En alternativ metode til geofysisk inversion af TEM-data

Præsenteret af:

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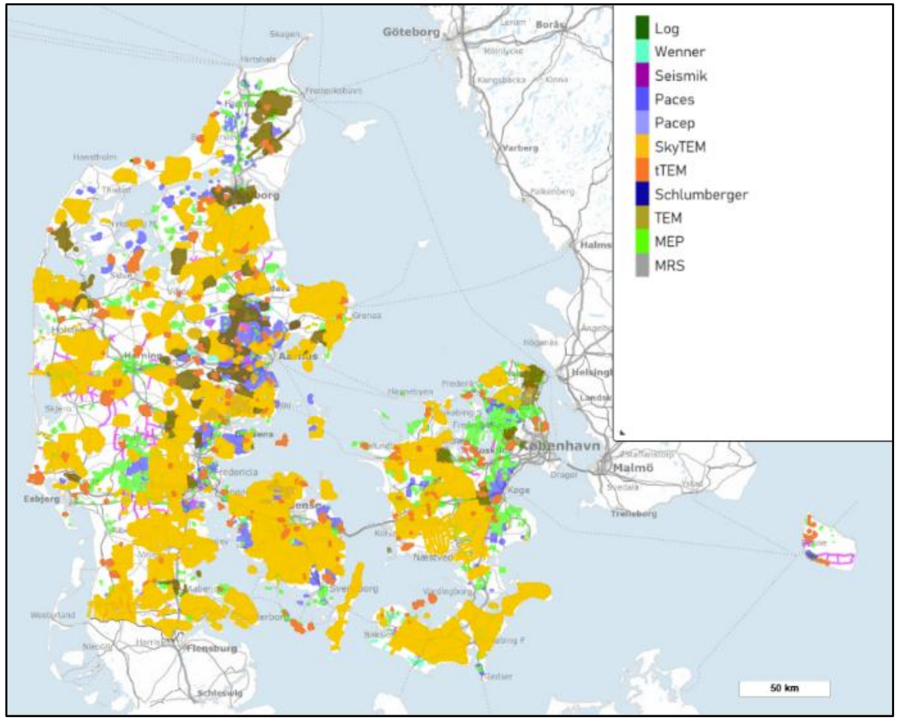
På vegne af:

Anne-Sophie Høyer, Senior Researcher, GEUS

Traditionel geologisk kortlægning

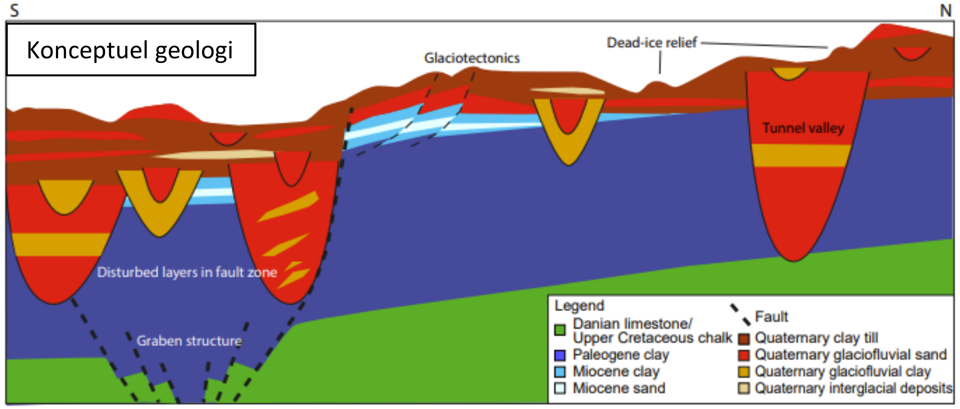
- Den øverste geologi typisk kortlagt med geofysiske metoder

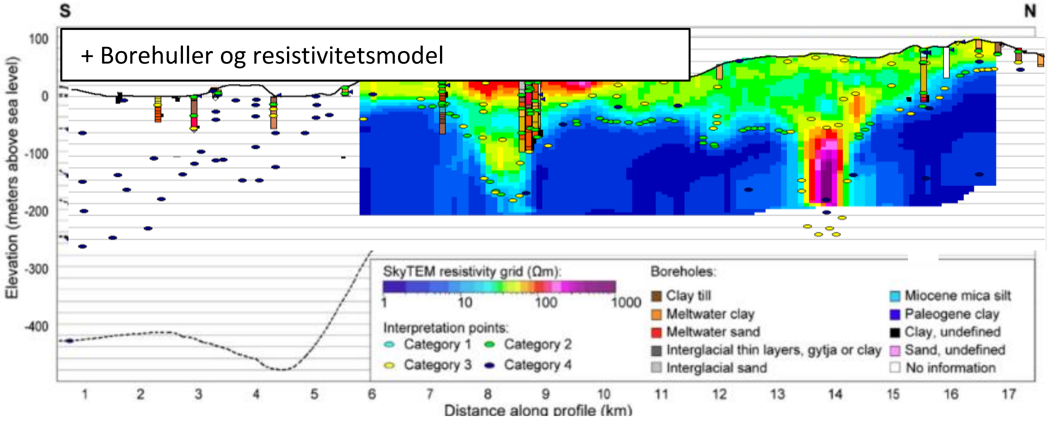


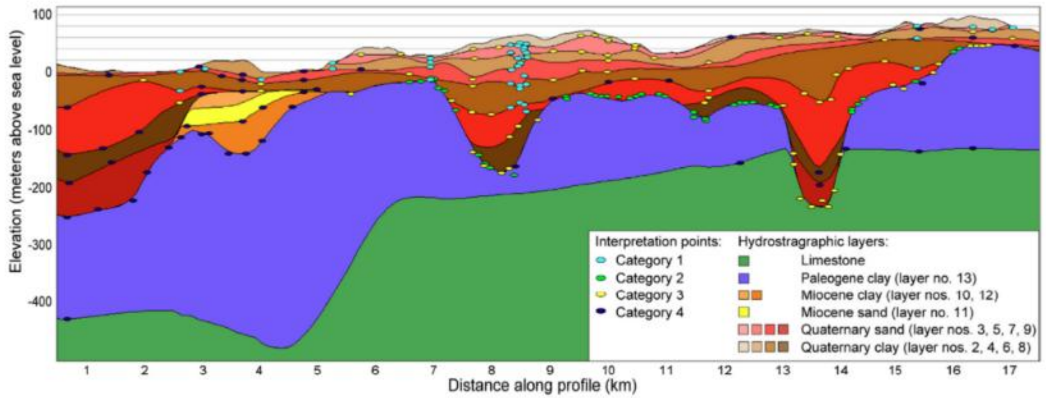
Gerda database over geofysik i Danmark

Data +
Tolkning

Geologisk
model







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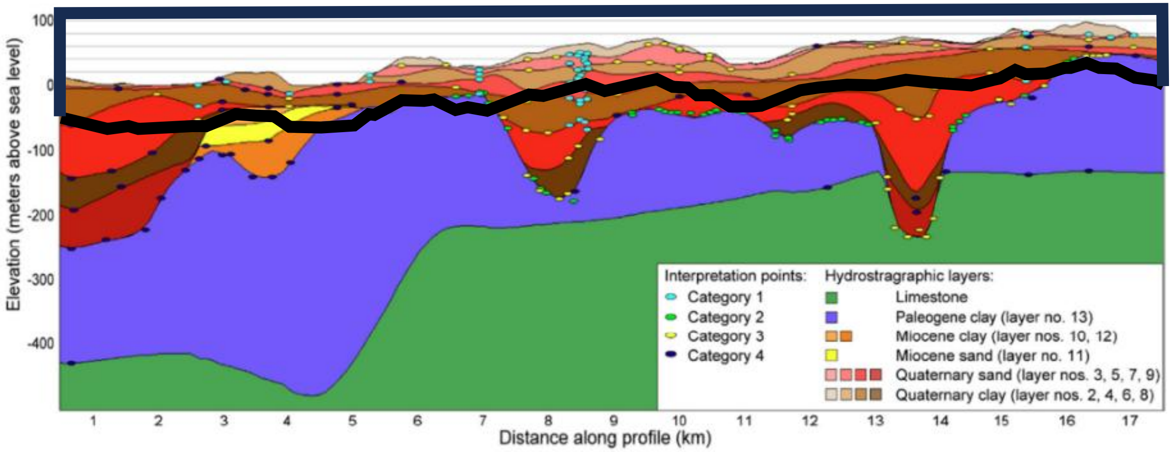
Stor fokus på høj-opløselige overfladenære modeller

Stor efterspørgsel efter detaljeret kortlægning af de øverst 50-100 meter (råstofskortlægning, sårbarheds analyser, grundvand, mm.)

tTEM systemet:

- Høj opløselighed i de øverste 100 meter
- Mobil og hurtig dataindsamling

Denne præsentation omhandler maksimal udnyttelse af tTEM målingerne.



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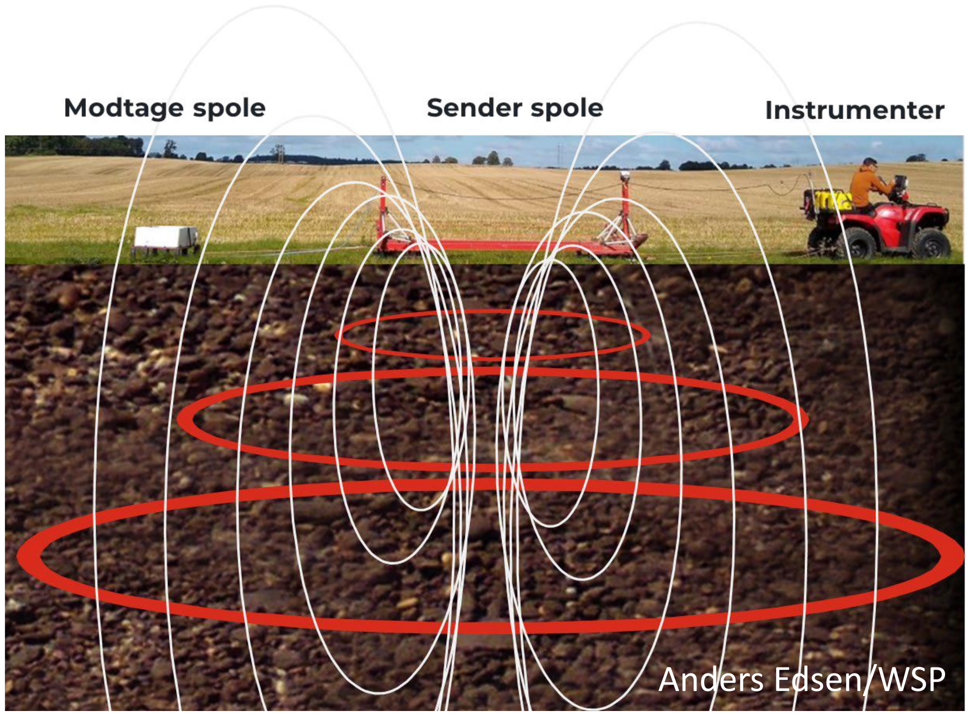

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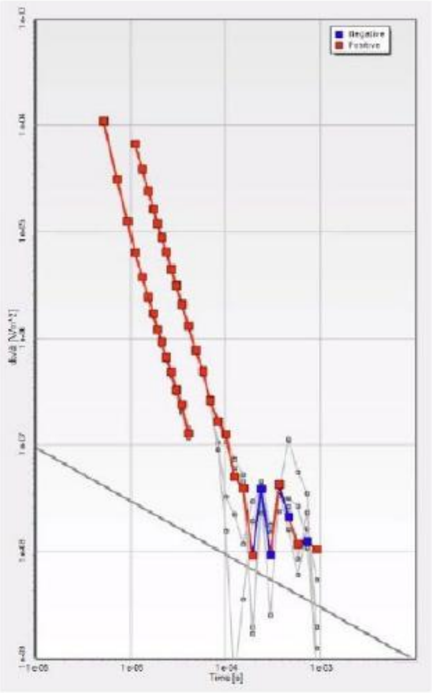
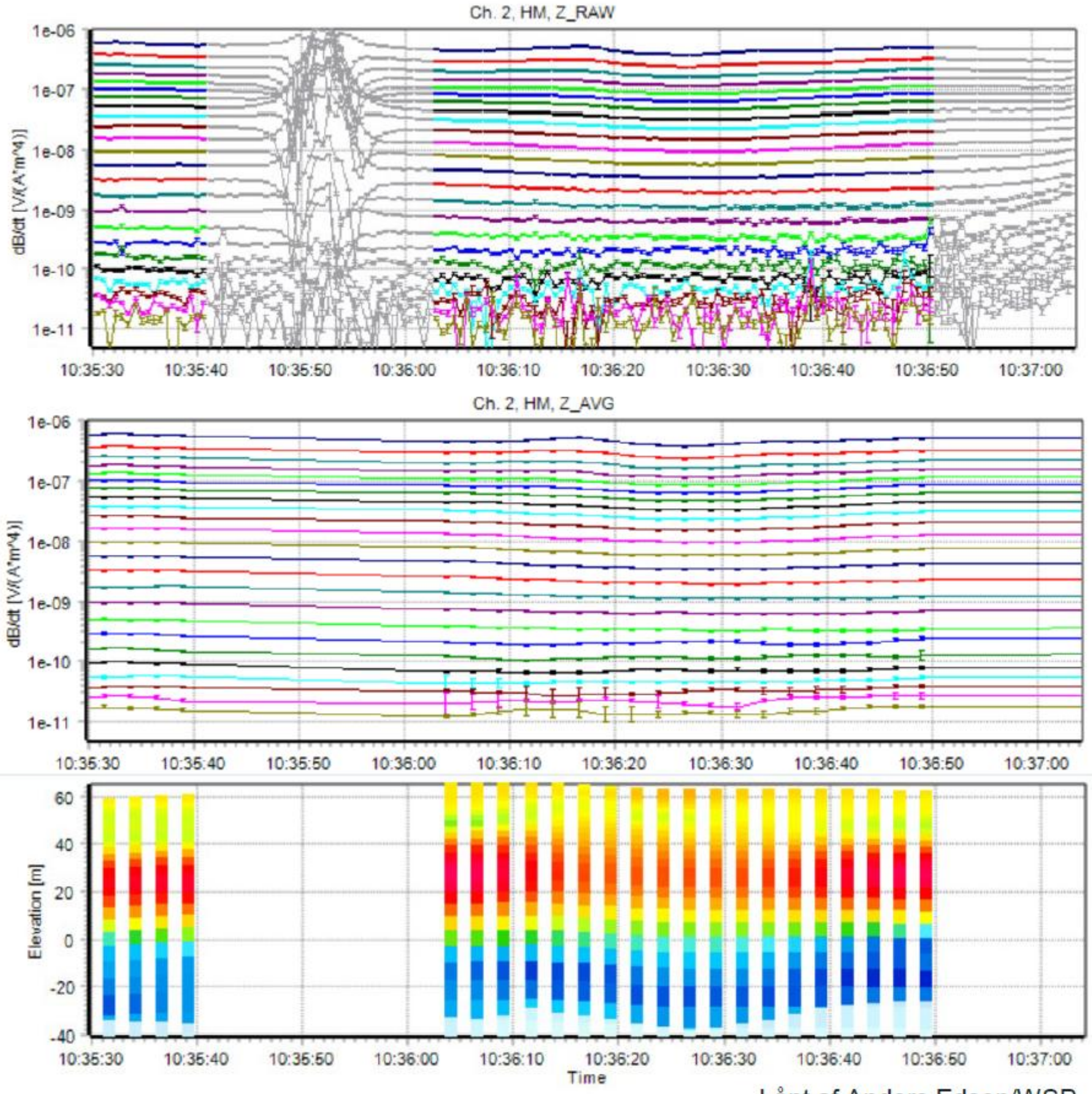
Fra data til geofysiske modeller

