

Accuracy estimation of alternative positioning in navigation

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GNSS errors

- geometric factor of the satellite
- segment,
- large spatial variation in ionospheric delay
- interference from ground based radio equipment
- Refraction from obstacles

that reduce the positioning accuracy

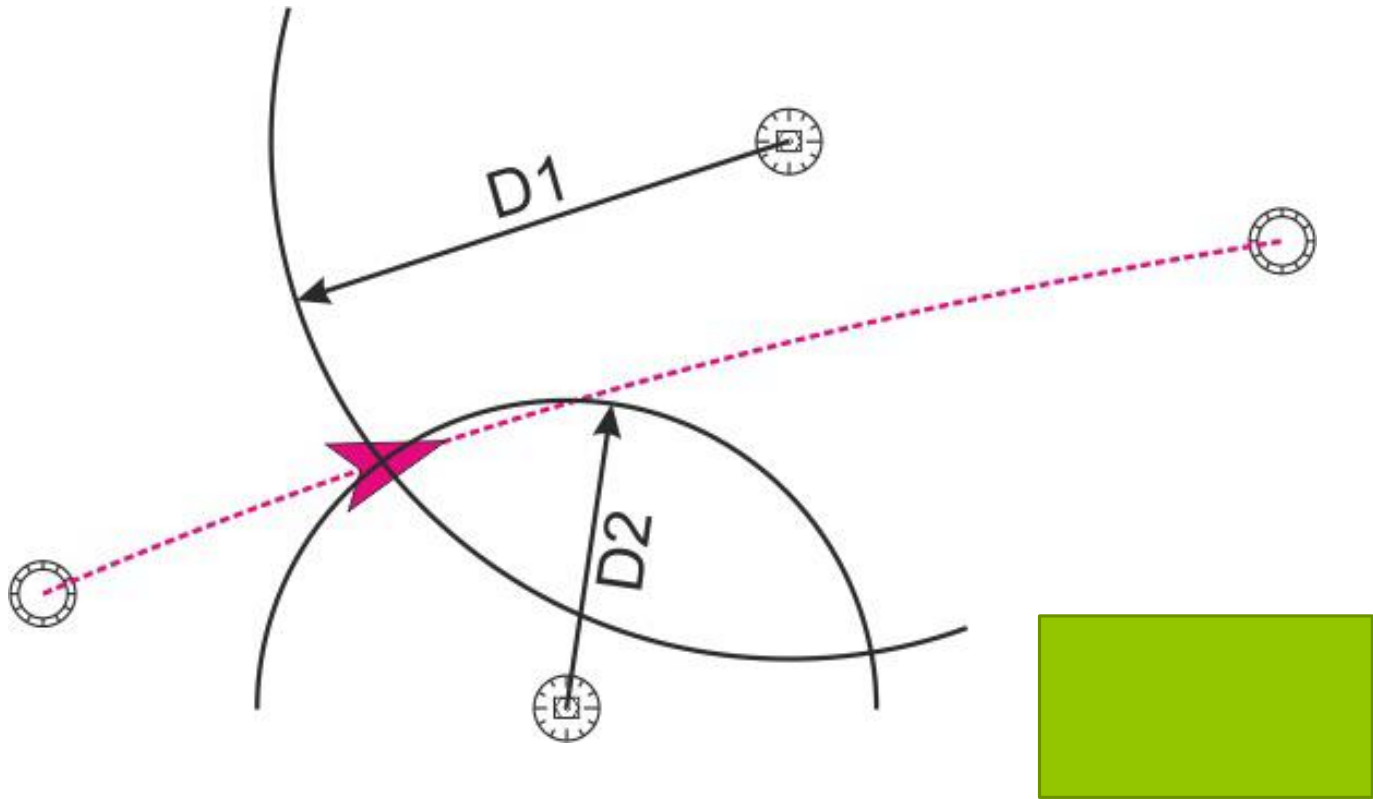
Alternative positioning technologies on-board

