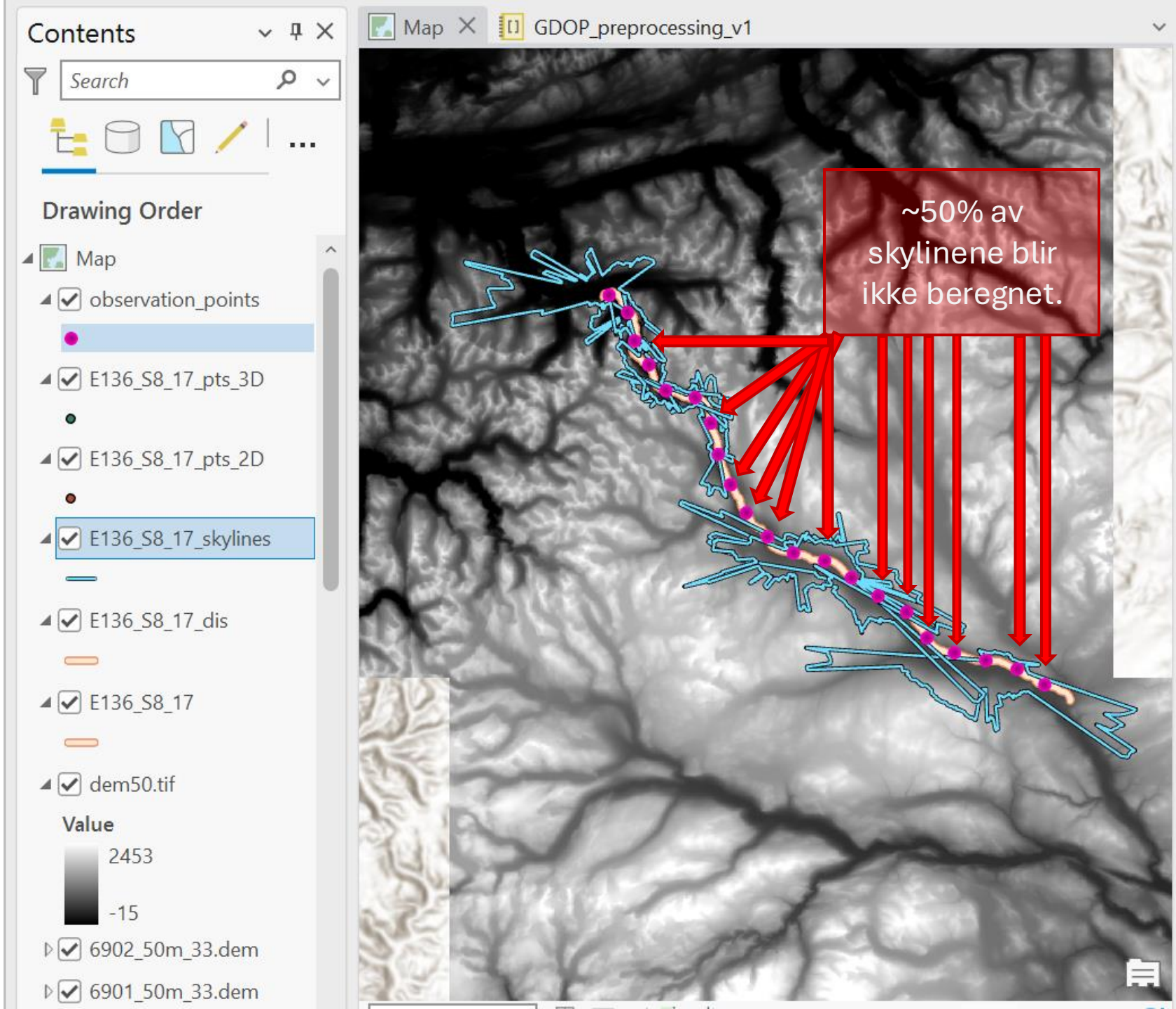
Steg 1: Last opp data

- Vegkurven E136_S8_17 er stykkedelt når den er lastet ned fra vegkart.no
- .dem filene har egen-definerte terrengprofiler (se langs sidene)