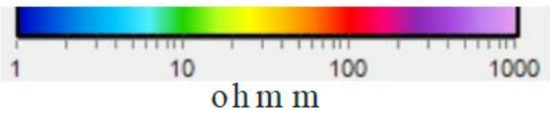


Processering og Midling

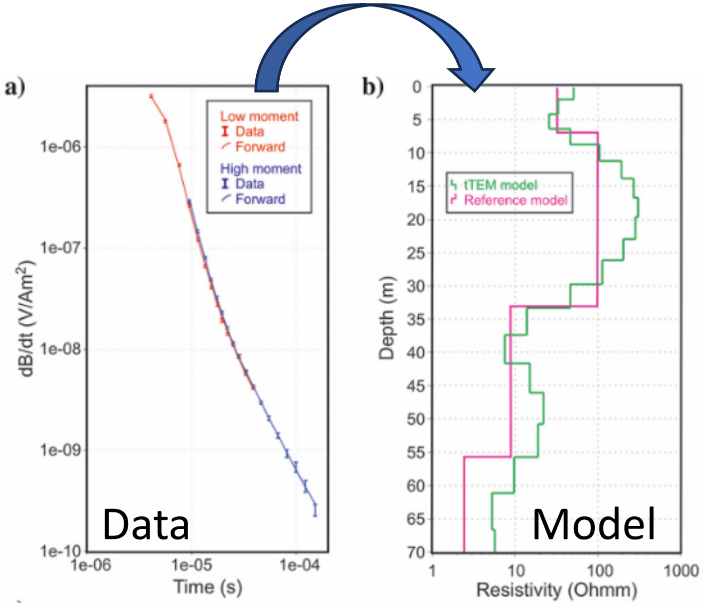
Inversion



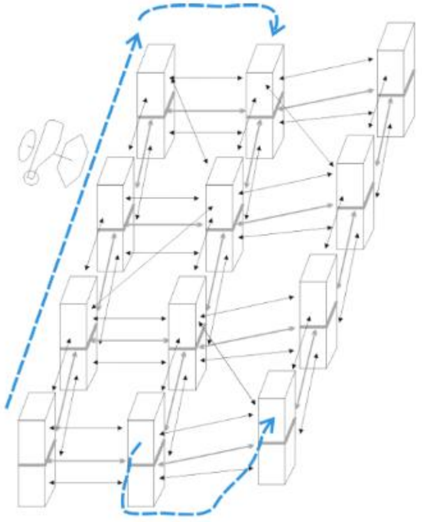
Lånt af Anders Edsen/WSP

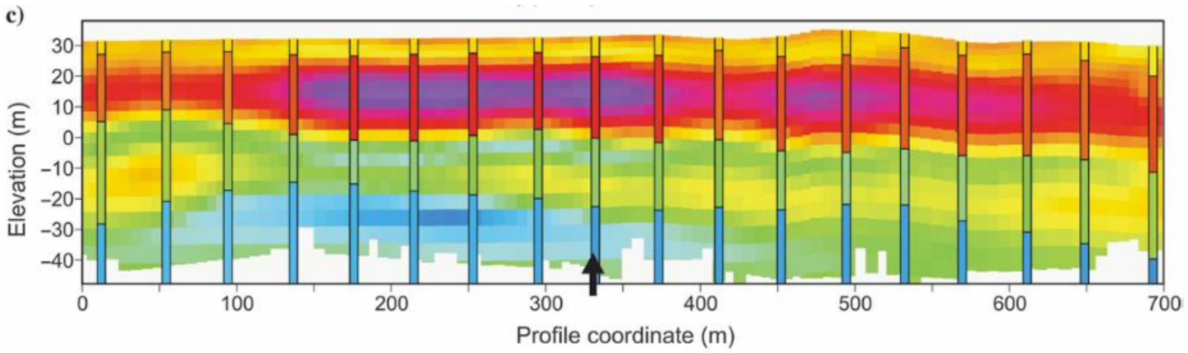


Traditionel tTEM inversion
(fra data til geofysisk model)



- Data (db/dt kurver) inverteres til resistivitets modeller
- Indstillinger og valg foretaget af geofysiker
- Horisontale og vertikale bånd mellem nabo-sonderinger
- **1 resistivitets model som grundlag for den geologisk model**



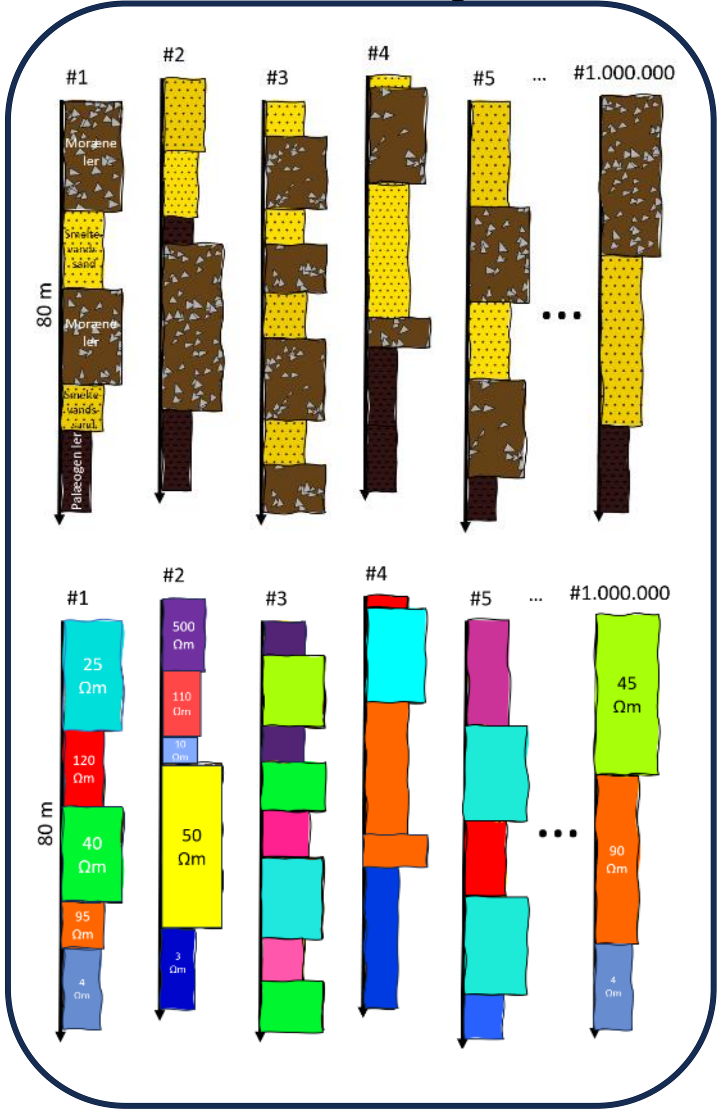


Item		Value
Model setup	Number of layers	30
	Starting resistivities (Ωm)	Area dependent
	Thickness of first layer (m)	1.0
	Depth to last layer (m)	~120.0 (area dependent)
	Thickness distribution of layers	Log increasing with depth
	Constraints distance scaling	1/distance$^{0.75}$ (power =0.75)
Smooth model: Constraints	Horizontal Constraints, resistivities (factor)	1.5
	Vertical constraints, resistivities (factor)	2.0
Sharp model: Constraints	Horizontal Constraints, resistivities (factor)	1.05
	Vertical constraints on resistivities (factor)	1.08
	Sharp vertical constraints	100
	Sharp horizontal constraints	200

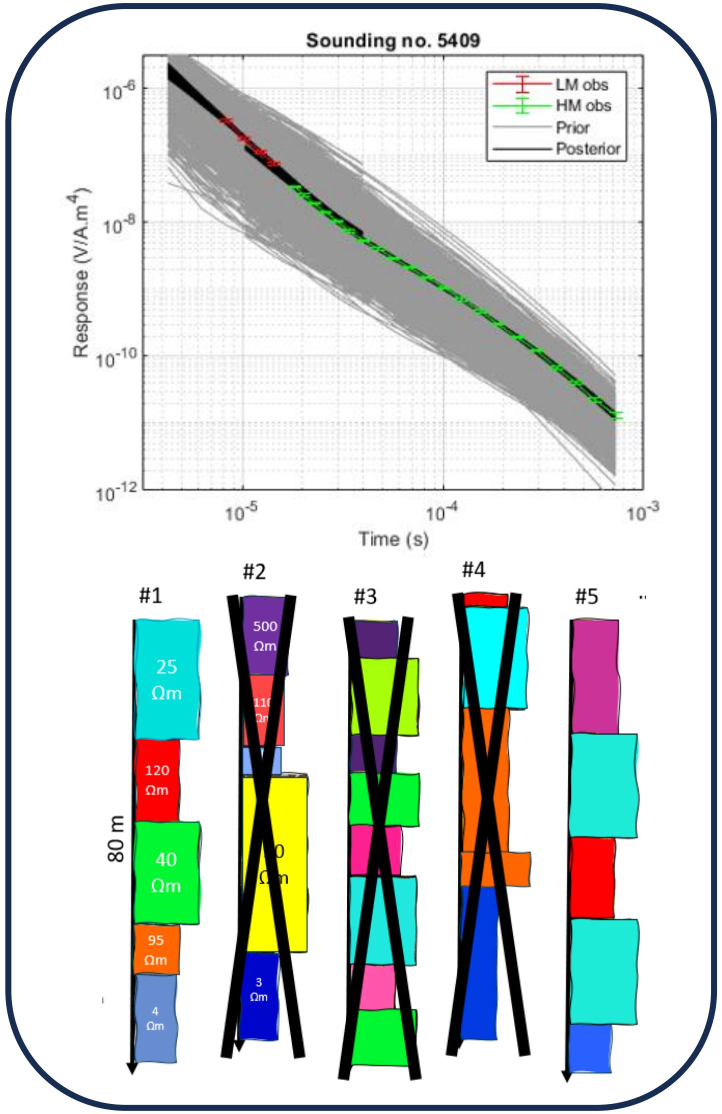
Table 3. Key inversion settings. Typical settings for smooth and sharp SCI setup.

Probabilistisk inversion

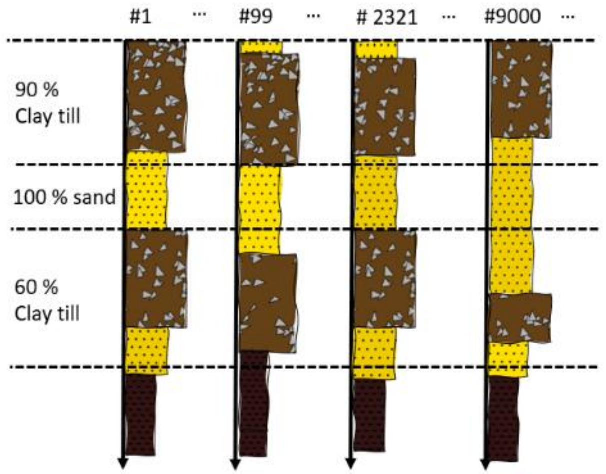
Modeller af undergrunden



Udelukkede modeller



Accepterede modeller

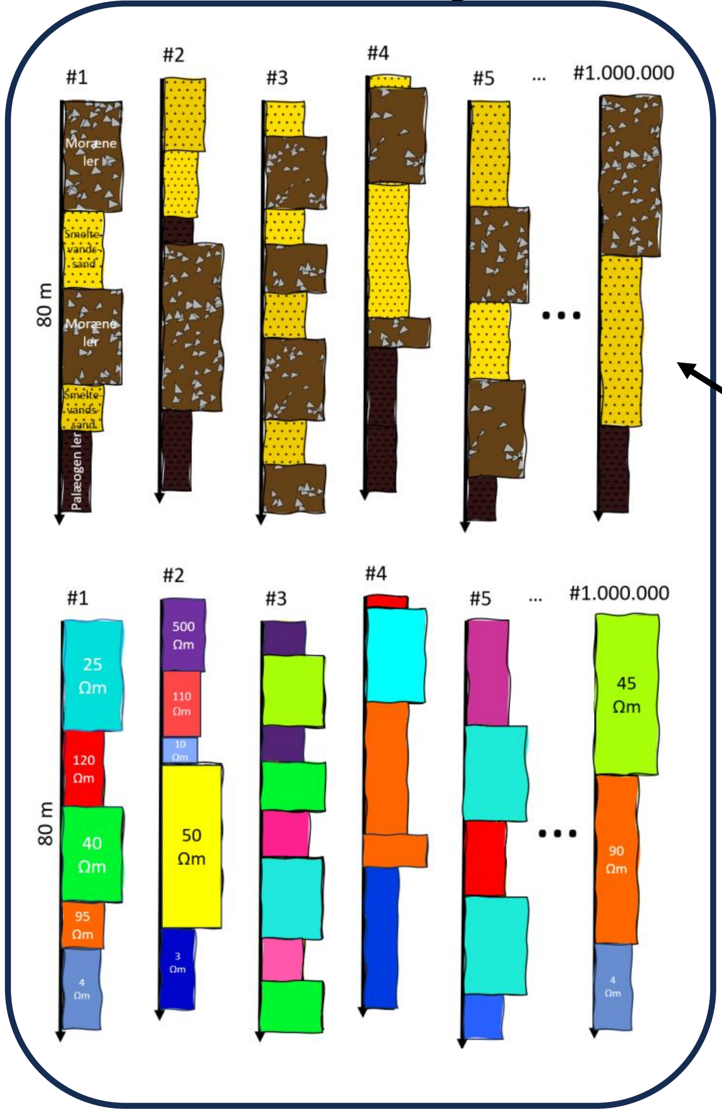


Spørgsmål til modellerne:

- Sandsynlighed for sand?
- Den forventede mægtighed af sand?
- Hvad er resistiviteten?
- Meget mere…

Hvor kommer modellerne fra?

Modeller af undergrunden



Tilfældigt genereret ifølge en algoritme.

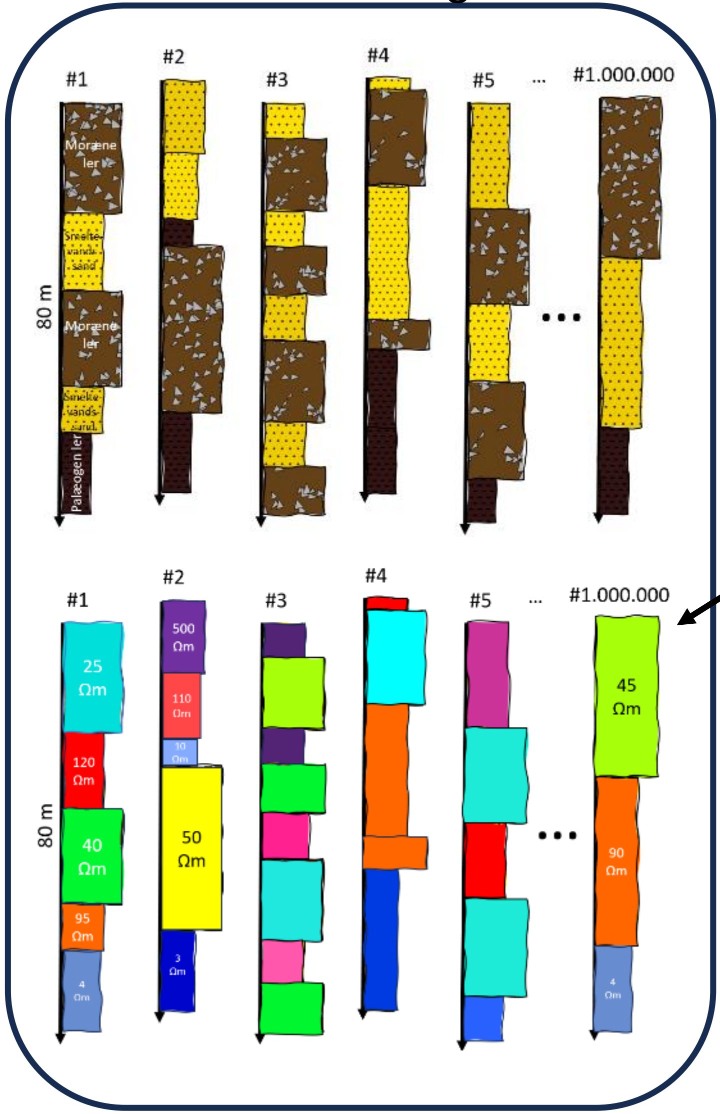
Indeholder ekspertviden:

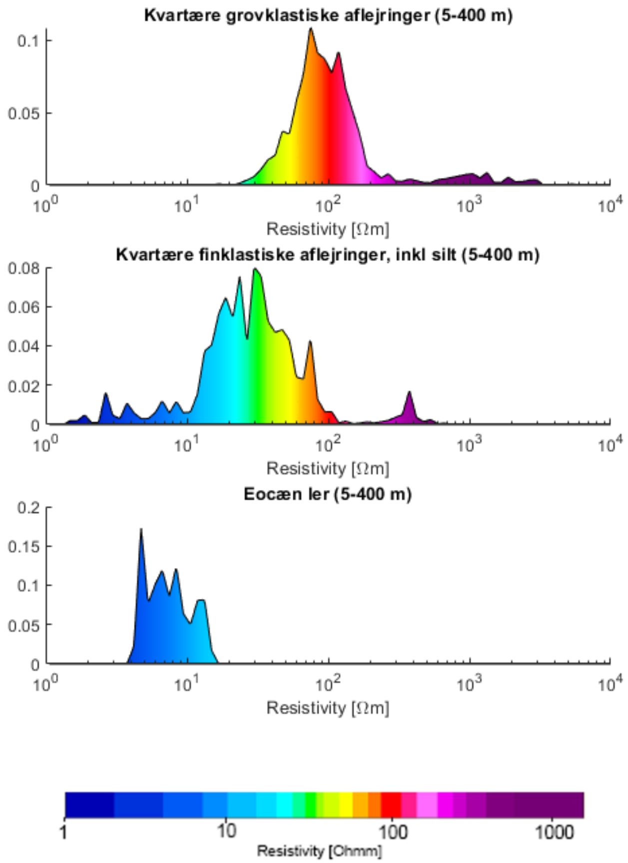
- Lagfølge
- Tykkelse af lag
- Lithologi-resistivitets forhold
- Andre på forhånd kendte relationer eller egenskaber

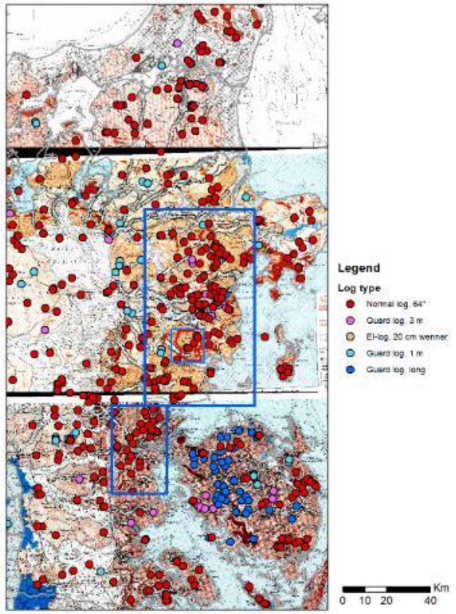
"Bred" nok til at indeholde de rigtige løsninger.

Hvor kommer modellerne fra?

Modeller af undergrunden







- Data fra resistivitetslogs (Wireline og Ellog) i borehuller
- Regionalt område med lignende geologiske aflejringer
- Kun data fra lag med tilstrækkelig tykkelse til at opnå pålidelige målinger

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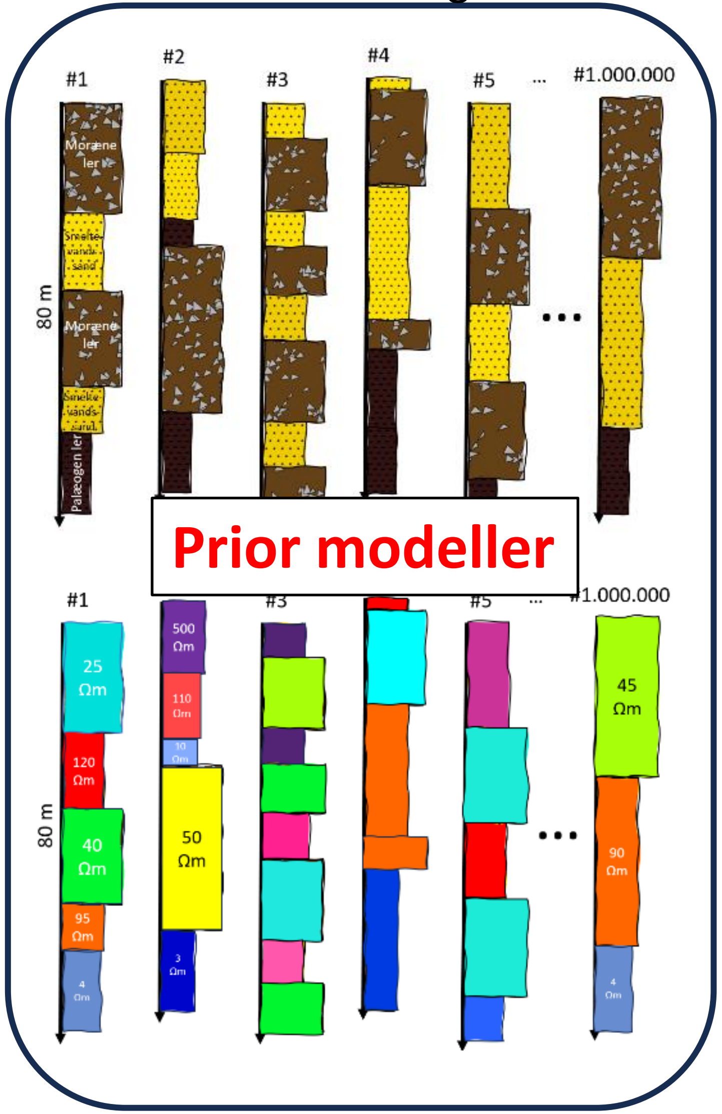
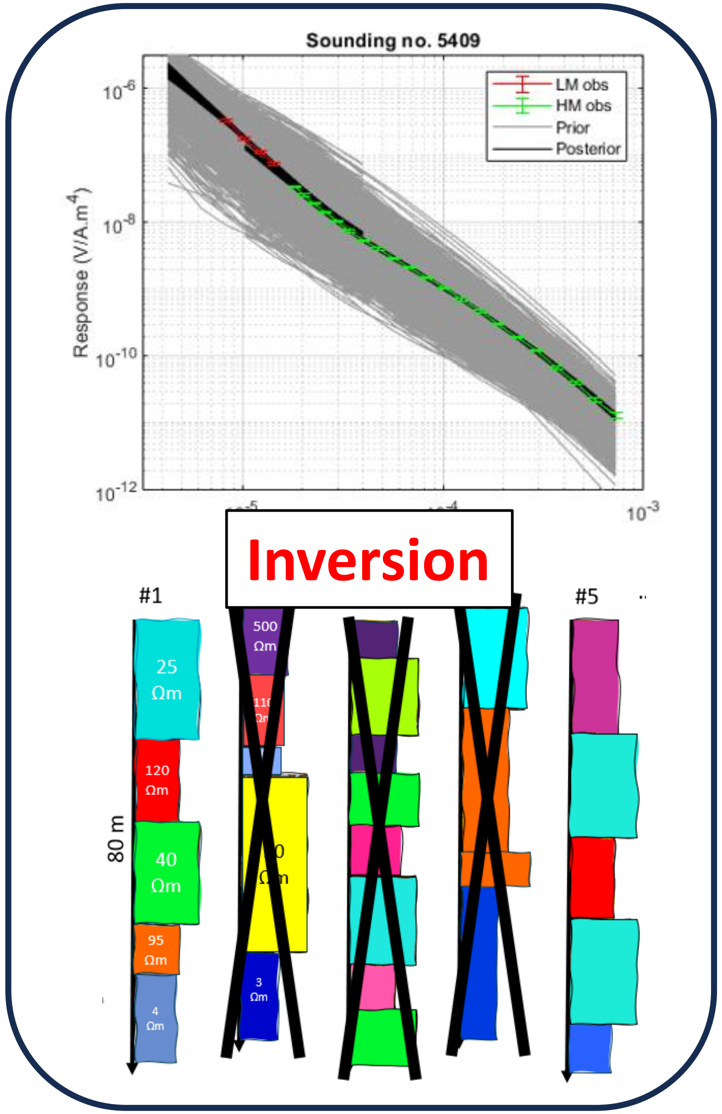
Terminologi

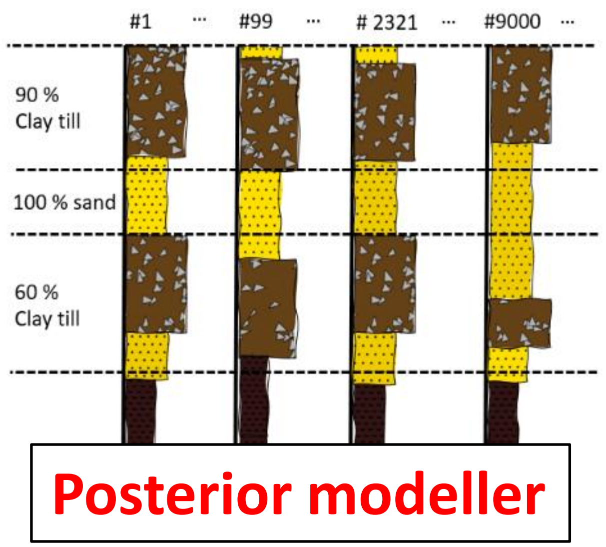
Modeller af undergrunden



Udelukkede modeller



Accepterede modeller



Spørgsmål til modellerne:

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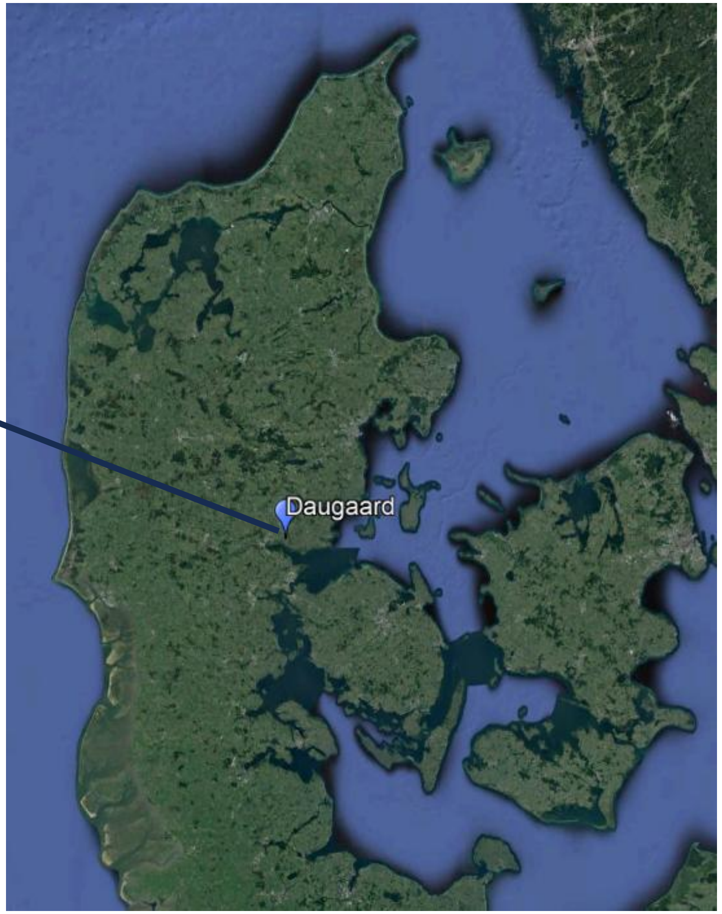
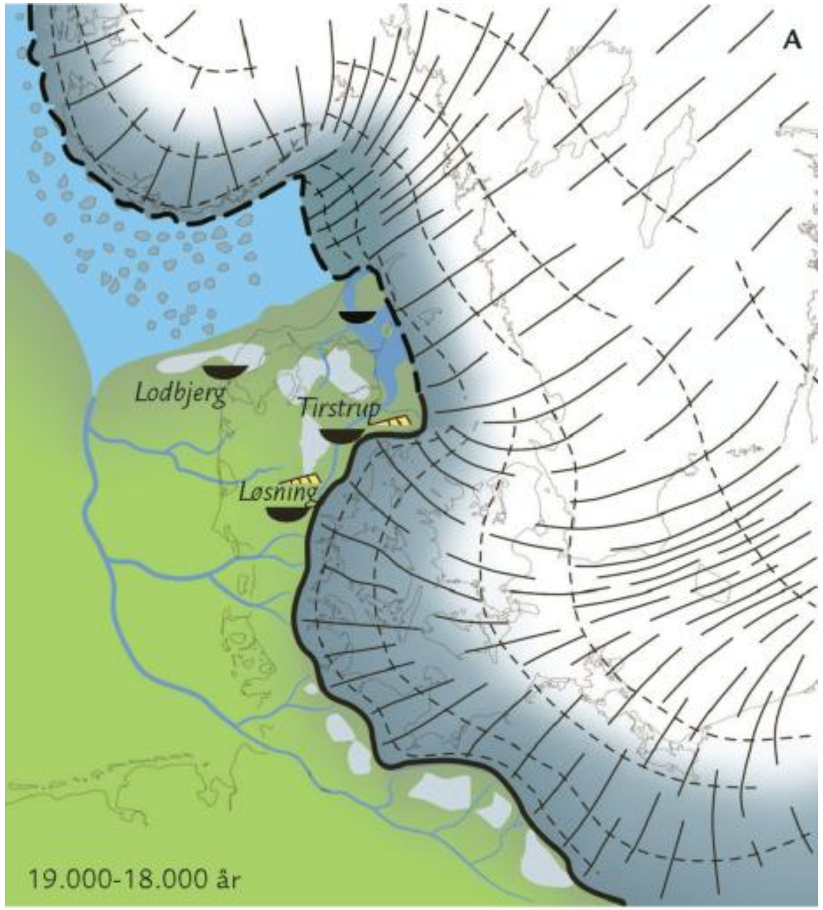
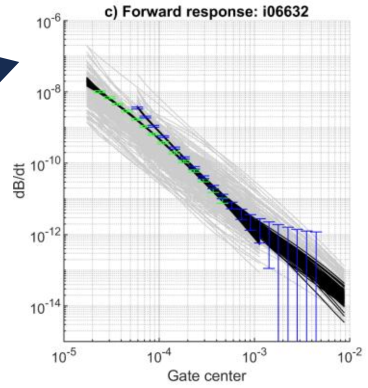
- Den forventede mægtighed af sand?
- Hvad er resistiviteten?
- Meget mere…