INS

Positioning algorithms in FMS

- DME/DME
- VOR/DME
- VOR/VOR
- NDB/NDB

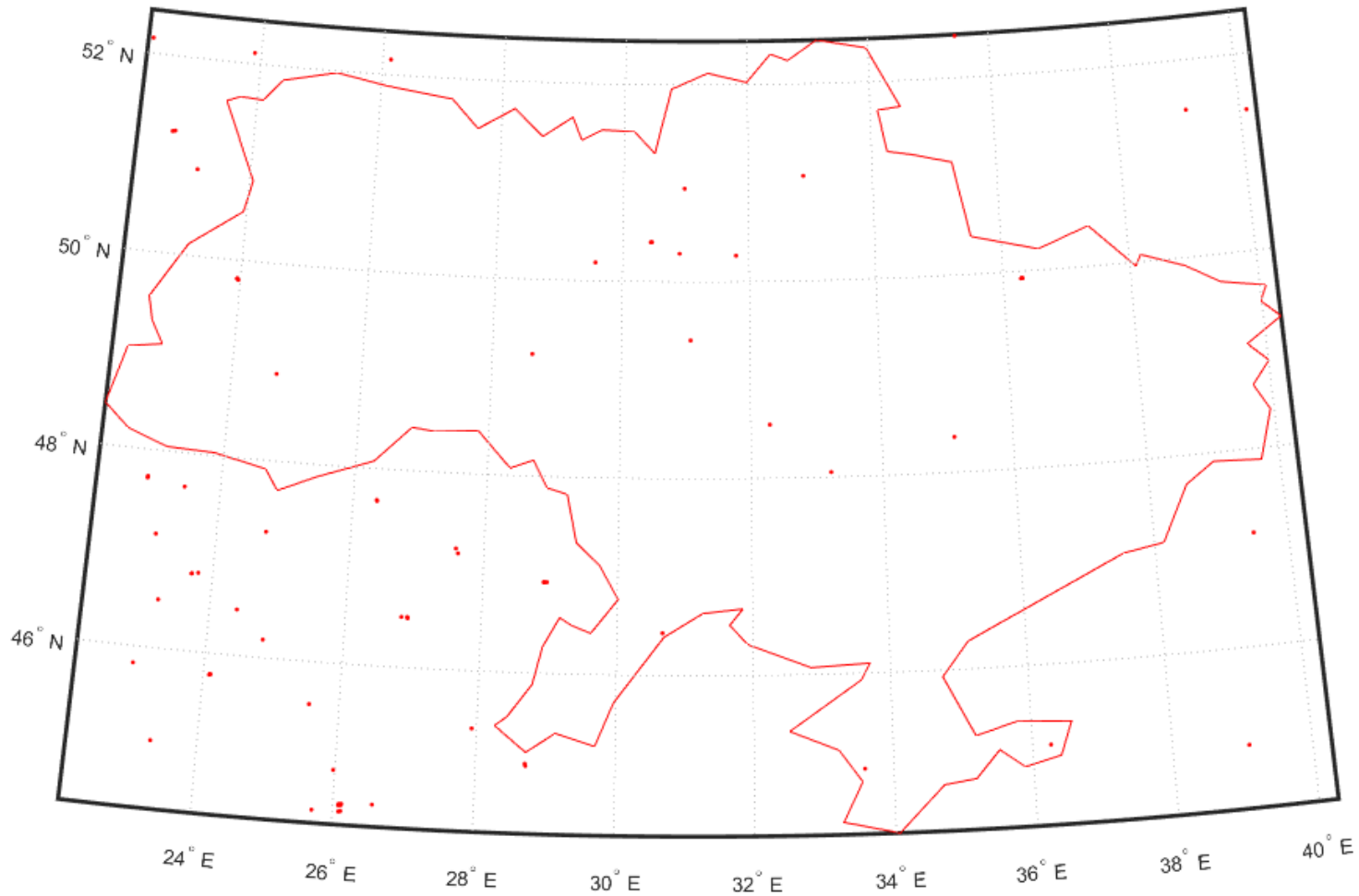
DME/DME positioning



DME network of Ukraine

Identification	Name	Latitude	Longitude	Type
BAH	Bakhmach	51.0354N	32.5312E	H
BRP	Boryspil	50.17085N	30.54035E	H
DNP	Dnipro	48.21354N	35.0611E	H
IVF	Ivano-Frankivs'k	48.5303N	24.4129E	H
IHA	Kharkiv	49.55441N	36.18102E	T
IHR	Kharkiv	49.55367N	36.16395E	T
IKI	Kyiv/ zhyliany	50.23599N	30.26265E	T
IKV	Kyiv/ zhyliany	50.24040N	30.27444E	T
KHR	Kharkiv	49.55441N	36.17256E	H
KSN	Koshany	50.56455N	30.58401E	H
KVH	Kirovohrad	48.32405N	32.17309E	H
KVR	Kryvyi rih	48.03036N	33.12437E	H
LIV	L'viv	49.4843N	23.5705E	H
ILO	L'viv	49.4854N	23.5653E	T
ILV	L'viv	49.4805N	23.5806E	T
ODS	Odesa	46.2549N	30.4015E	H
SLV	Soloviivka	50.11125N	29.34125E	H
STB	Stebliv	49.24187N	31.04364E	H
VIN	Vinnytsia	49.1424N	28.3715E	H
YHT	Yahotyn	50.15544N	31.47403E	H

Ukrainian DME network



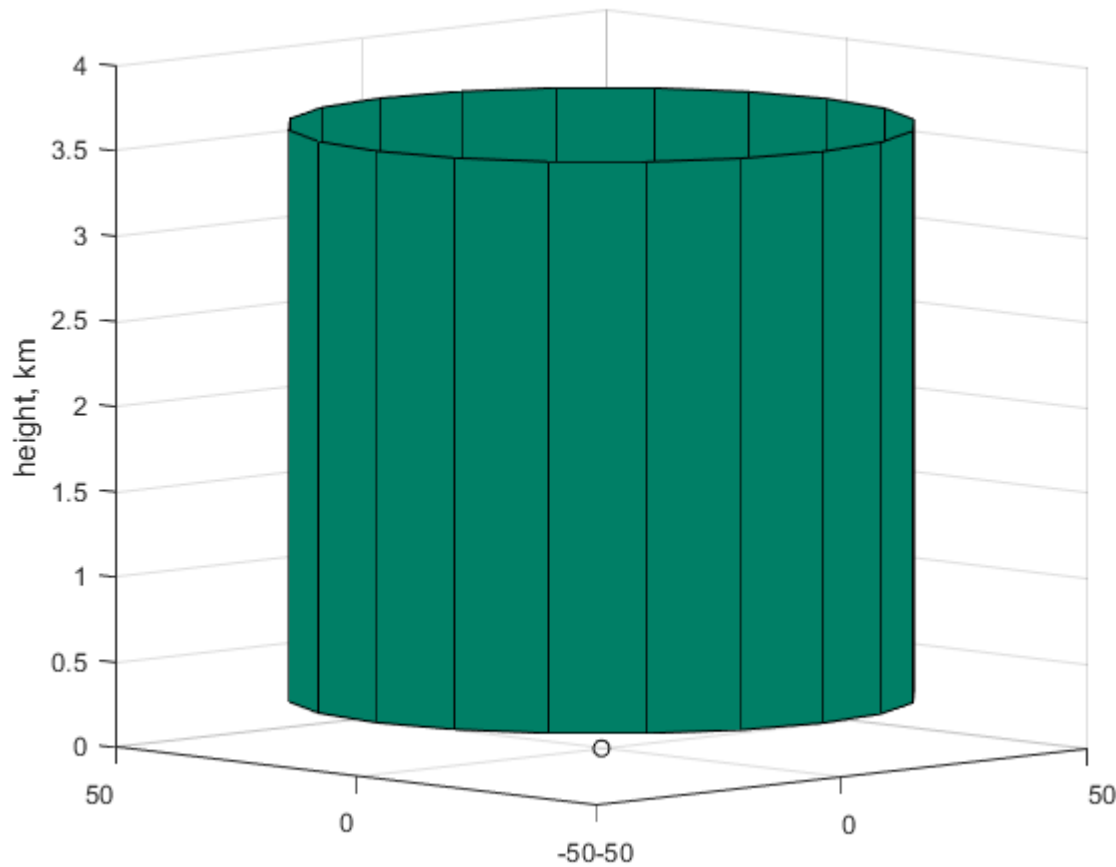
Lost DMEs

- DON, Donetsk, 48.0718002319336 N, 37.7359008789062 E;
- SMF, Simferopol, 45.051399230957 N, 33.9793014526367 E;
- KER, Kerch, 45.3708992004395 N, 36.405101776123 E;
- MRP, Mariupol, 47.0750999450684 N, 37.4518013000488 E.

NAVAIDS classes

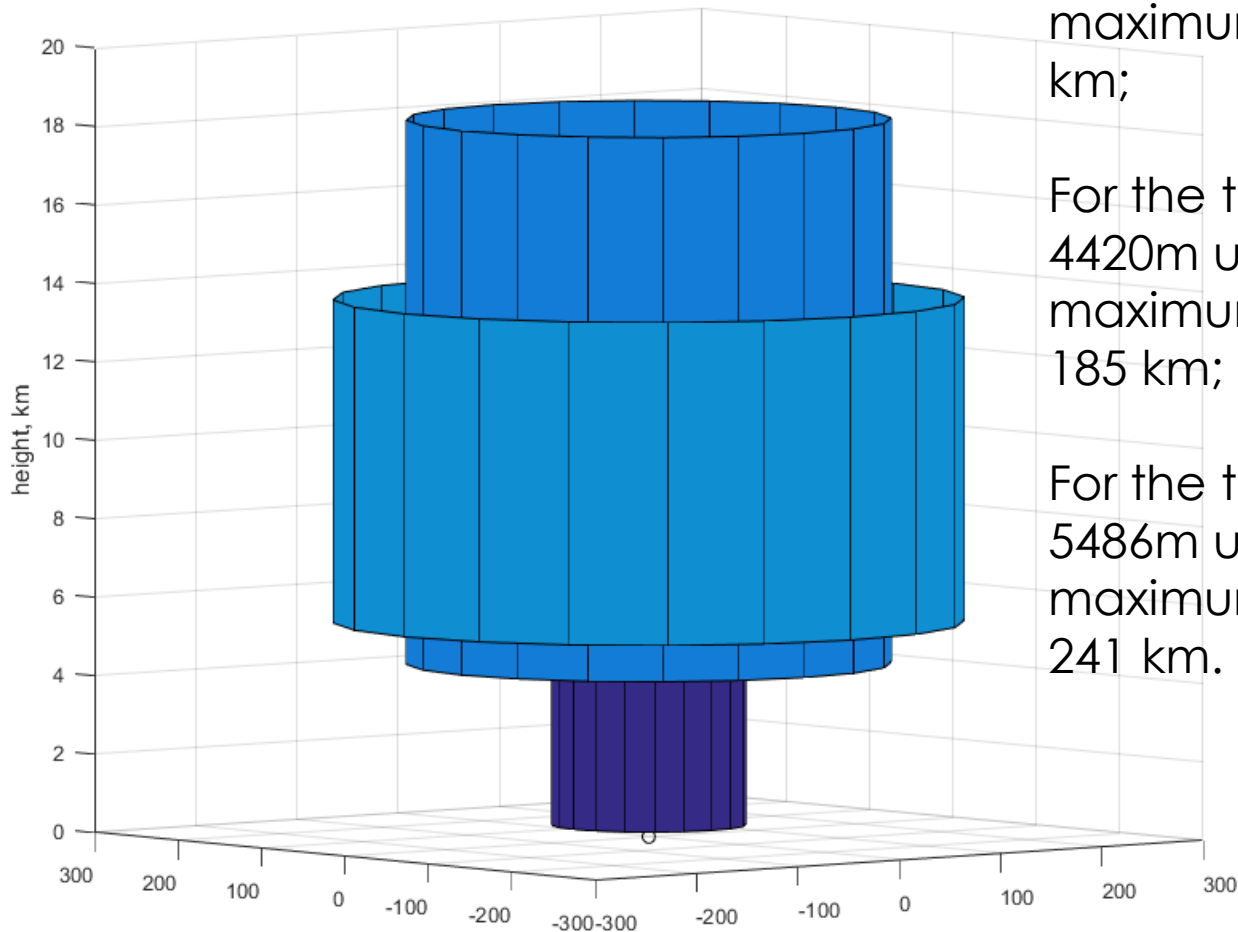
- Terminal (T). For the true heights from 305m up to 3658m maximum slant range is 46km;
- Low altitude (L). For the true heights from 305m up to 5486m maximum slant range is 74km;
- High Altitude (H).
 - For the true heights from 305m up to 4420m maximum slant range is 74 km;
 - For the true heights from 4420m up to 18288m maximum slant range is 185 km;
 - For the true heights from 5486m up to 13716m maximum slant range is 241 km.