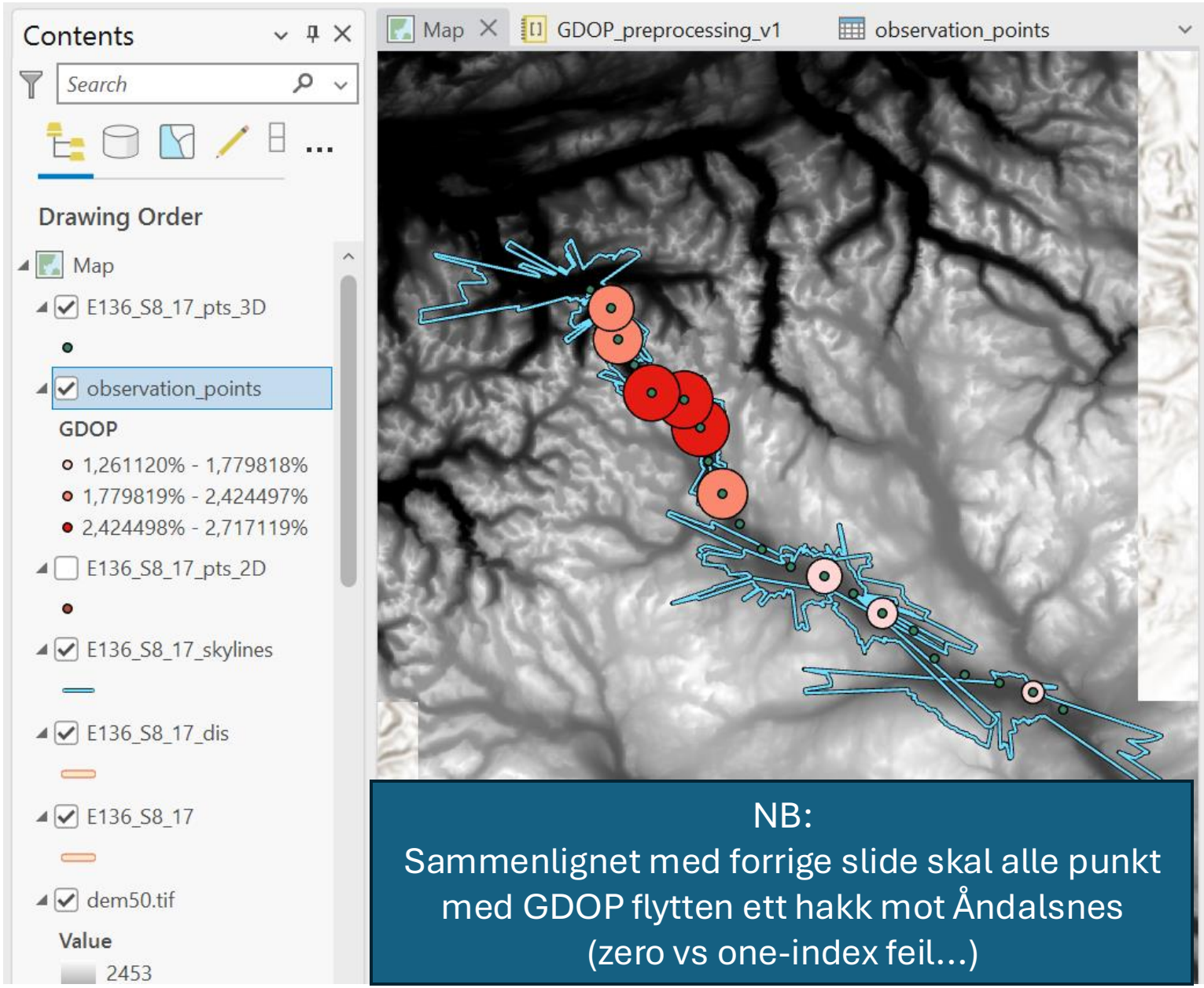
Steg 2: Kjør jupyter notebook

1. Vegstrekningene samles til èn, og .dem filene slås sammen.
2. Observasjonspunkt blir samplet etter gitt intervall, og projektert på terrengkartet.
3. Skyline blir beregnet I obersvasjonspunktene og lagret som .csv filer.