Daugaard pilotområde





tTEM survey



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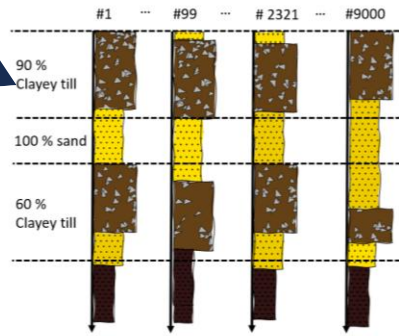
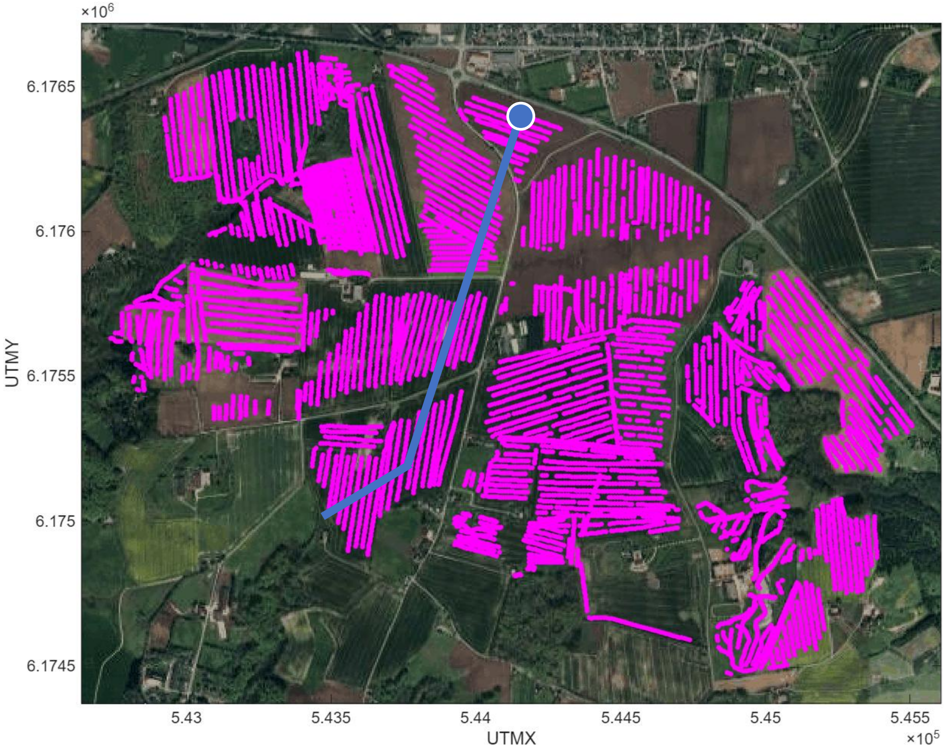
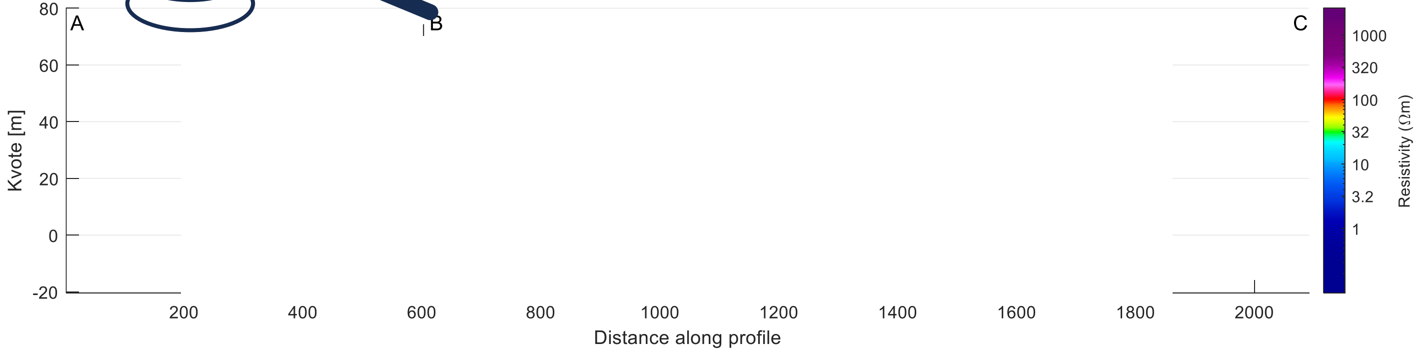
dB/dt
Gate center



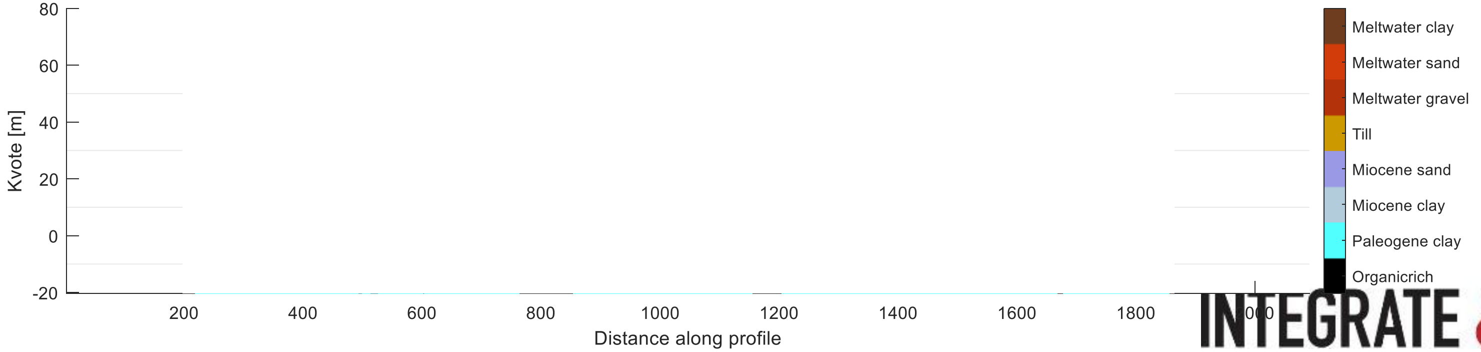
#1
#99
2321
#9000
90 %
Clayey till
100 % sand
60 %
Clayey till



UTMY
UTMX
6.1765
6.176
6.1755
6.175
6.1745
5.43
5.435
5.44
5.445
5.45
5.455

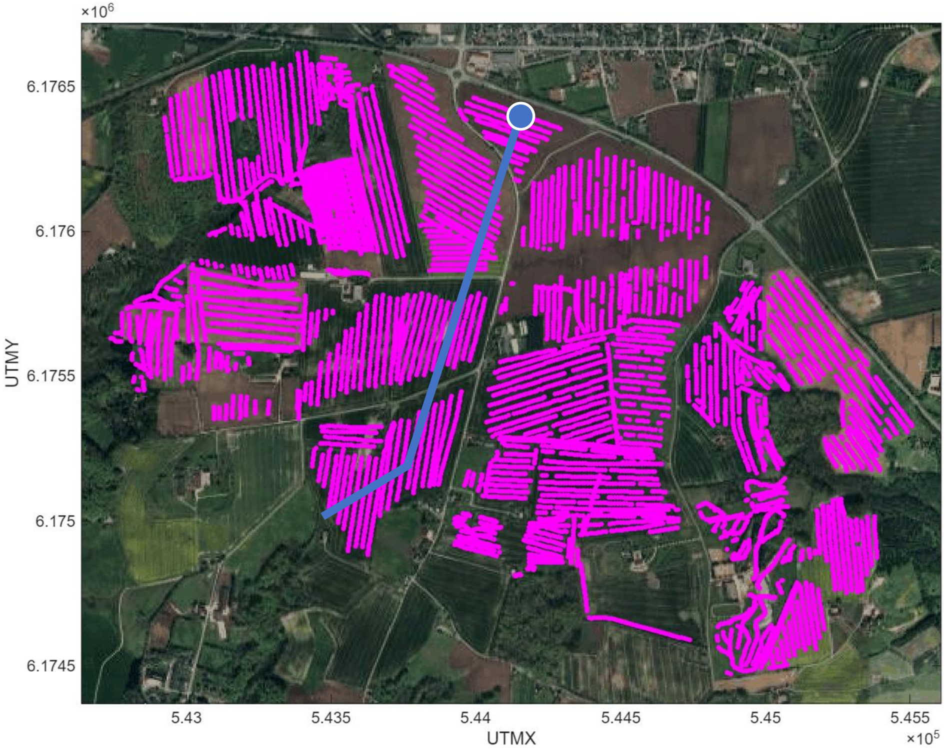


A
B
C
Kvote [m]
Distance along profile
Resistivity (Ωm)
1000
320
100
32
10
3.2
1



Kvote [m]
Distance along profile
Meltwater clay
Meltwater sand
Meltwater gravel
Till
Miocene sand
Miocene clay
Paleogene clay
Organicrich

tTEM survey



×10^6
6.1765
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×10^5
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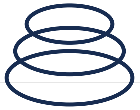

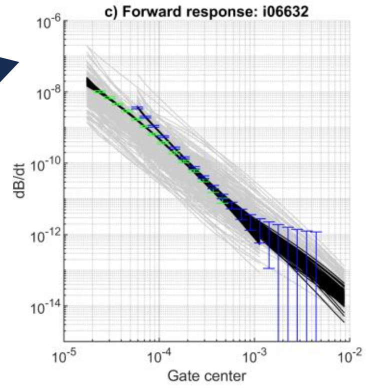

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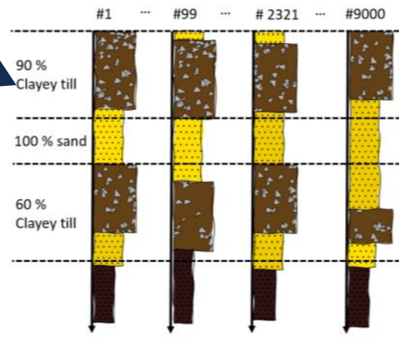

#1
#99
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90 % Clayey till
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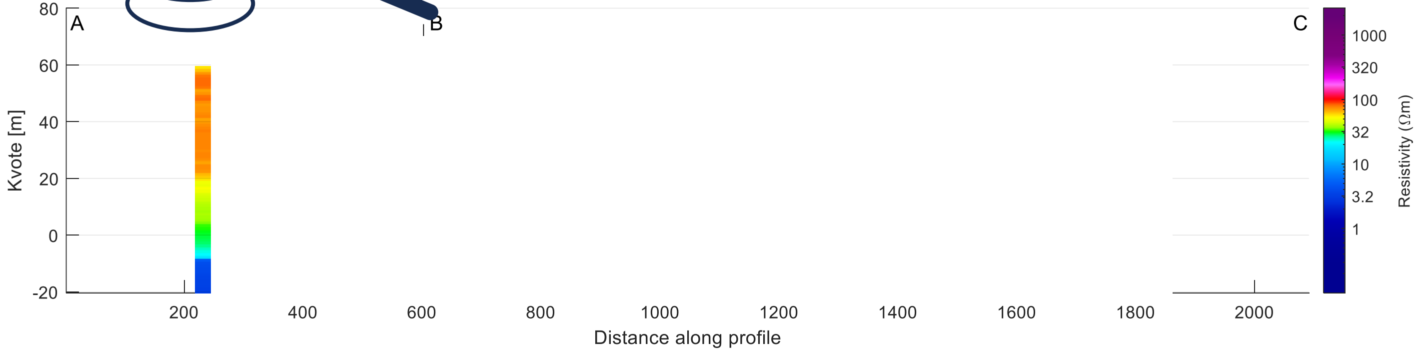

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1000
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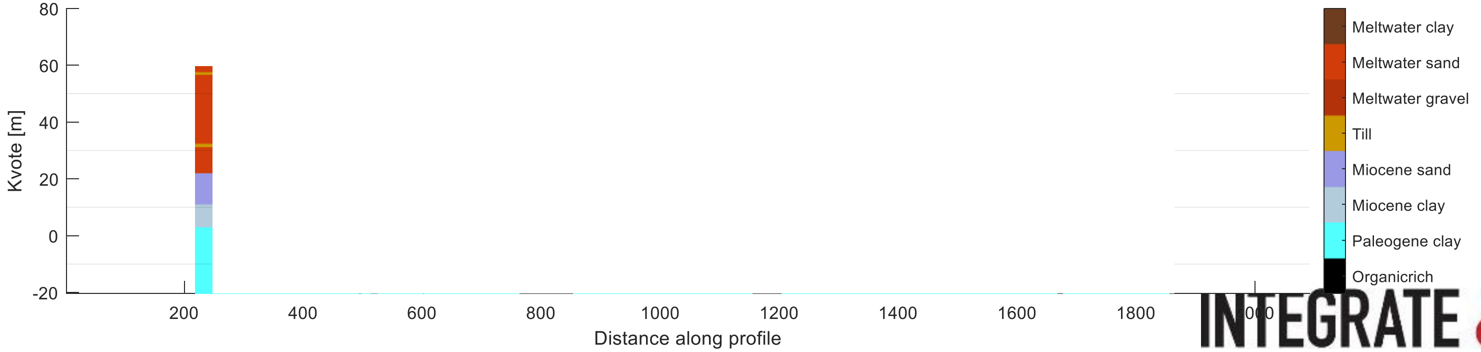

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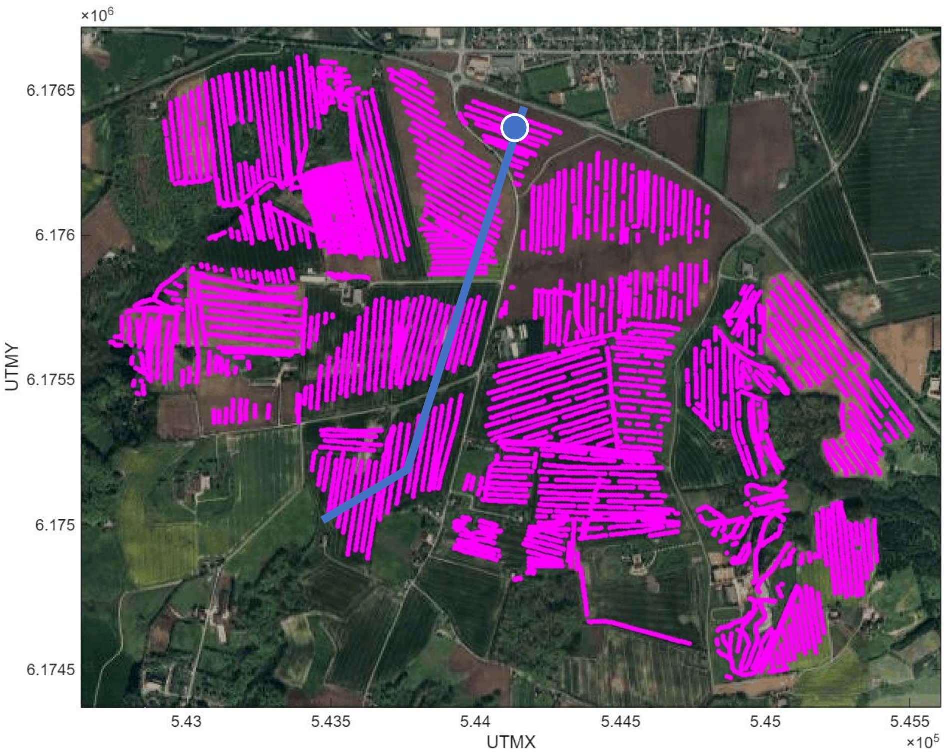
tTEM survey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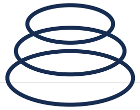