Area of Terminal DME (T)



heights from 305m
up to 3658m
maximum slant
range is 46km

High Altitude (H)



For the true heights from 305m up to 4420m
maximum slant range is 74
km;

For the true heights from 4420m up to 18288m
maximum slant range is
185 km;

For the true heights from 5486m up to 13716m
maximum slant range is
241 km.

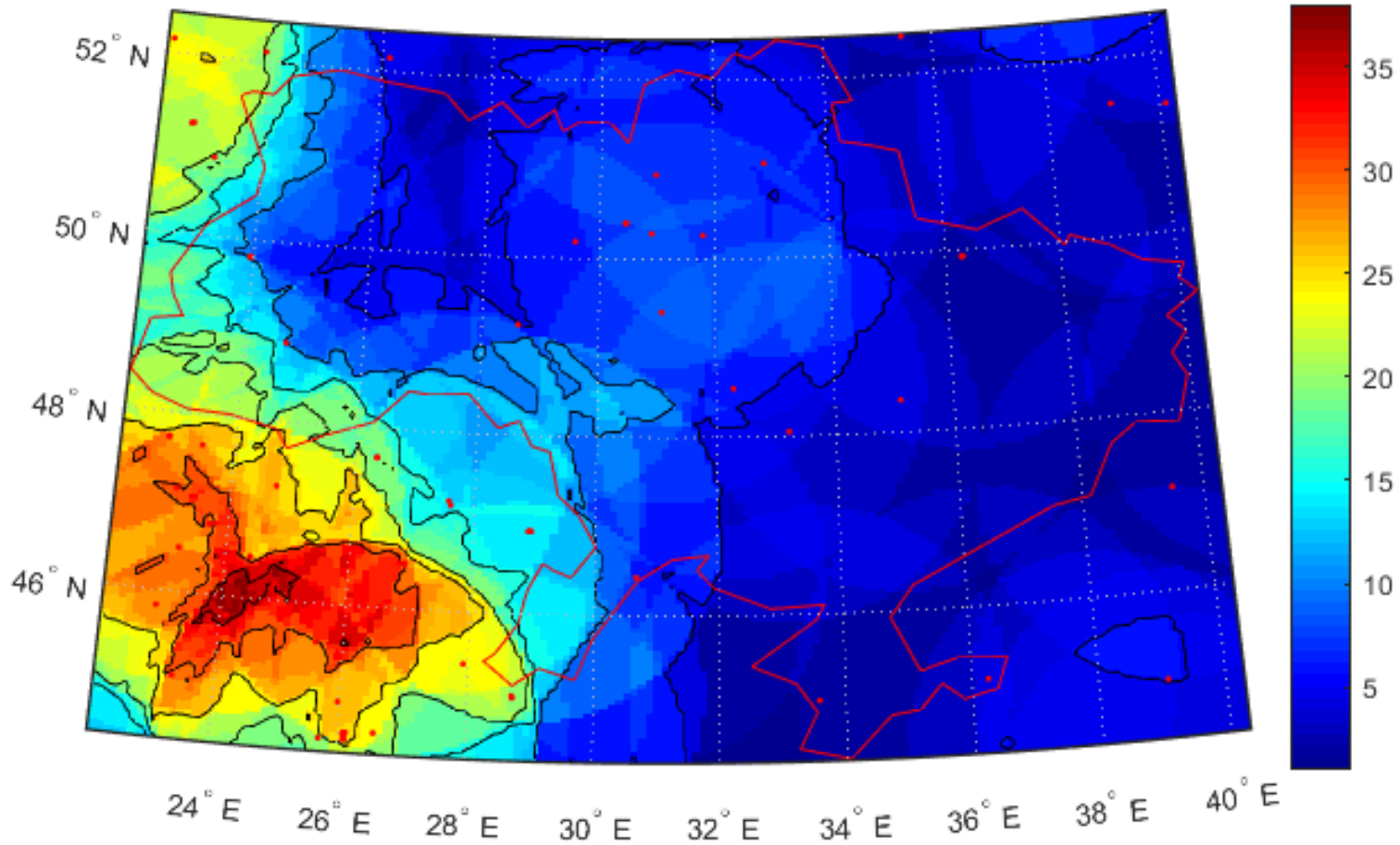
Availability estimation

- Nodes principle
- FL320 was used
- Slant range calculation

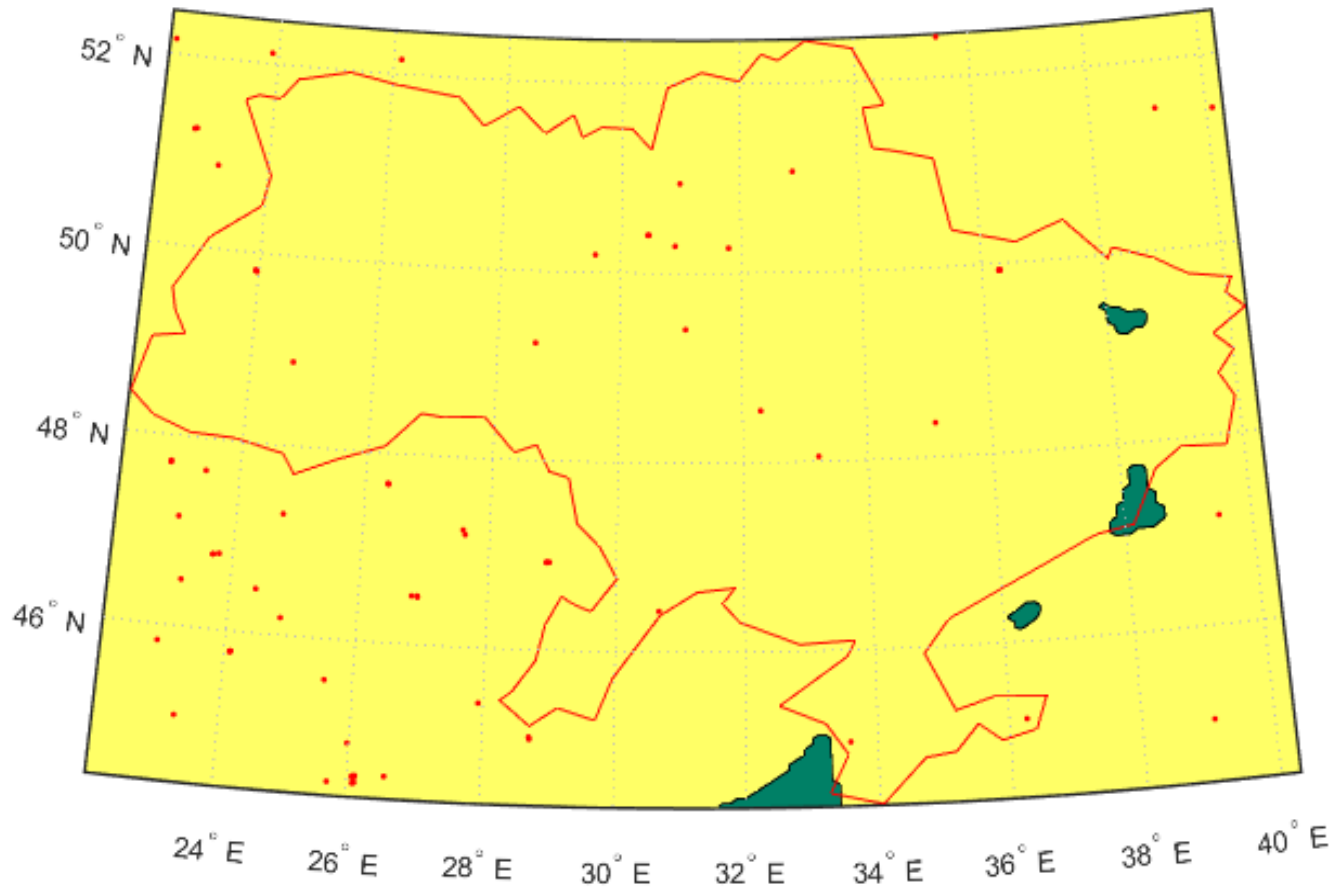
$$D_i^2 = (x_i - x_{\mathbf{DME}})^2 + (y_i - y_{\mathbf{DME}})^2 + (z_i - z_{\mathbf{DME}})^2$$