Steg 3: Kjør DOP kode på horisontkurver og observasjonspunkt

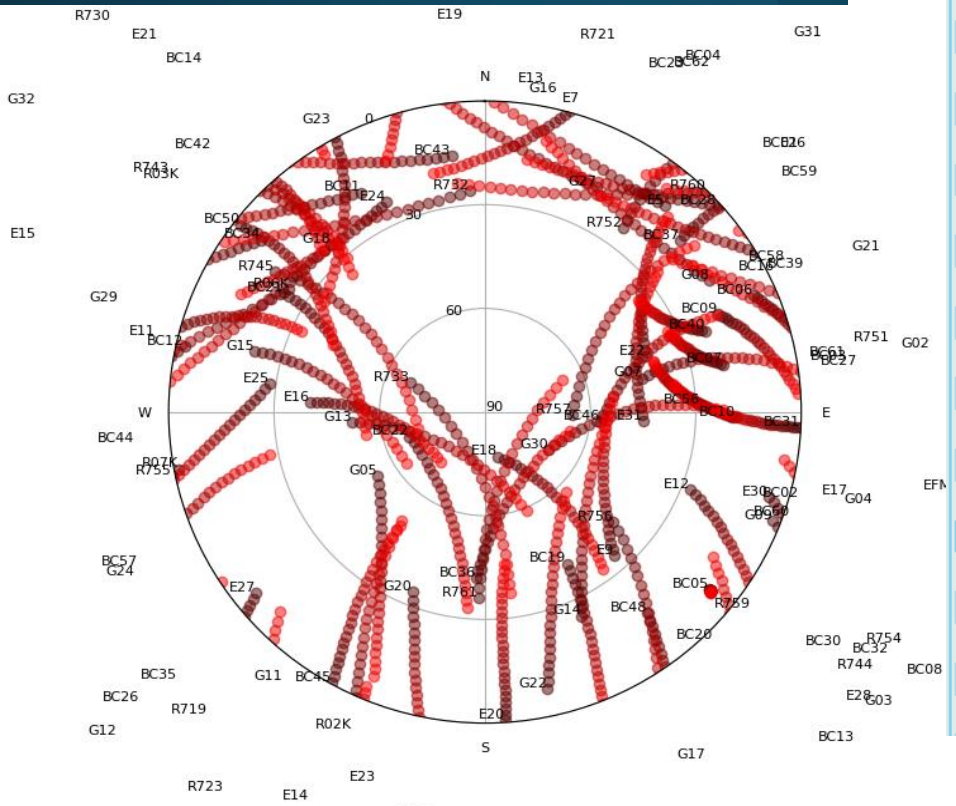
1. Vegstrekningene samles til èn, og .dem filene slås sammen.
2. Observasjonspunkt blir samplet etter gitt intervall, og projektert på terrengkartet.
3. Skyline blir beregnet I obersvasjonspunktene og lagret som .csv filer.



NB:
Sammenlignet med forrige slide skal alle punkt med GDOP flytten ett hakk mot Åndalsnes (zero vs one-index feil…)

Satellitt banedata

– celestrak.org/NORAD/elements



GNSS

Current as of 2024 Oct 07 22:05:35 UTC (Day 281)