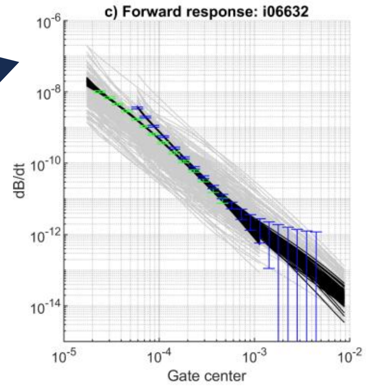
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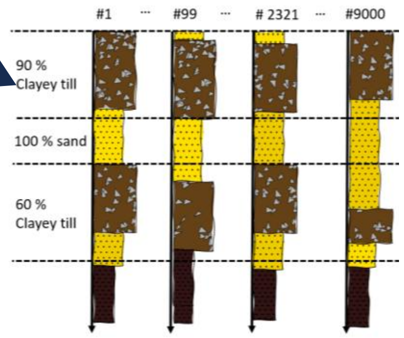
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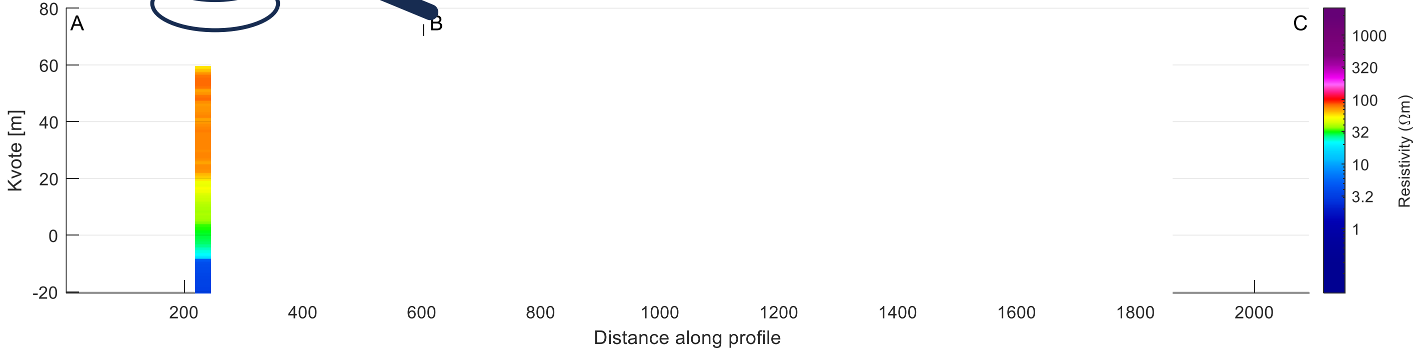
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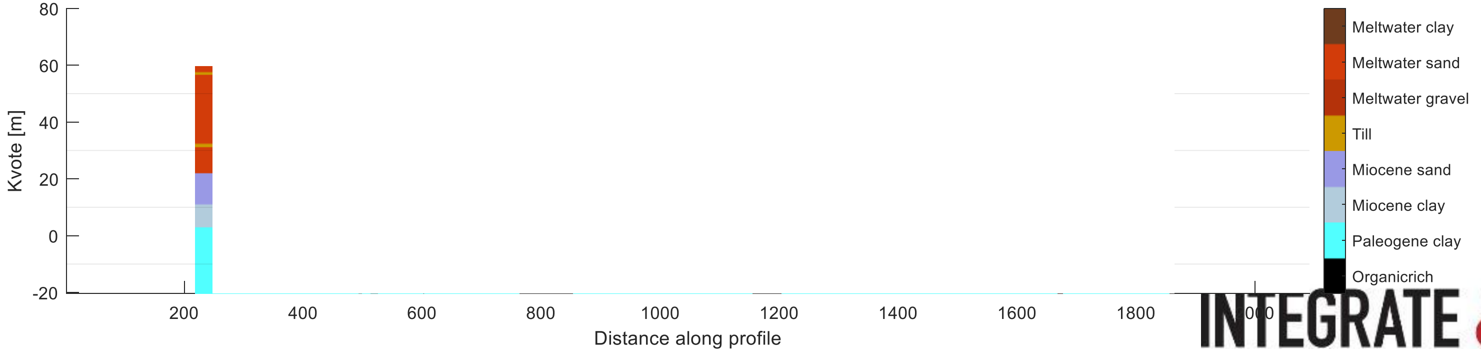
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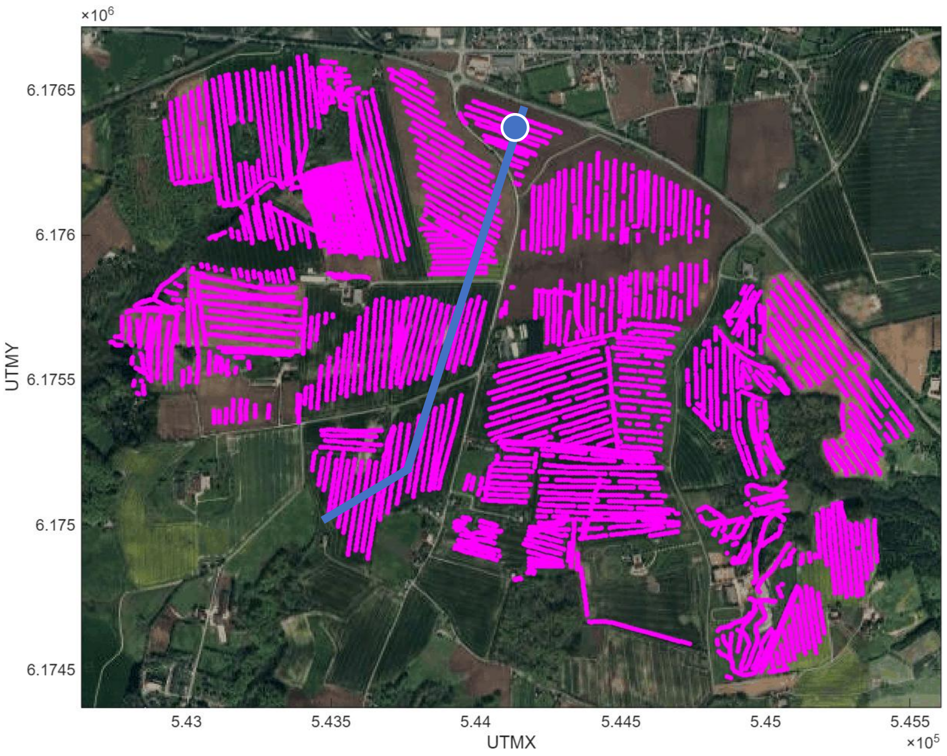

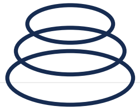

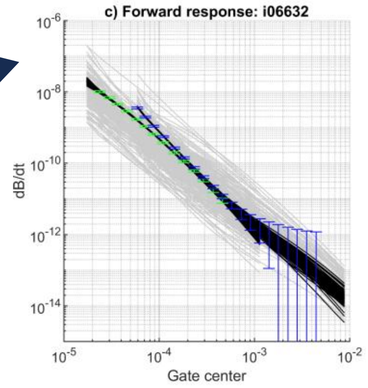

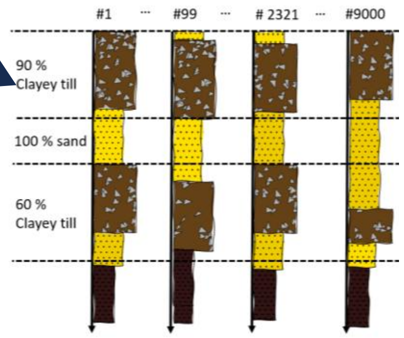

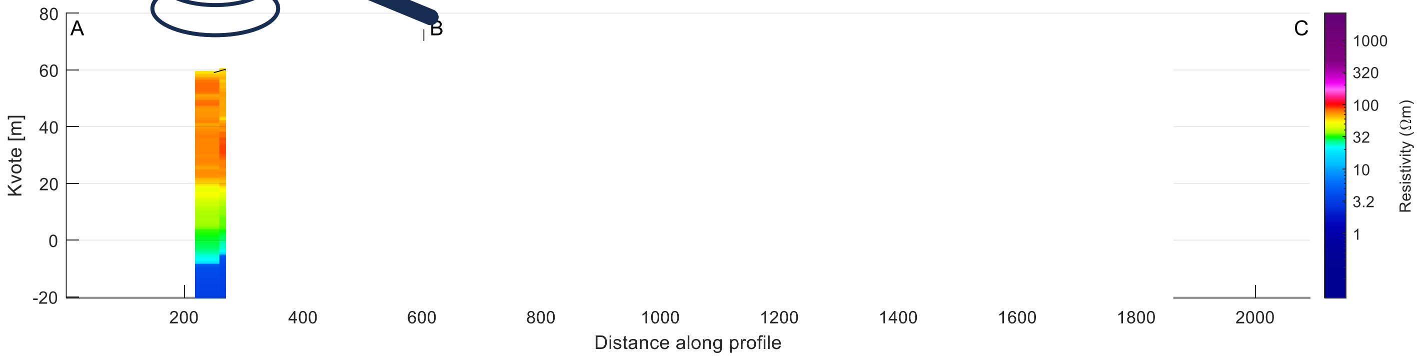

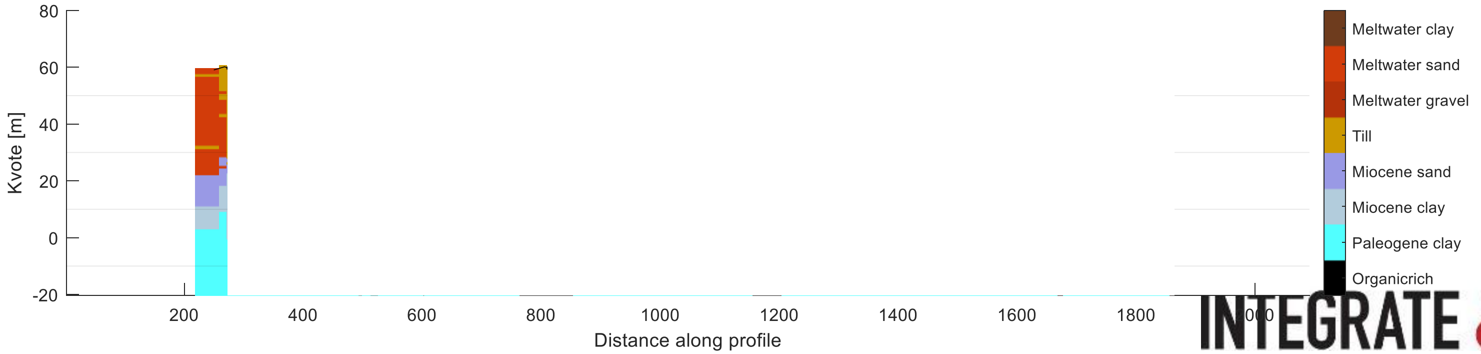

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tTEM survey


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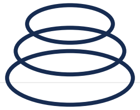

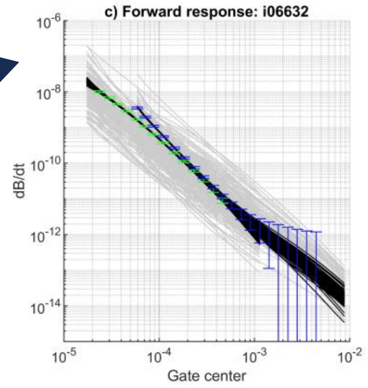
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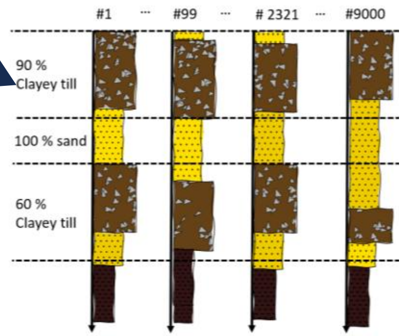
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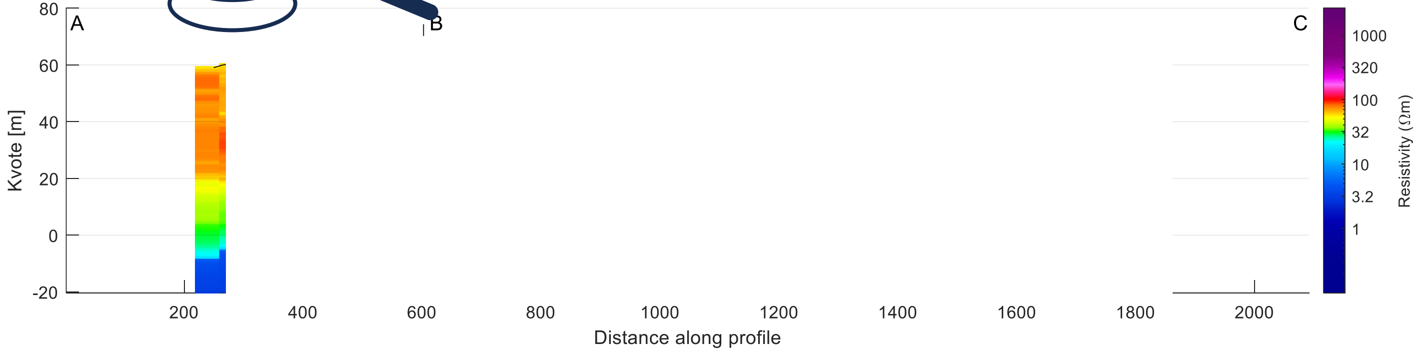
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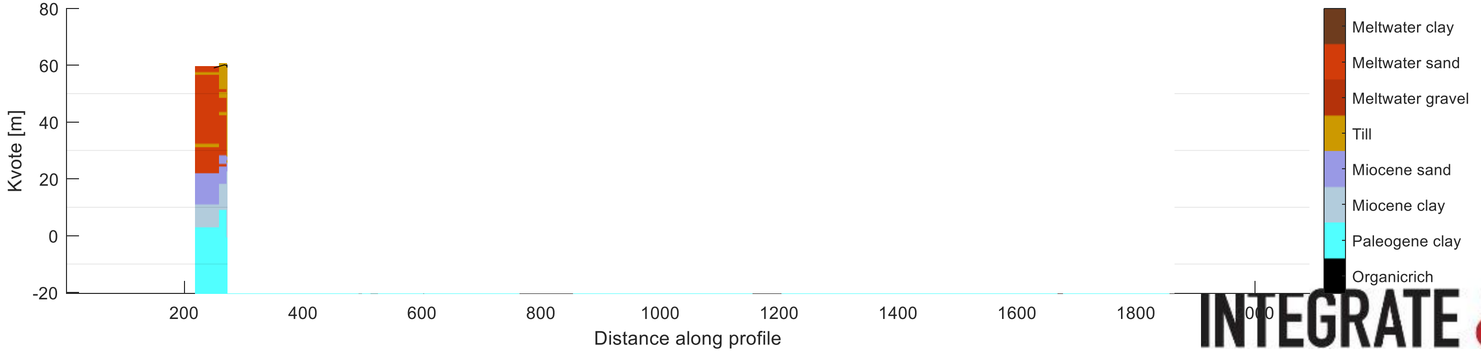
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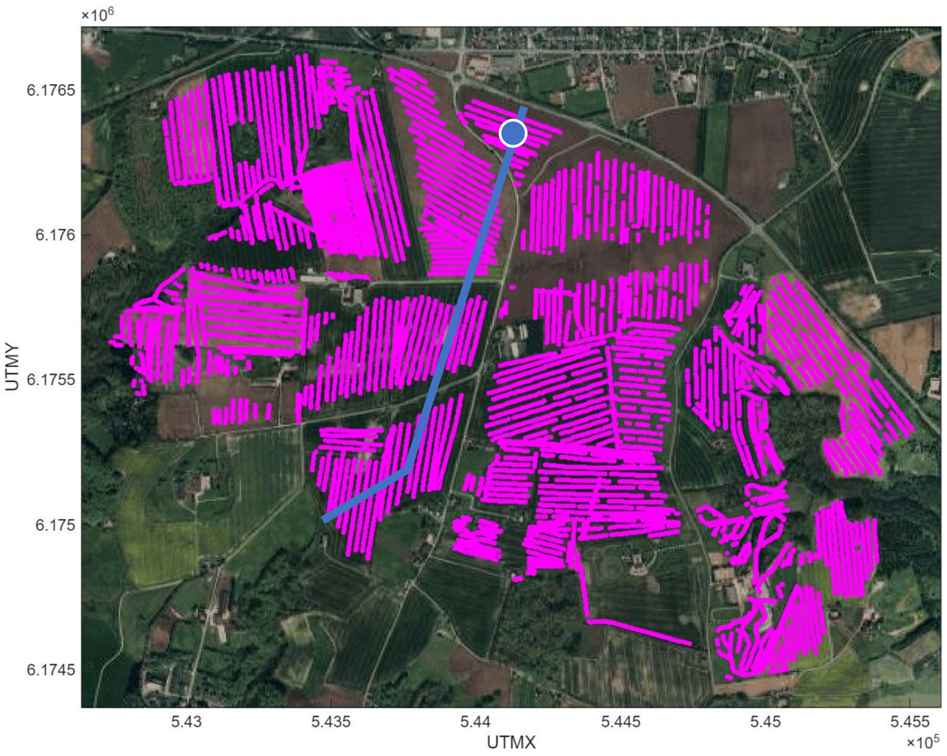
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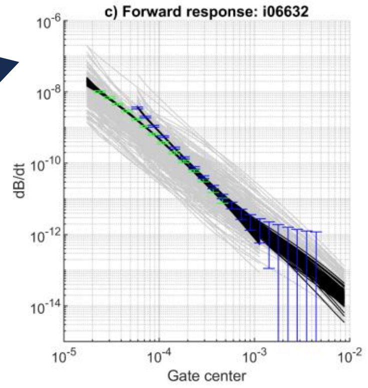
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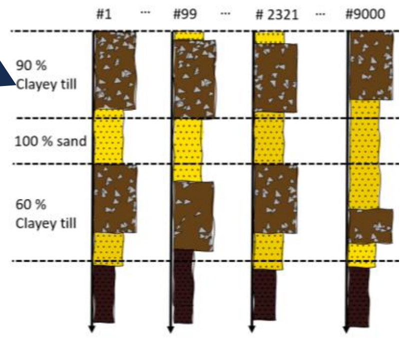
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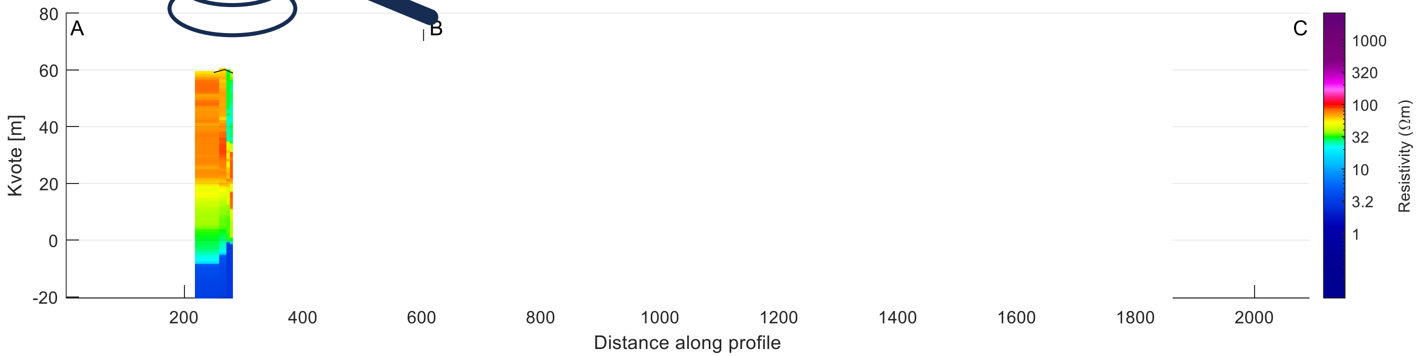
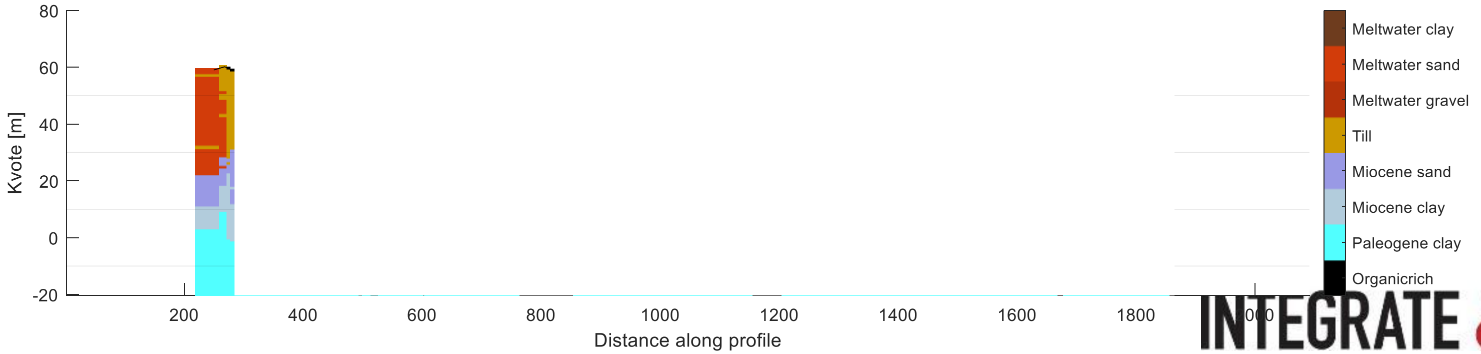
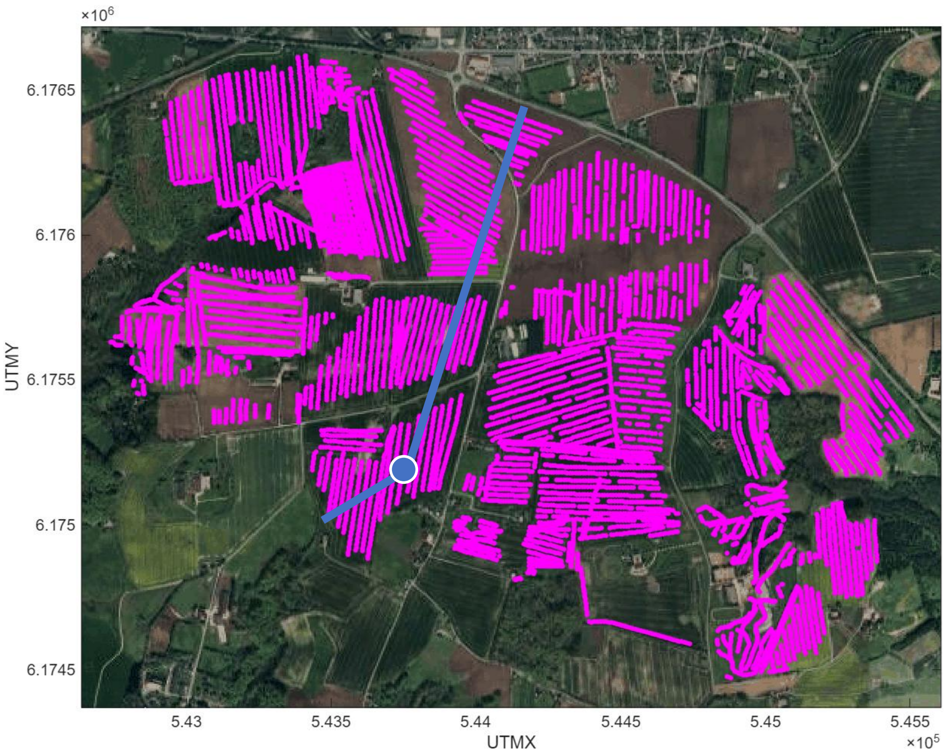
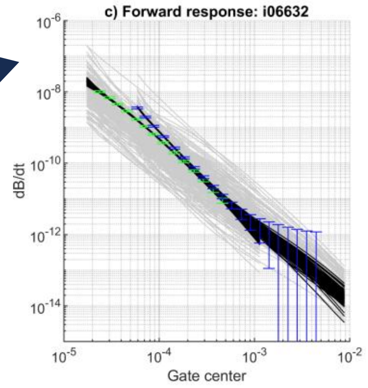
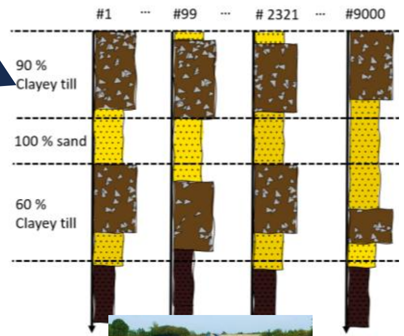