- Compare with DME type area operation

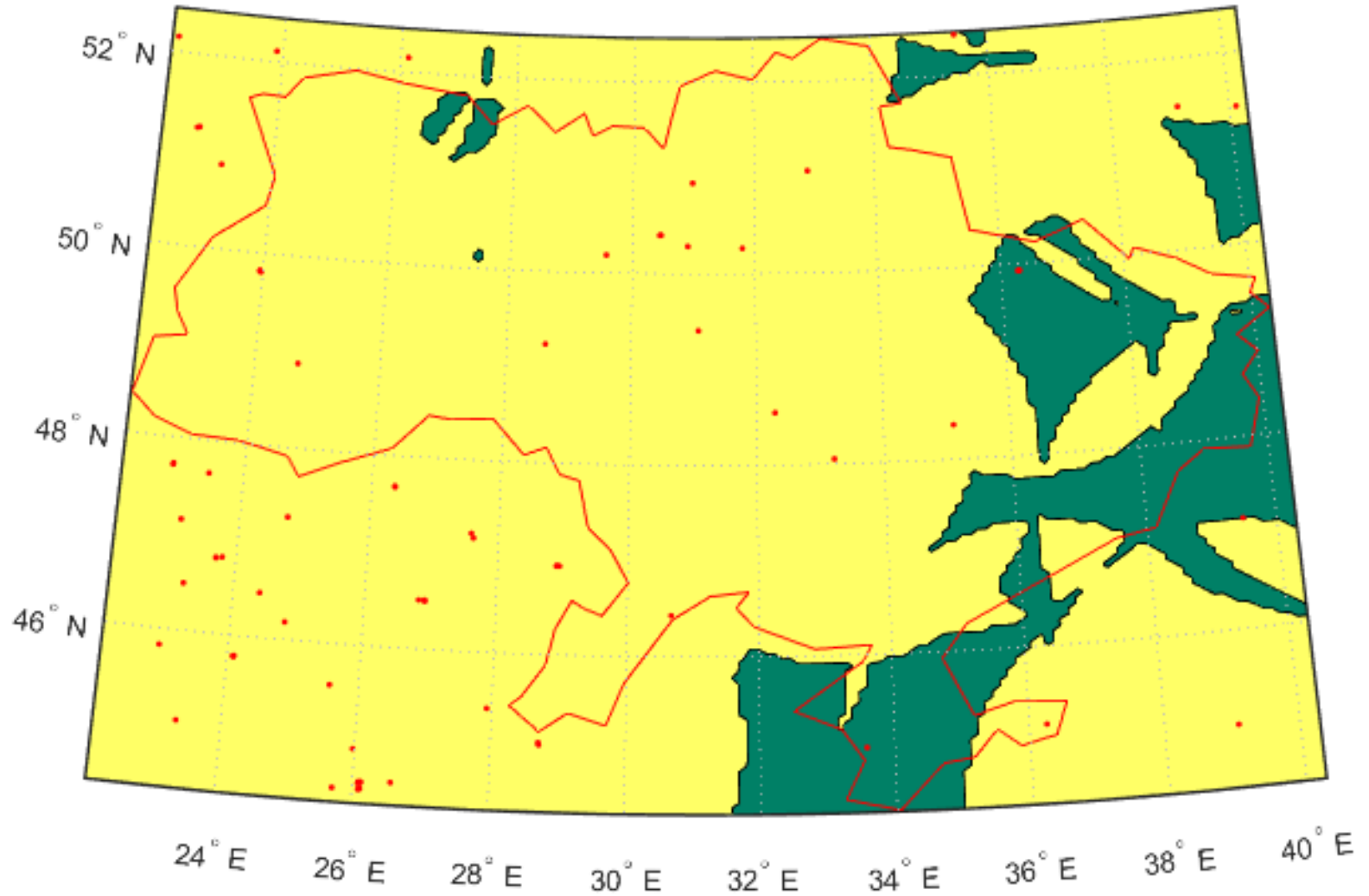
Amount of available DMEs ground stations (FL 320)