Latest GP (TLE format) Data

Element Set Age (days)						
0–5	5–10	10–15	15–20	20–25	25–30	> 30

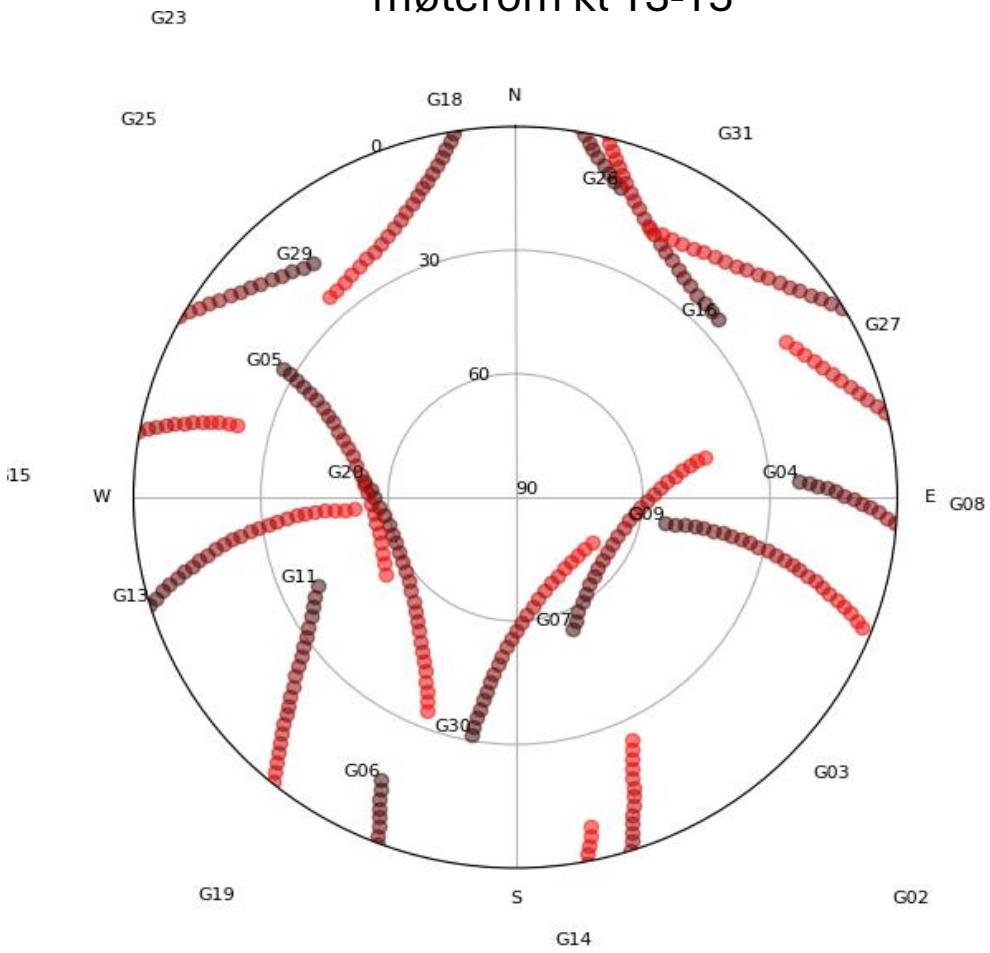
Show 25 entries

Search:

International Designator	NORAD Catalog Number	Name	Period (minutes)	Inclination (degrees)	Apogee Height (km)	Perigee Height (km)	Eccentricity	Latest Data	GP Age (days)
1997-035A	24876	GPS BIIR-2 (PRN 13)	717.98	55.71	20,408	19,957	0.0084912		0.97
2000-025A	26360	GPS BIIR-4 (PRN 20)	717.95	54.76	20,286	20,077	0.0039497		0.58
2000-040A	26407	GPS BIIR-5 (PRN 22)	717.98	55.03	20,560	19,805	0.0142033		0.61
2003-005A	27663	GPS BIIR-8 (PRN 16)	717.96	55.06	20,550	19,813	0.0138672		0.33
2003-010A	27704	GPS BIIR-9 (PRN 21)	717.96	55.07	20,860	19,504	0.0255410		0.33
2004-009A	28190	GPS BIIR-11 (PRN 19)	718.00	55.36	20,446	19,920	0.0098877		0.54
2004-045A	28474	GPS BIIR-13 (PRN 02)	717.98	55.40	20,619	19,745	0.0164513		0.32
2005-036A	28868	CRE (WAAS/PRN 138)	1,436.09	2.72	35,797	35,775	0.0002611	*G	0.56
2005-038A	28874	GPS BIIRM-1 (PRN 17)	717.93	55.40	20,546	19,816	0.0137437		1.08
2005-044A	28899	IOR-W (EGNOS/PRN 126)	1,436.10	4.31	35,798	35,776	0.0002586	*G	0.64
2006-042A	29486	GPS BIIRM-2 (PRN 31)	717.94	54.68	20,460	19,903	0.0104814		0.50
2006-052A	29601	GPS BIIRM-3 (PRN 12)	717.94	55.10	20,407	19,956	0.0085021		0.75
2007-047A	32260	GPS BIIRM-4 (PRN 15)	717.99	53.67	20,606	19,760	0.0159211		0.44
2007-052A	32275	COSMOS 2433 (720)	675.73	65.89	19,143	19,116	0.0005363		0.56
2007-052B	32276	COSMOS 2432 (719)	675.73	65.90	19,155	19,105	0.0009706		0.41
2007-062A	32384	GPS BIIRM-5 (PRN 29)	718.01	55.55	20,258	20,109	0.0028076		0.44
2007-065A	32393	COSMOS 2434 (721)	675.73	64.32	19,135	19,125	0.0001810		0.36
2007-065C	32395	COSMOS 2436 (723)	675.74	64.33	19,173	19,087	0.0016702		0.36
2008-012A	32711	GPS BIIRM-6 (PRN 07)	717.95	54.45	20,685	19,678	0.0189570		1.03
2009-043A	35752	GPS BIIRM-8 (PRN 05)	717.98	55.77	20,331	20,033	0.0056021		0.53
2009-070A	36111	COSMOS 2456 (730)	675.73	64.67	19,133	19,126	0.0001395		1.15
2009-070B	36112	COSMOS 2457 (733)	675.74	64.65	19,146	19,114	0.0006251		0.32
2010-007C	36402	COSMOS 2460 (732)	675.72	65.74	19,136	19,123	0.0002386		1.65
2010-022A	36585	GPS BIIF-1 (PRN 25)	718.00	54.41	20,492	19,873	0.0116558		0.52
2010-036A	36828	BEIDOU-2 IGSO-1 (C06)	1,436.41	54.25	35,965	35,621	0.0040753	*G	0.47