A
B
C
Kvote [m]
Distance along profile
Resistivity (Ωm)
1000
320
100
32
10
3.2
1

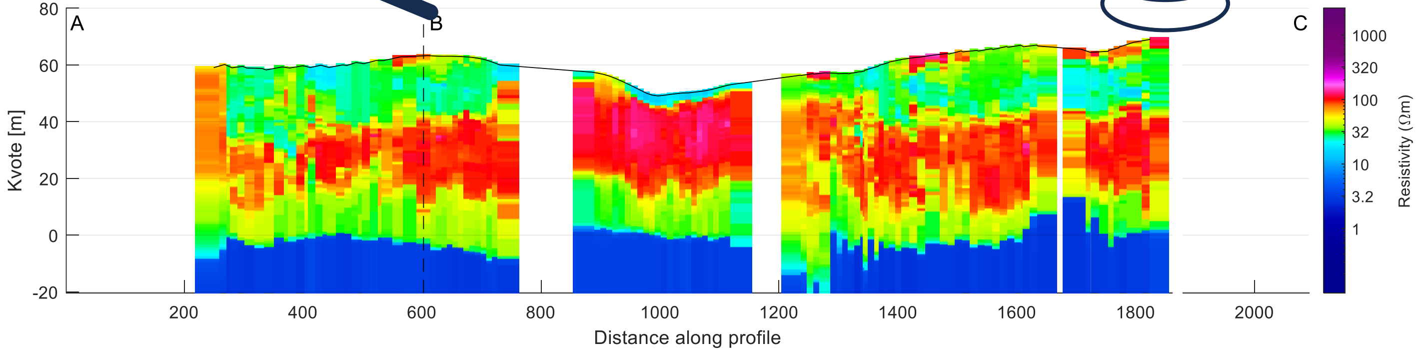

Kvote [m]
Distance along profile
Meltwater clay
Meltwater sand
Meltwater gravel
Till
Miocene sand
Miocene clay
Paleogene clay
Organicrich

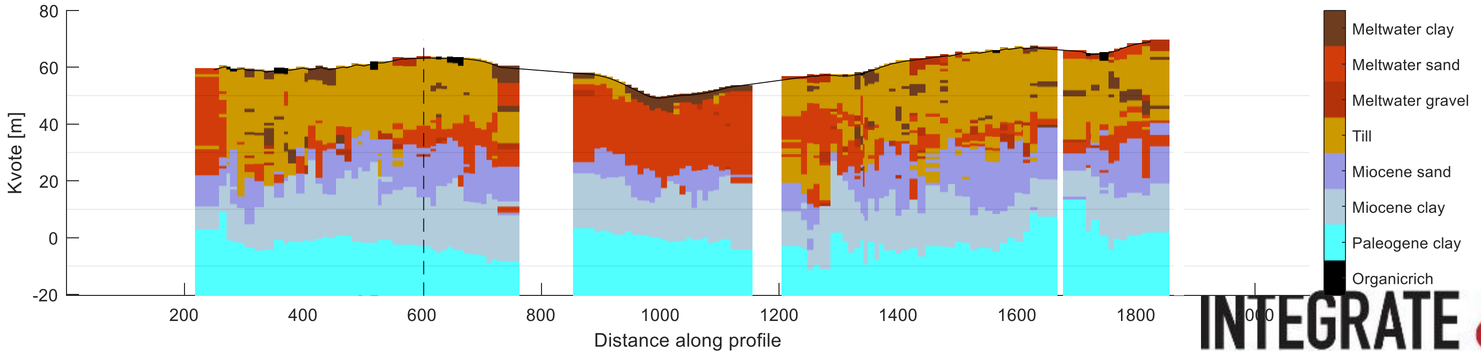
tTEM survey


×10^6
6.1765
6.176
6.1755
6.175
6.1745
UTMY
5.43
5.435
5.44
5.445
5.45
5.455
×10^5
UTMX

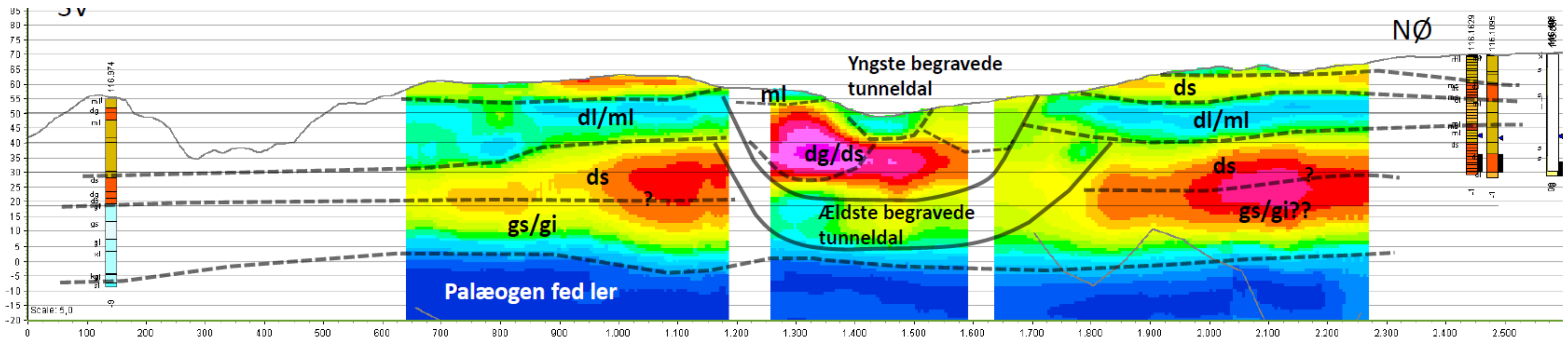

c) Forward response: i06632
dB/dt
Gate center


#1
#99
2321
#9000
90 % Clayey till
100 % sand
60 % Clayey till

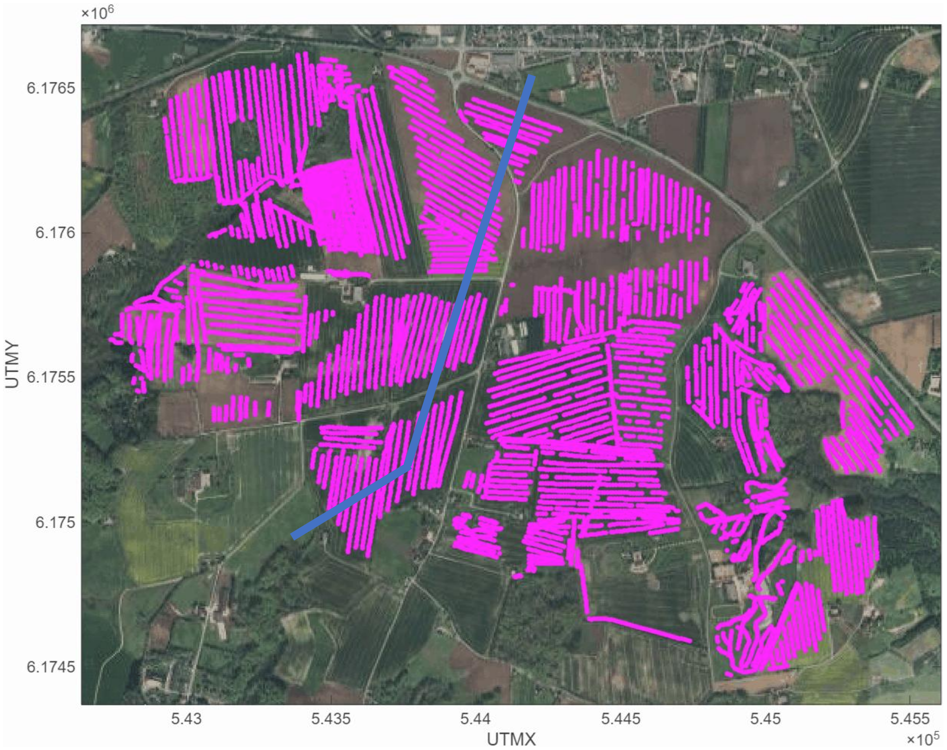

A
B
C
Kvote [m]
Distance along profile
Resistivity (Ωm)
1000
320
100
32
10
3.2
1

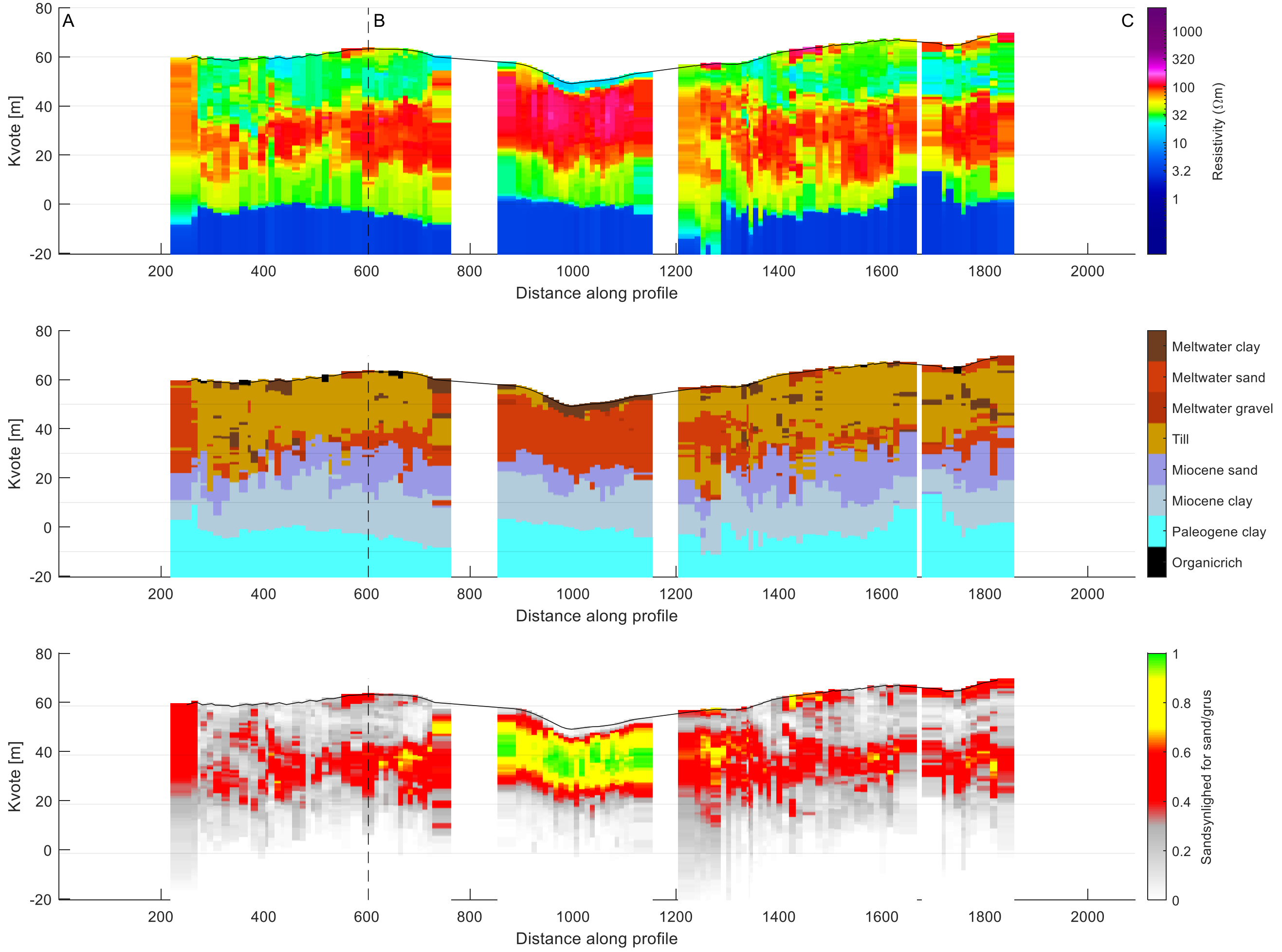

Kvote [m]
Distance along profile
Meltwater clay
Meltwater sand
Meltwater gravel
Till
Miocene sand
Miocene clay
Paleogene clay
Organicrich