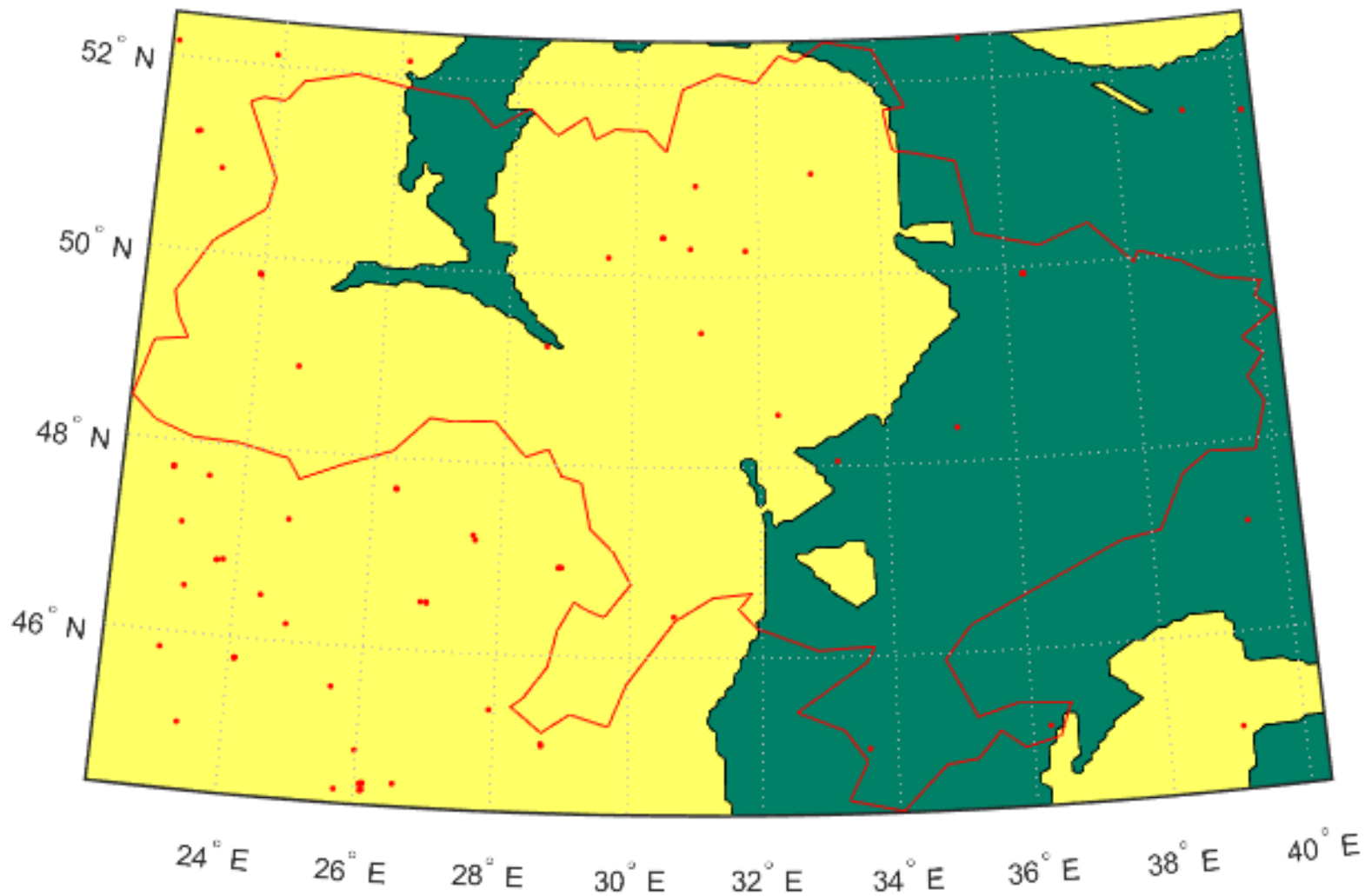
Only one DME is available (green areas)



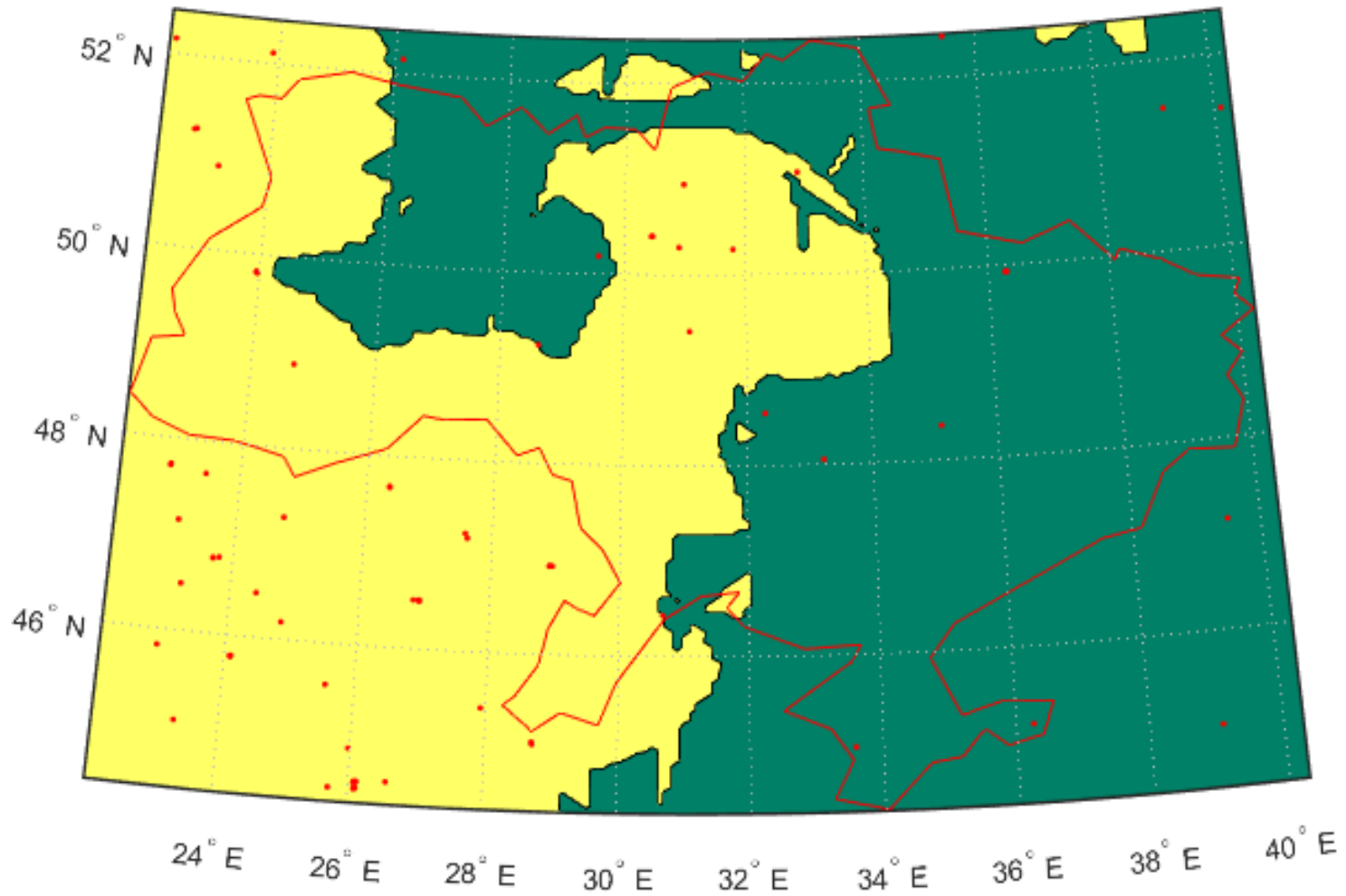
More than Two DMEs (Yellow areas)