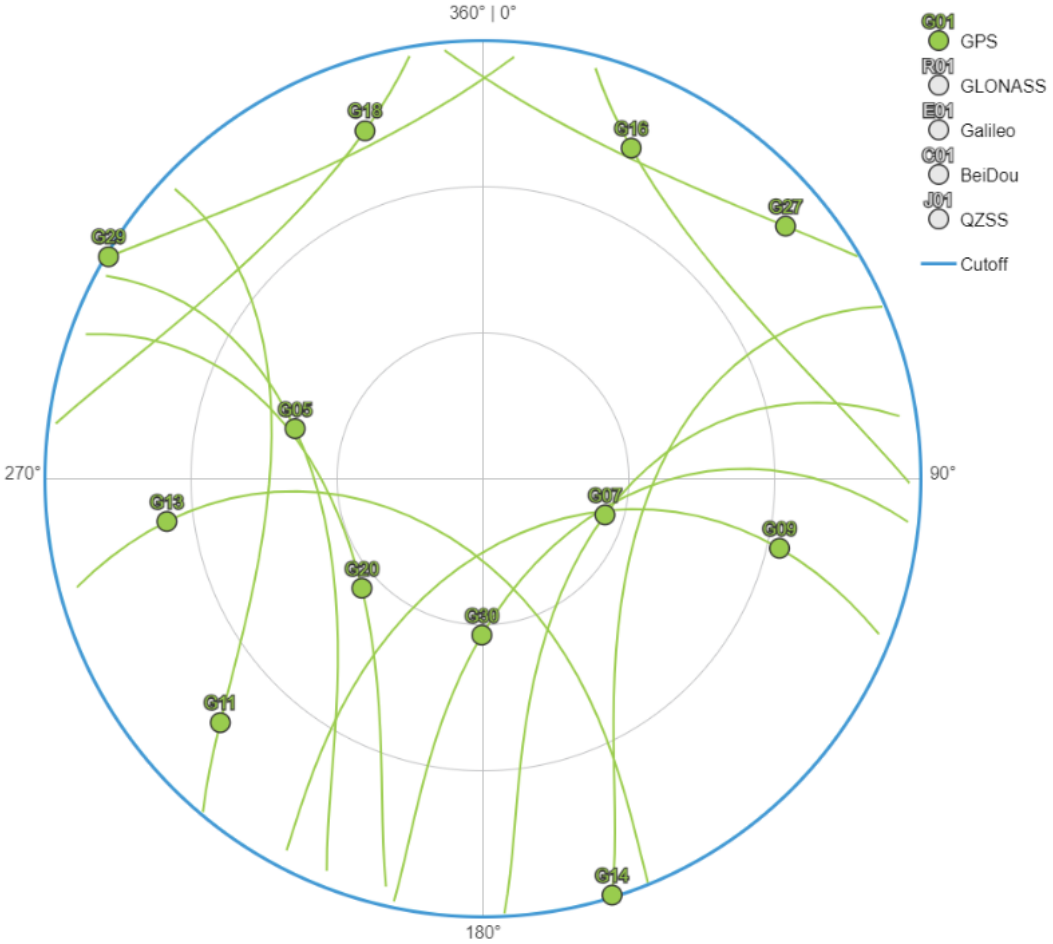
Validering av satellitt posisjoner

Beregnet GPS over møterom kl 13-15



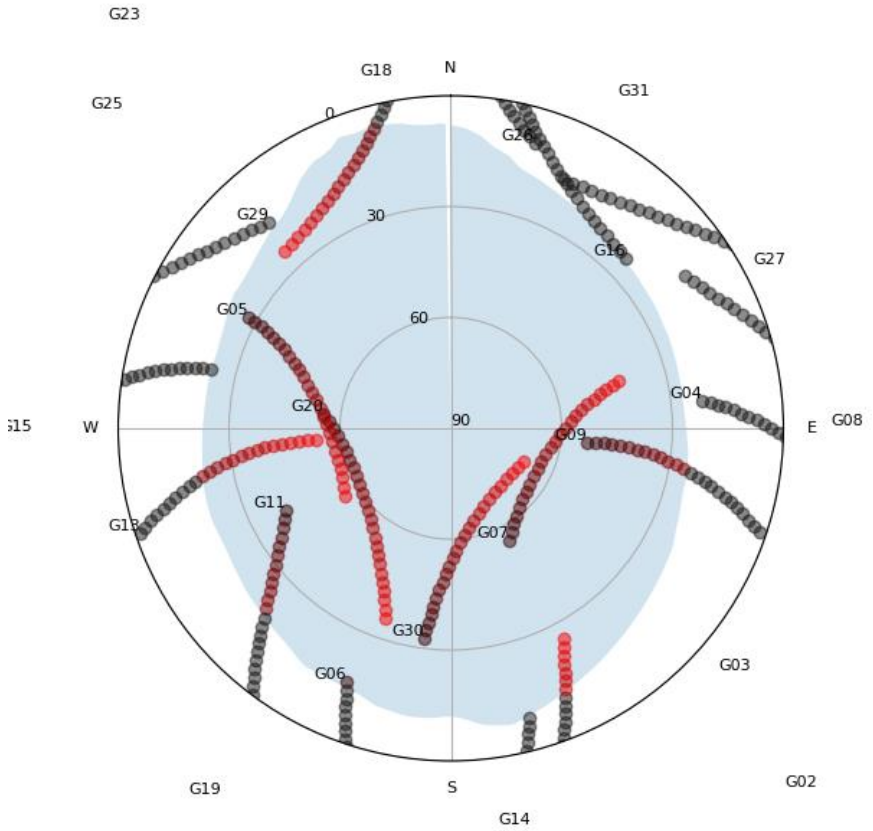
https://www.gnssplanning.com/#/skyplot

GPS over møterom kl 14

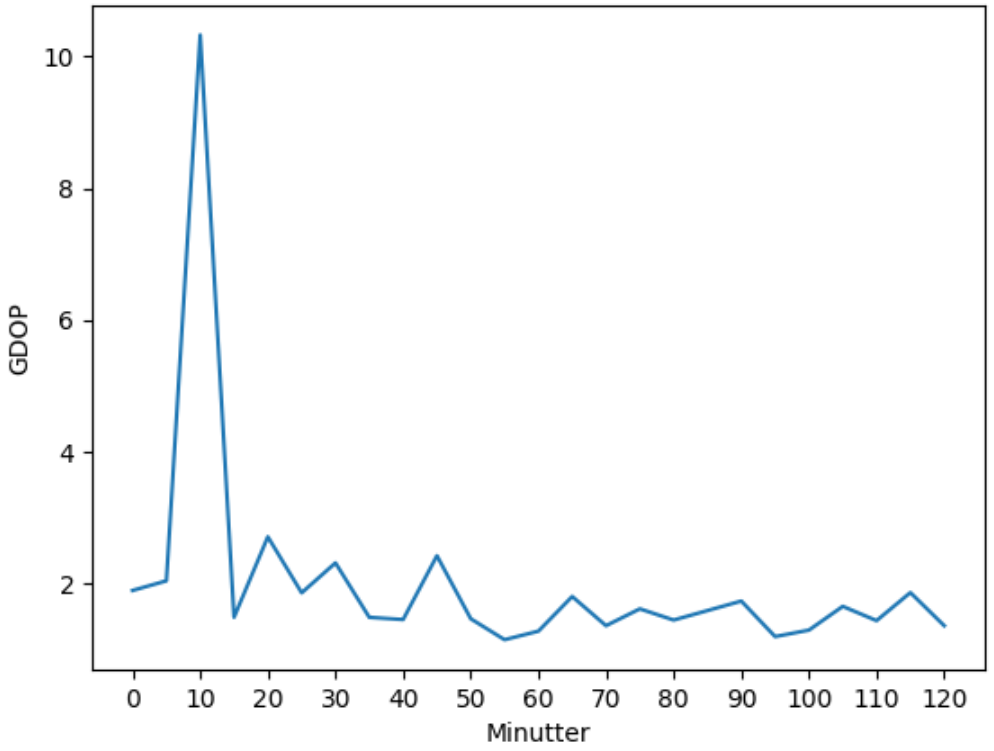


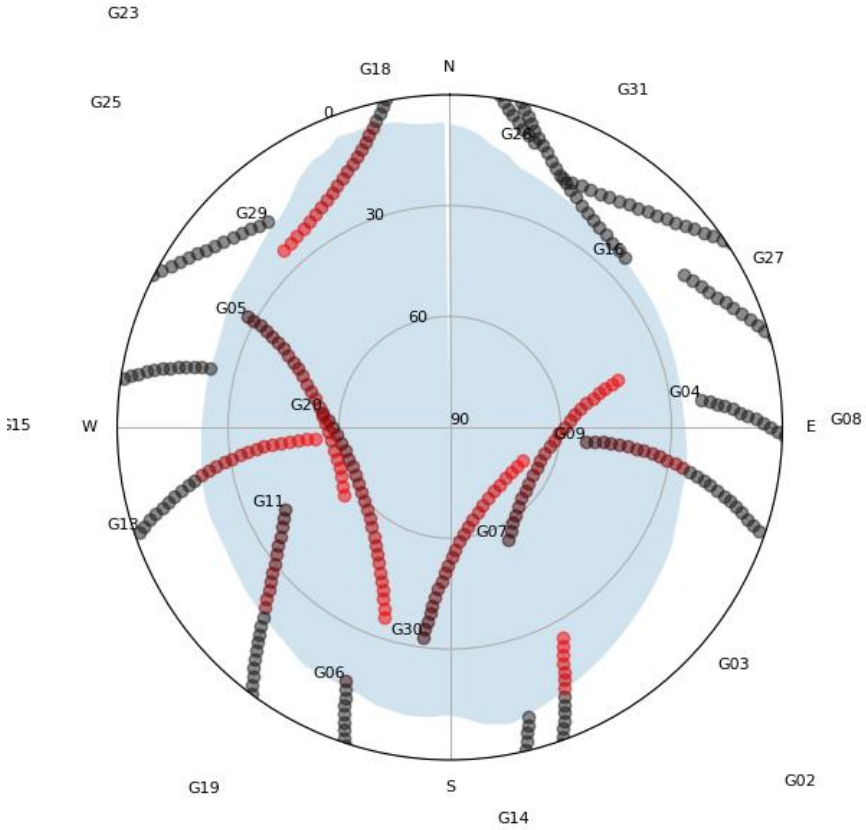
Eksempel

Tors, 10 Okt 2024 09.15 UTC
Lat/Long: 62.3981961,8.0124574



GDOP kl 9.15-11.15





Veien videre – validering og optimalisering

1. **Hvor ofte** (tid) skal DOP beregnes?
2. Følger satelittene **periodiske baner** over samme punkt på jorda, slik at man gjenbruke utregninger for et gyldighets vindu?
3. **Hvilken avstand** langs vegkurven bør DOP utregnes?
4. **Løs skyline bug.**
5. Bestem **satelitt støy** σ = UERE, for konstellasjon, med banehøyder? eller egen for hver satelitt?

6. Er **terrengmodellen gyldig** for beregning av horisontkurve i bebygde områder eller ved skog?
7. **Hvilken vinkel-oppløsning** egner seg for beregning av horisontkurve?

8. **Multipath effekter** fra dalside eller høye flate bygg?

https://github.com/Sindre-Havn/Estimation-of-GDOP-in-Norwegian-Valleys