Daugaard pilotområde

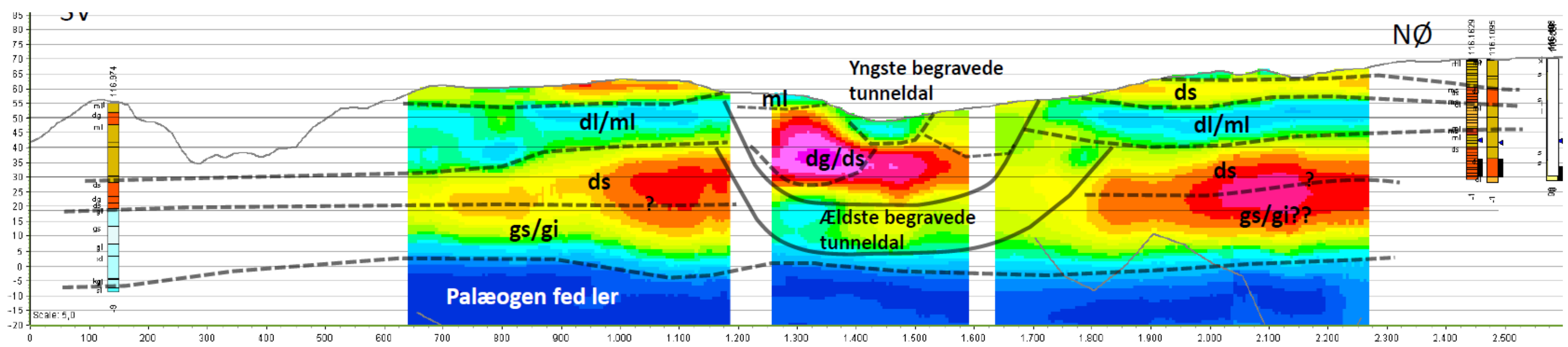


Inversionsresultater langs profil i pilotområdet.



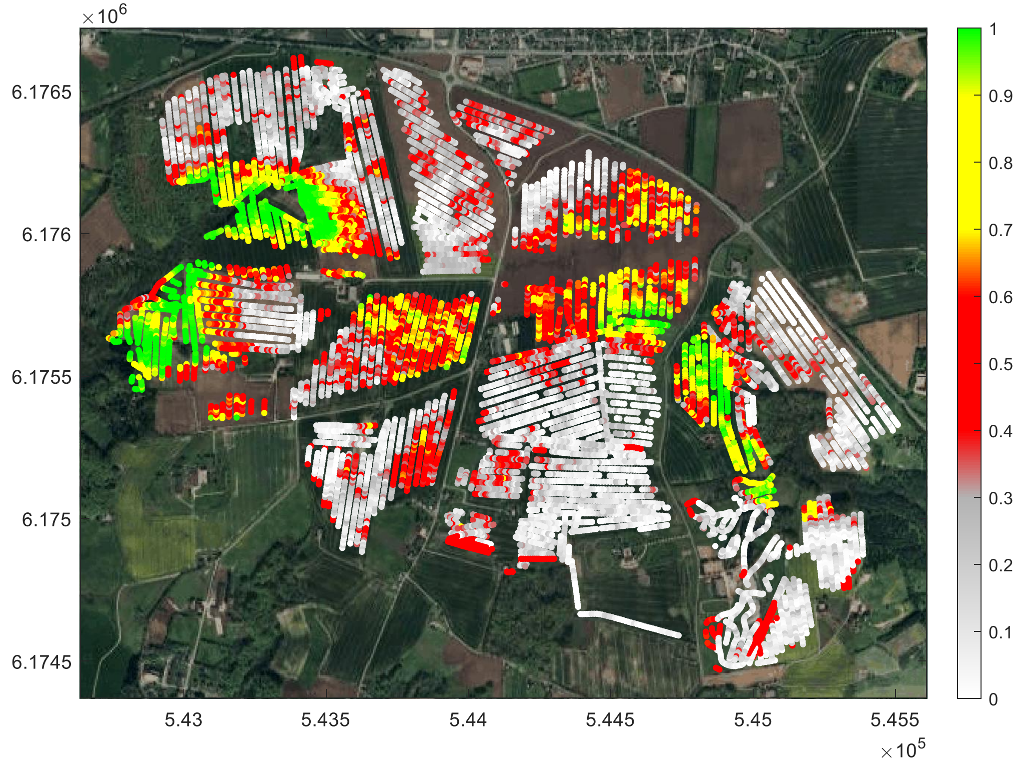


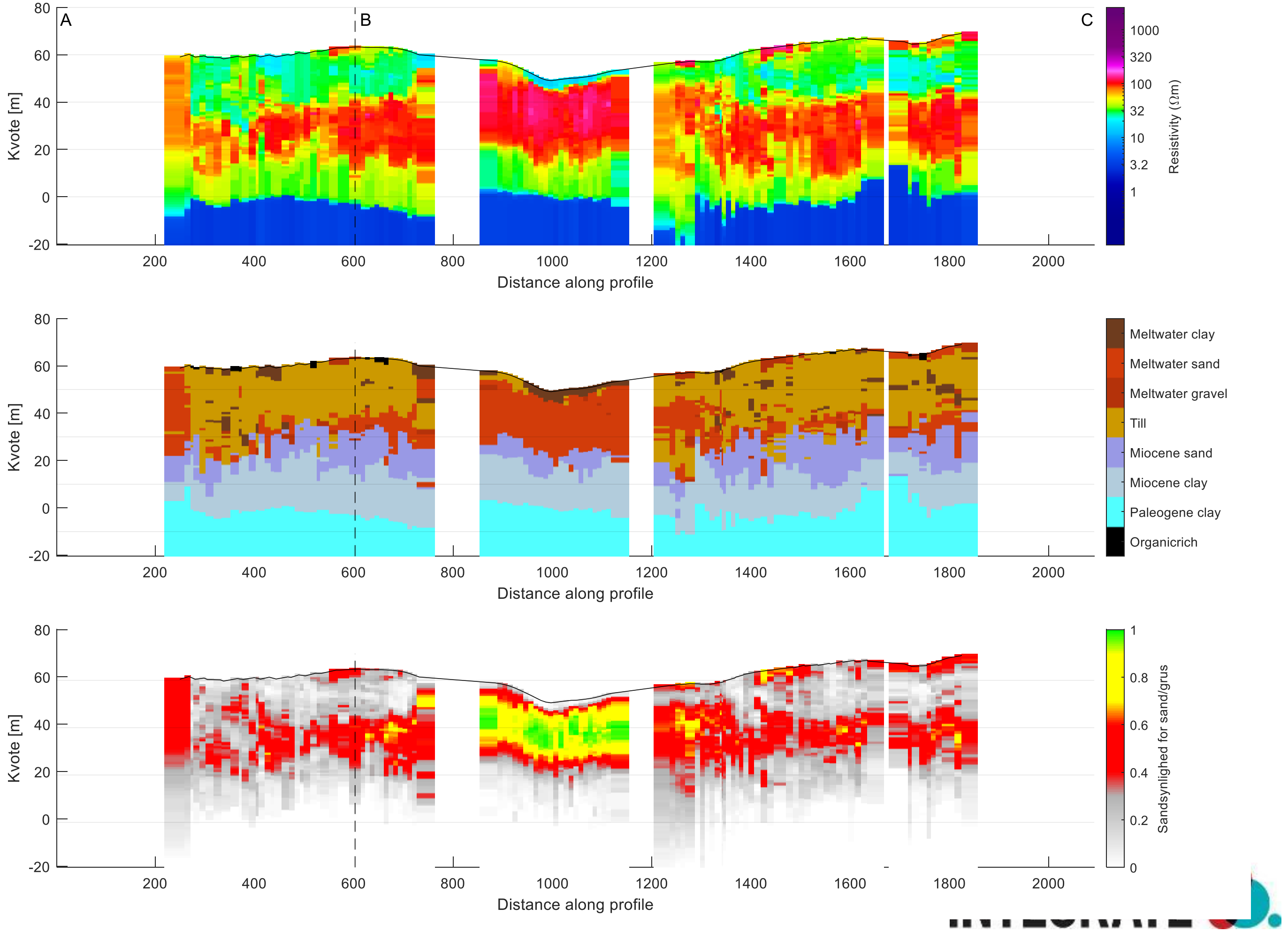
Daugaard pilotområde



Inversionsresultater langs profil i pilotområdet.

Sandsynlighed for at finde 5 m sammenhængende sand/grus i de øverste 10 m:



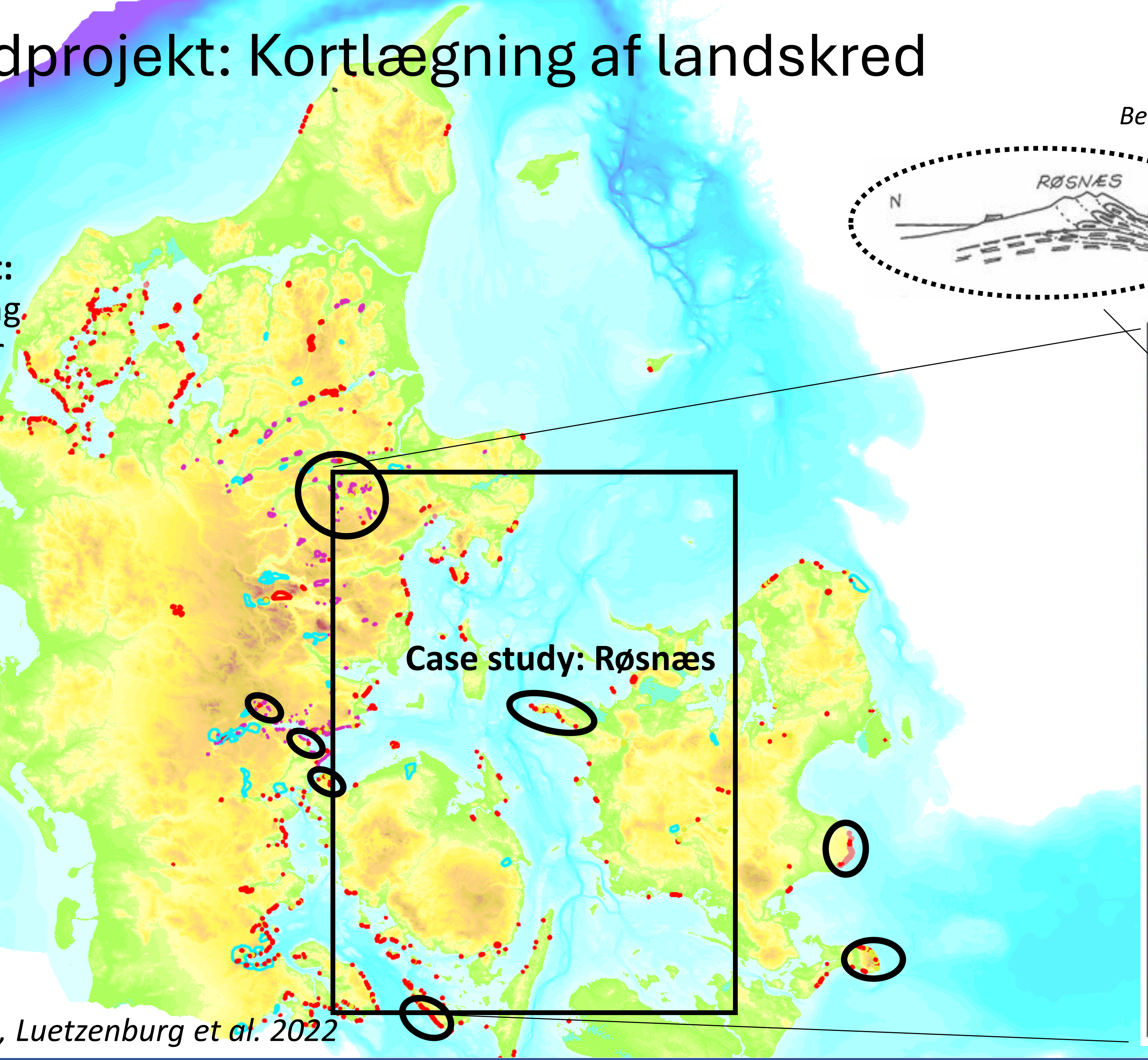


Landskredprojekt: Kortlægning af landskred

Landskredsprojektet: Geofysisk kortlægning af landskred 8 steder i Danmark

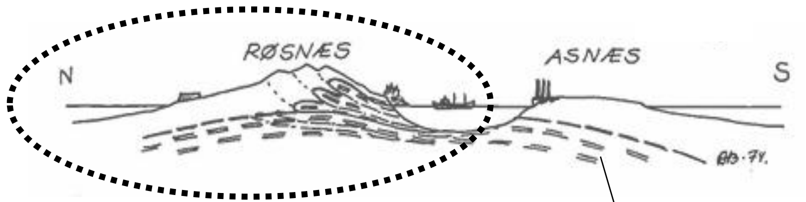
Casestudie: Modellering ved hjælp af den nyudviklede metode

Formål: Bedre opløsning af de glaciotektoniske processer som styre landskred i området