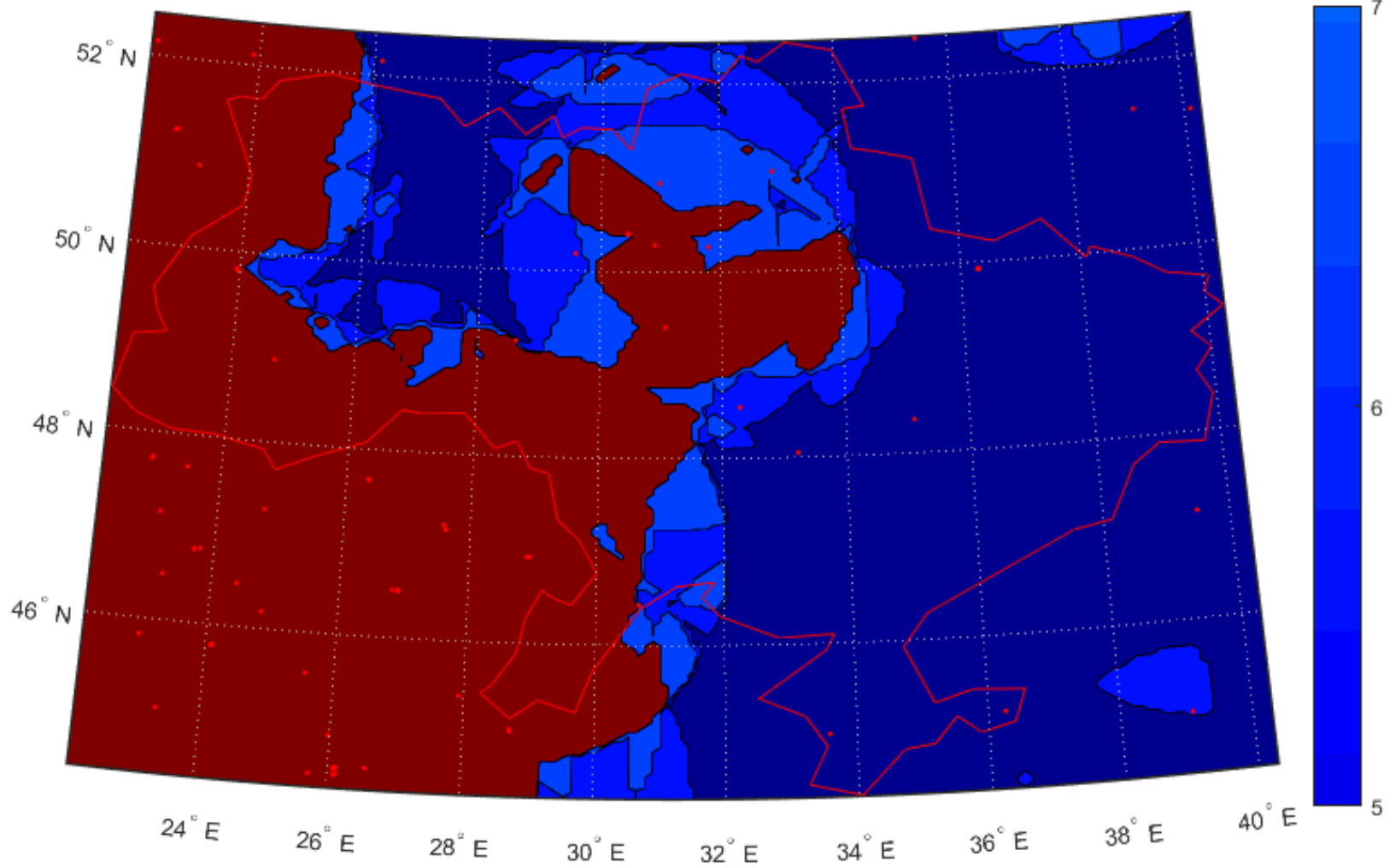


More than 4 DMEs (Yellow areas)



More than 6 DMEs





Amount of available DMEs

Dilution Of Precision (DOP)

- NDOP (North DOP) – accuracy rate of change in the north direction,
- EDOP (East DOP) – accuracy rate of change in the east direction,
- HDOP (Horizontal DOP) – accuracy rate of change in the horizontal plane,
- VDOP (Vertical DOP) – accuracy rate of change in the vertical plane,
- PDOP (Position DOP) – total accuracy rate coefficient.

DOP coefficients calculation

$$H = \begin{pmatrix} a_{x1} & a_{y1} & a_{z1} \\ a_{x2} & a_{y2} & a_{z2} \\ \vdots & \vdots & \vdots \\ a_{xN} & a_{yN} & a_{zN} \end{pmatrix}$$

$$a_{xi} = \frac{x_{DME} - x_i}{r_i^2}$$

$$a_{yi} = \frac{y_{DME} - y_i}{r_i^2}$$

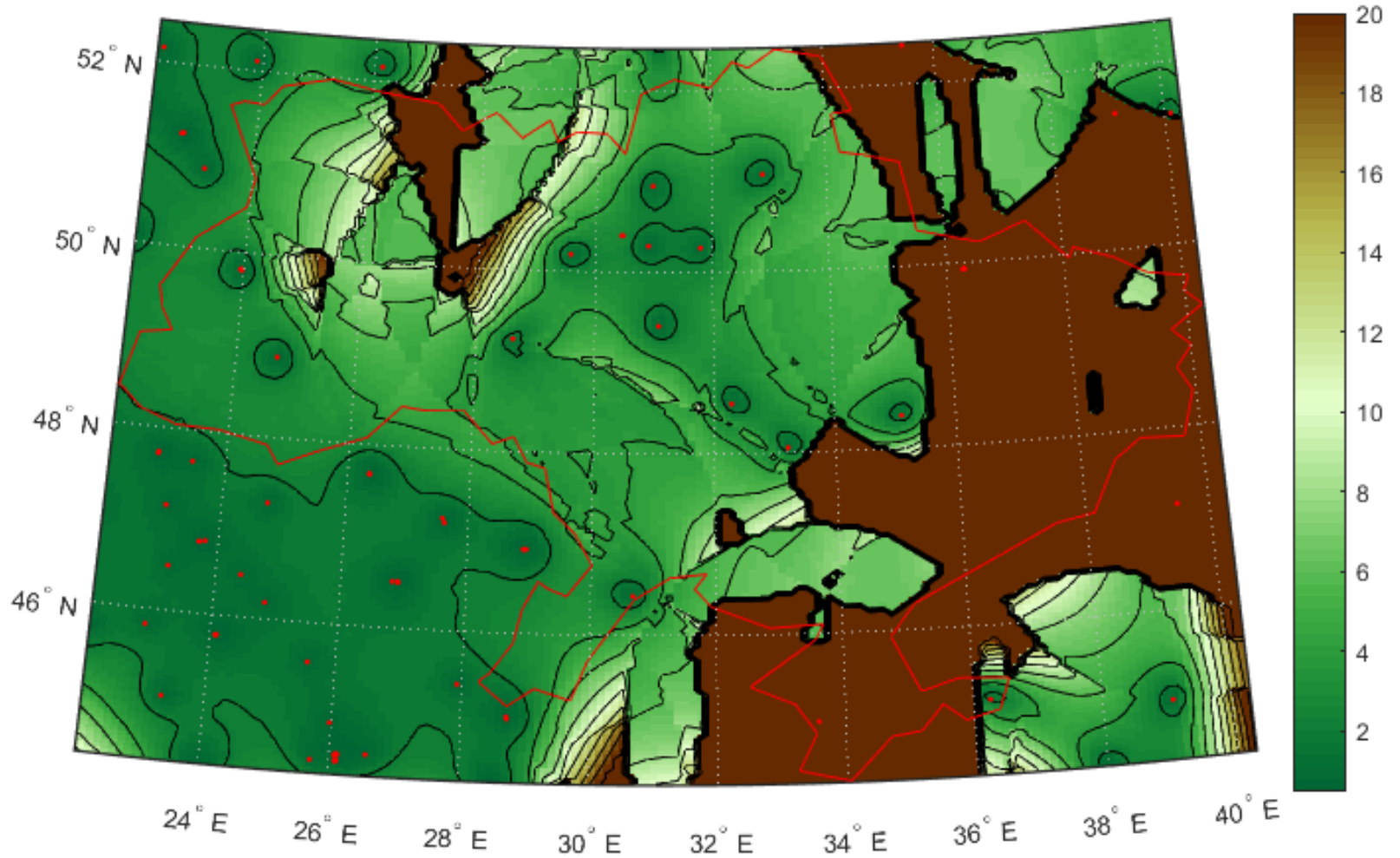
$$a_{zi} = \frac{z_{DME} - z_i}{r_i^2}$$

$$(H^T H)^{-1} = \begin{pmatrix} EDOP^2 & \sigma_{xy}^2 & \sigma_{xz}^2 \\ \sigma_{yx}^2 & NDOP^2 & \sigma_{yz}^2 \\ \sigma_{zx}^2 & \sigma_{zy}^2 & VDOP^2 \end{pmatrix}$$

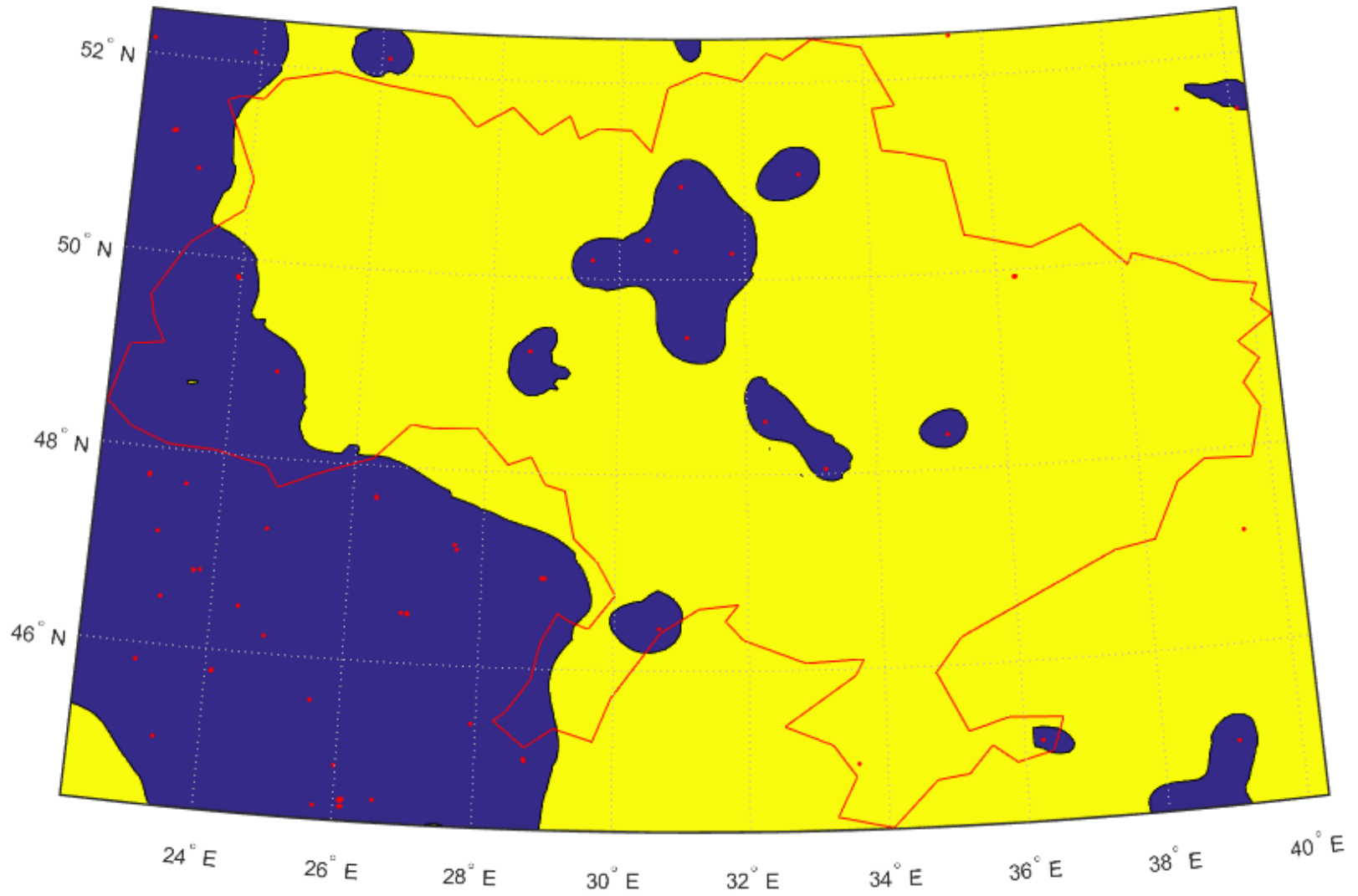
$$HDOP = \sqrt{EDOP^2 + NDOP^2}$$

$$PDOP = \sqrt{EDOP^2 + NDOP^2 + VDOP^2}$$

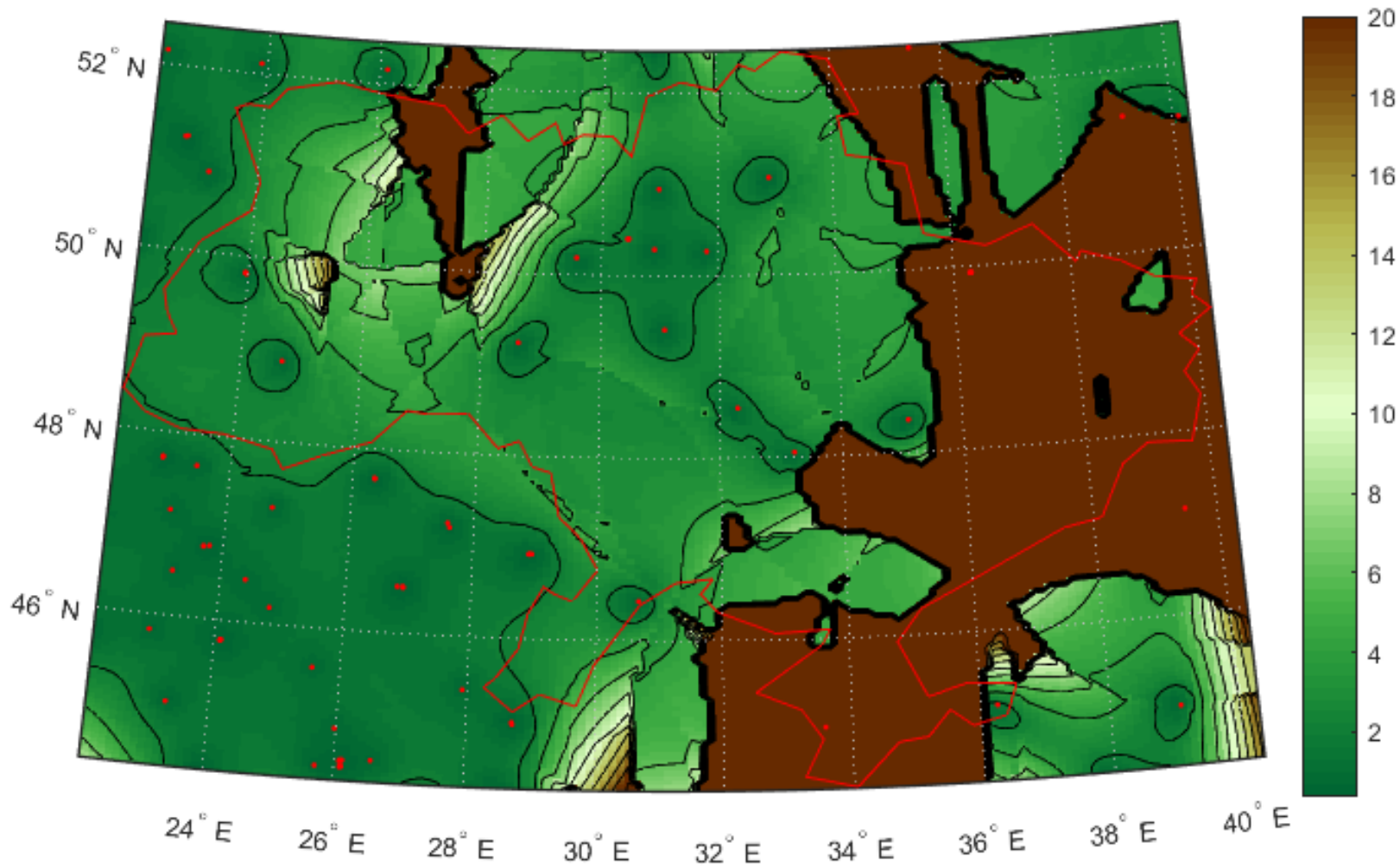
HDOP



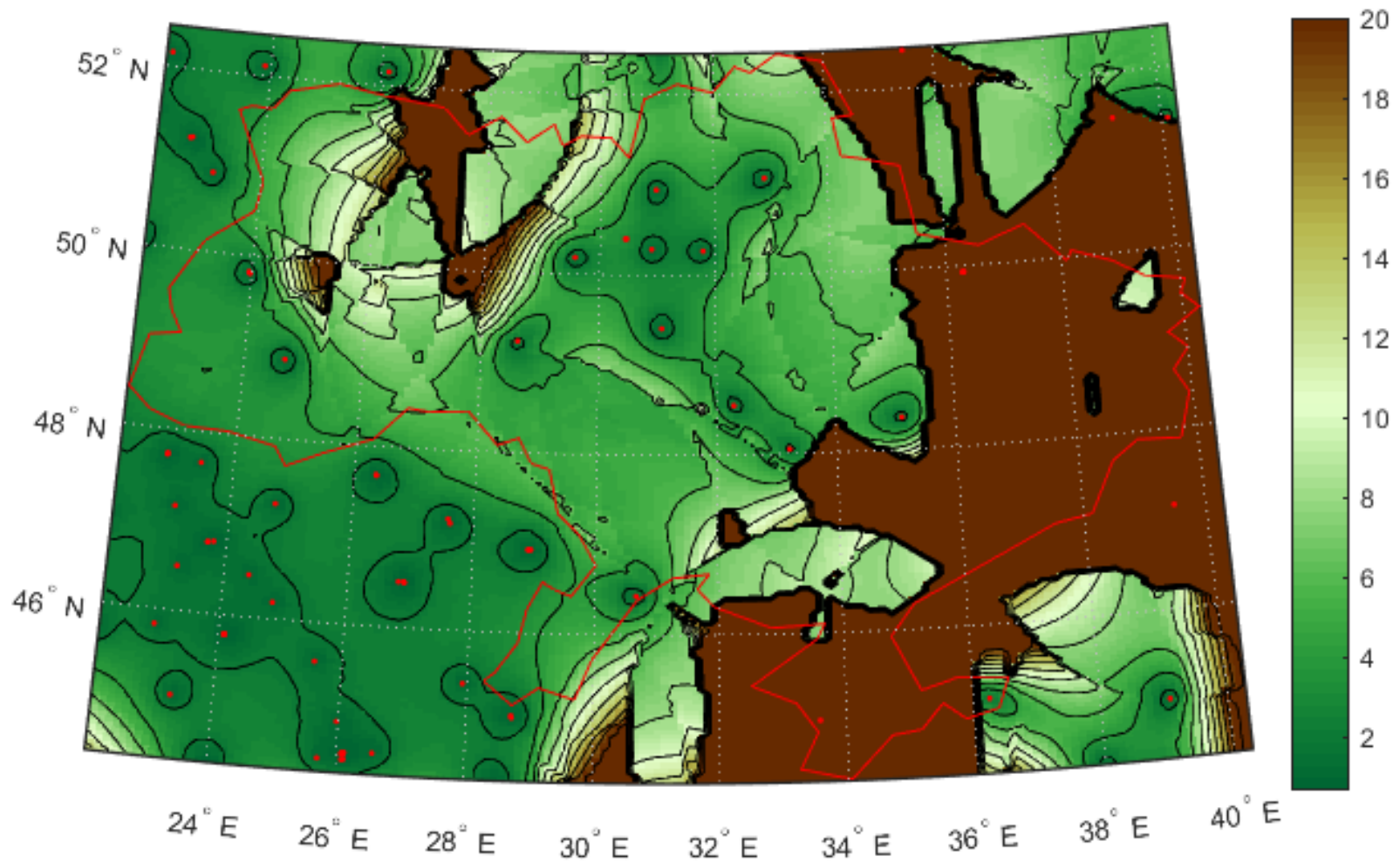
HDOP < 3



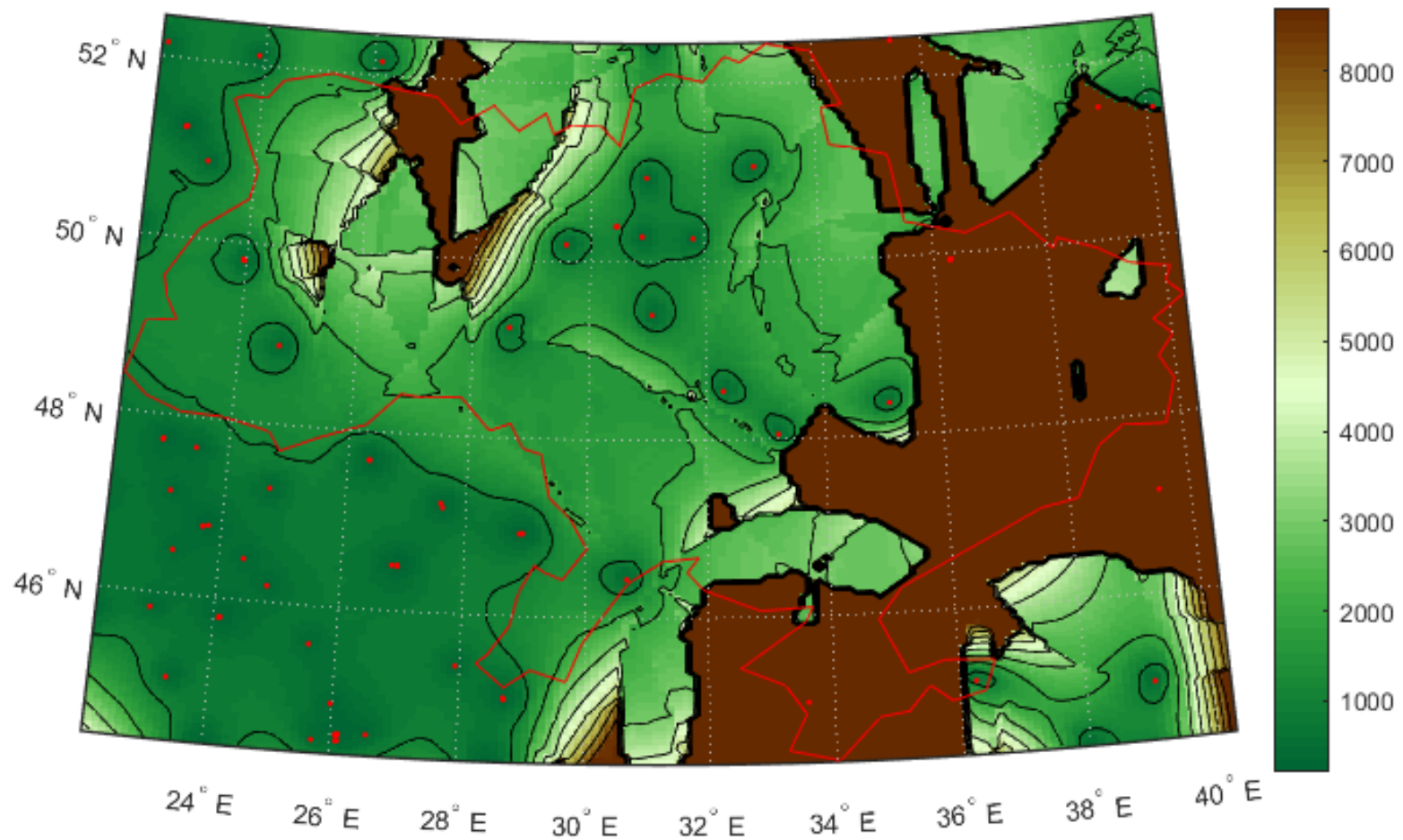
VDOP



PDOP



Total accuracy of multi DMEs positioning for Ukrainian region



- accuracy of positioning in horizontal plane is 500 m for 67% of Ukrainian territory,
- 1000m –72% and more 2000m for 45%