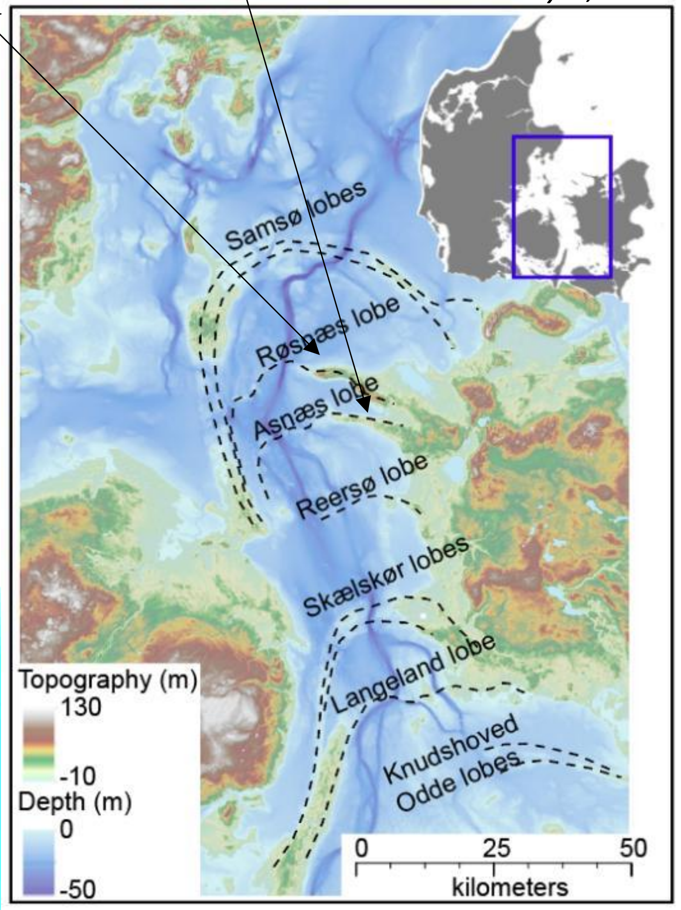


Mapped landslides: Svennevig et al. 2020, Luetzenburg et al. 2022

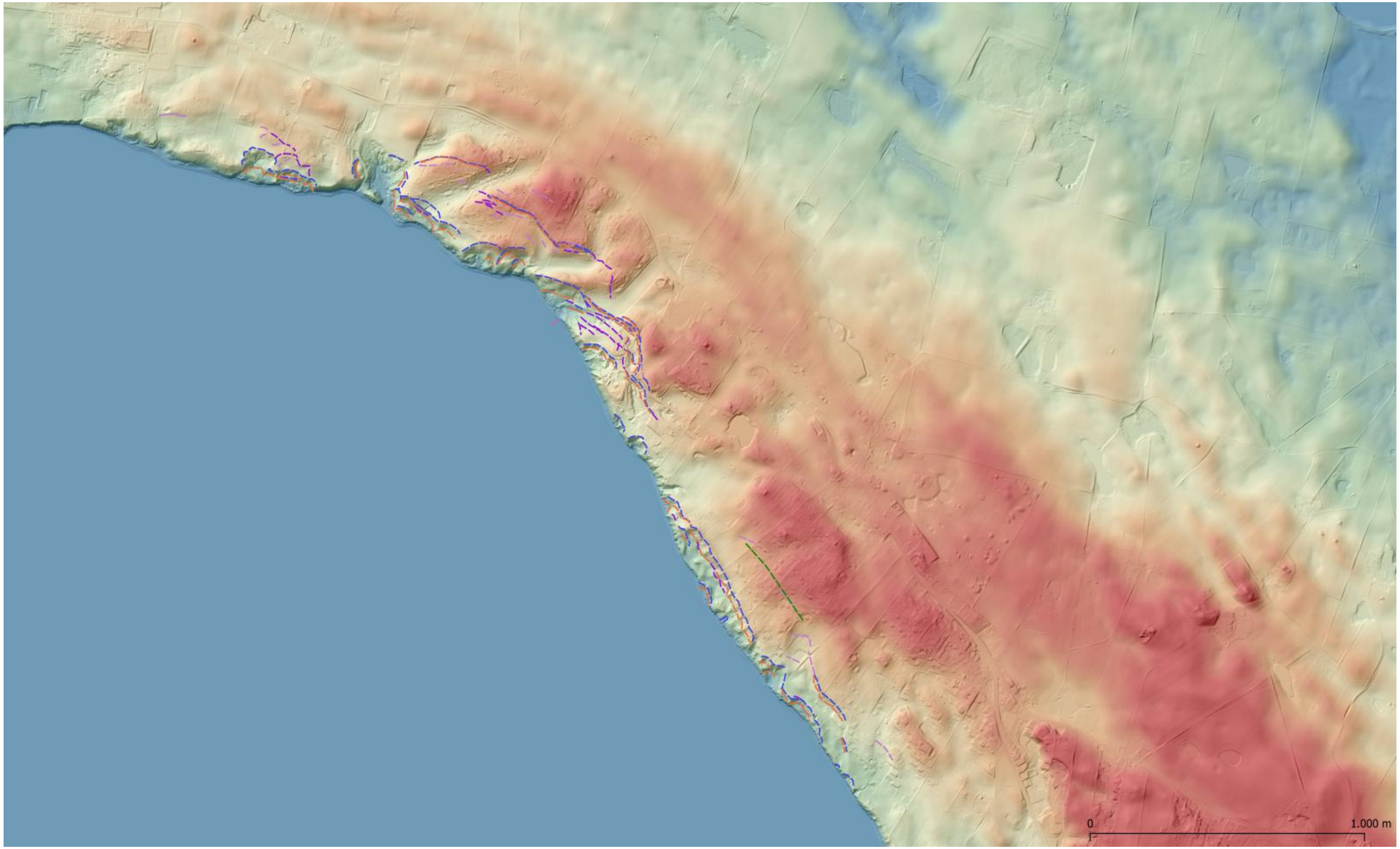
Berthelsen, 1975



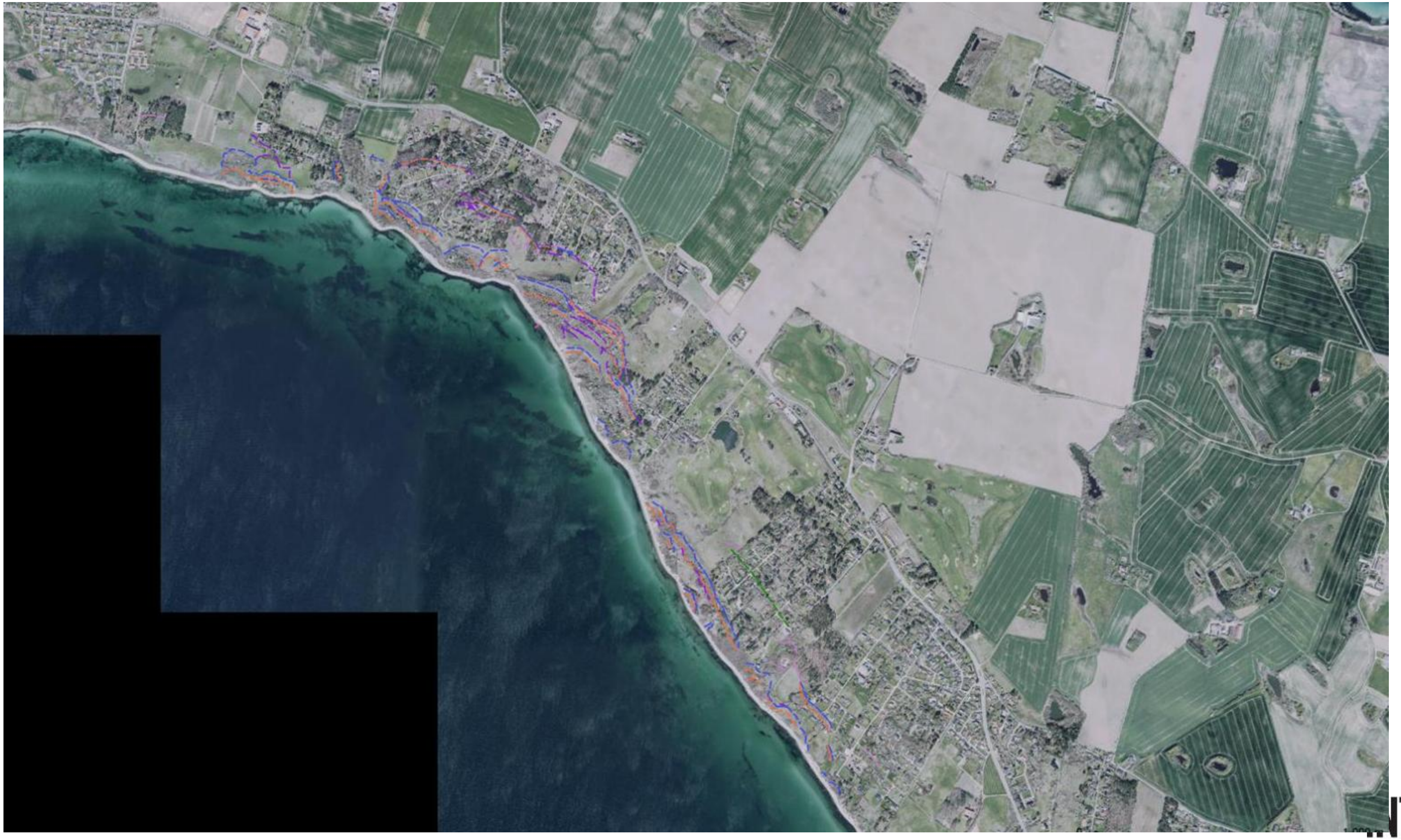
Høyer, 2019



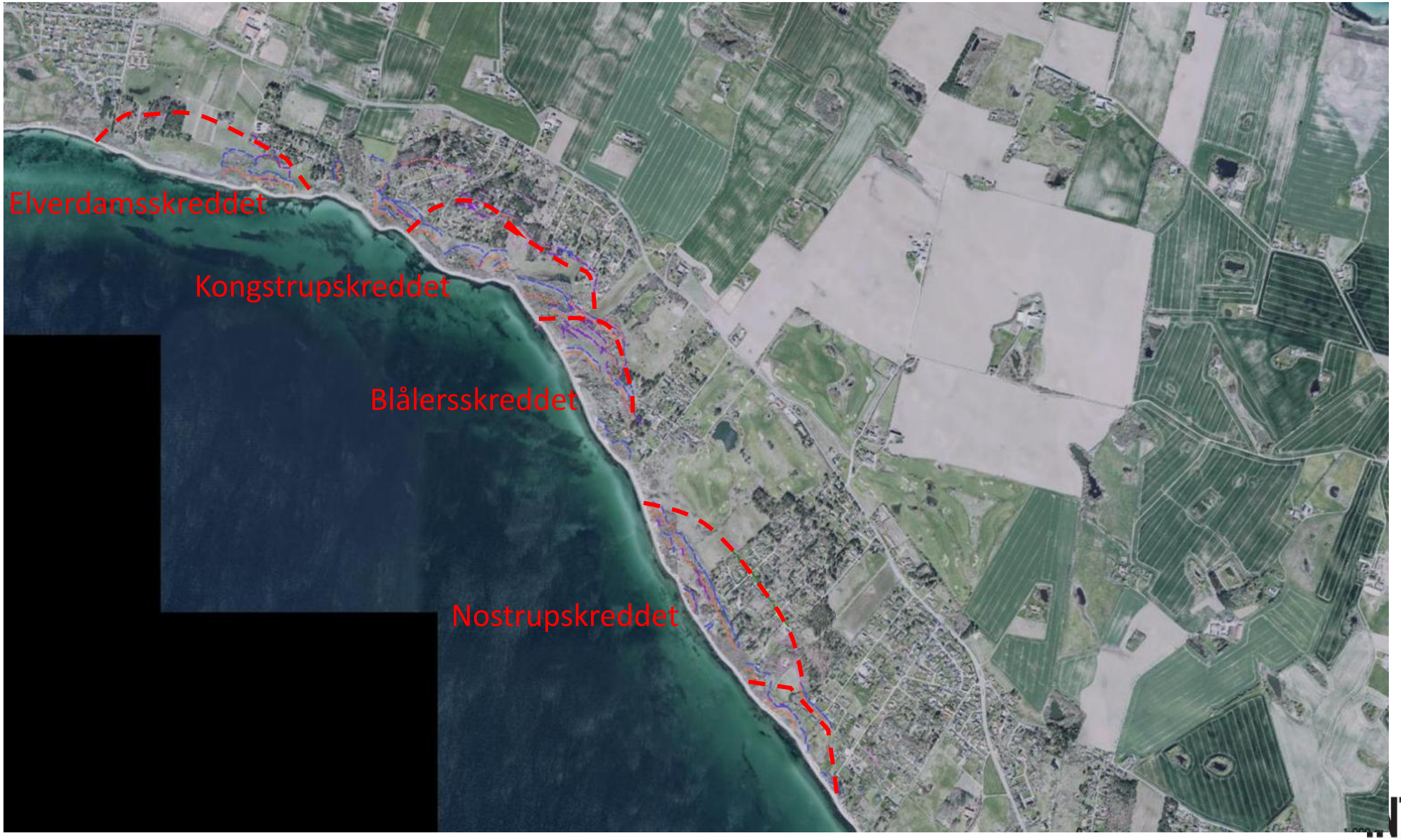
Landskred ved Røsnæs



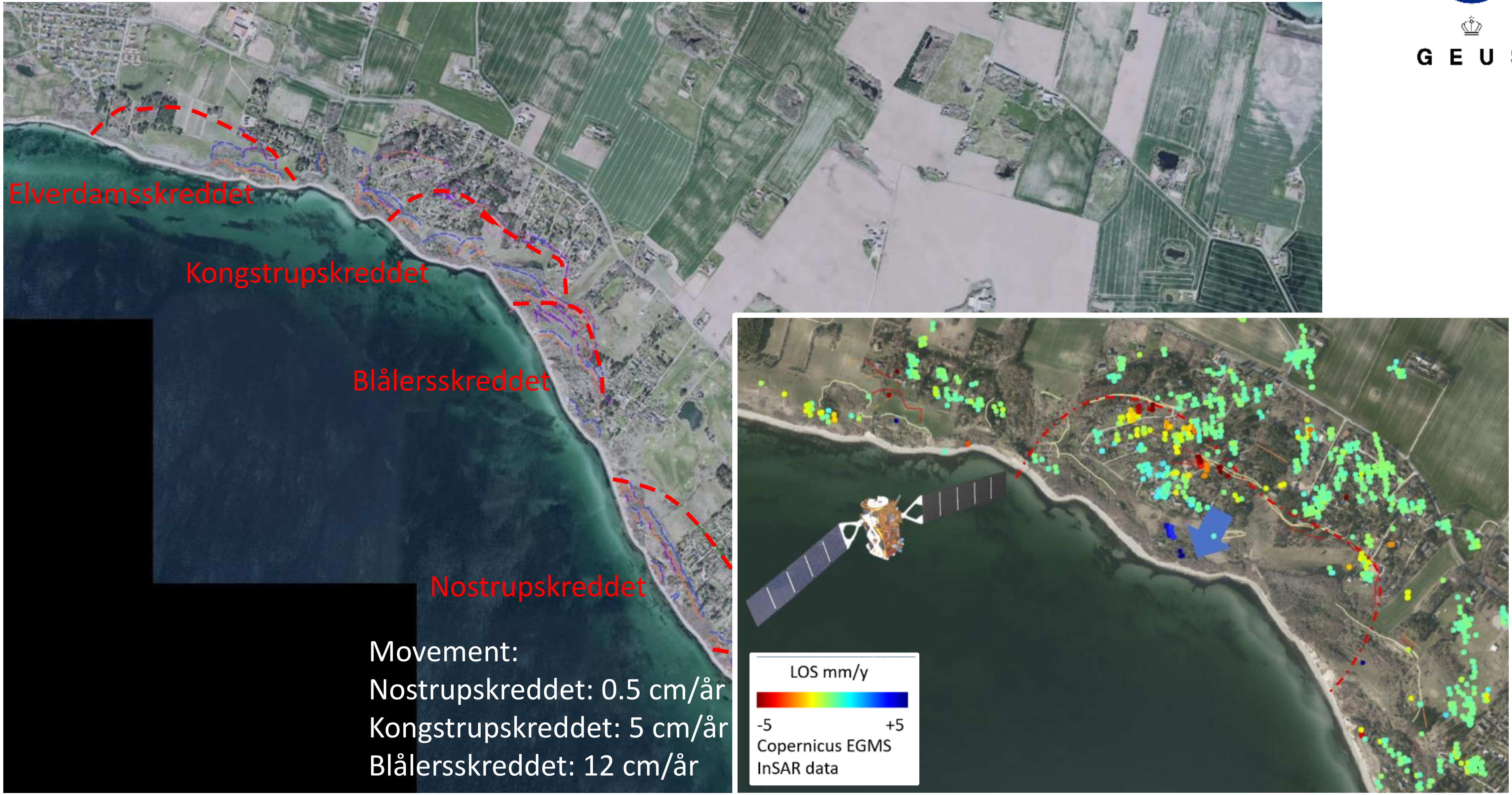
Landskred ved Røsnæs



Landskred ved Røsnæs

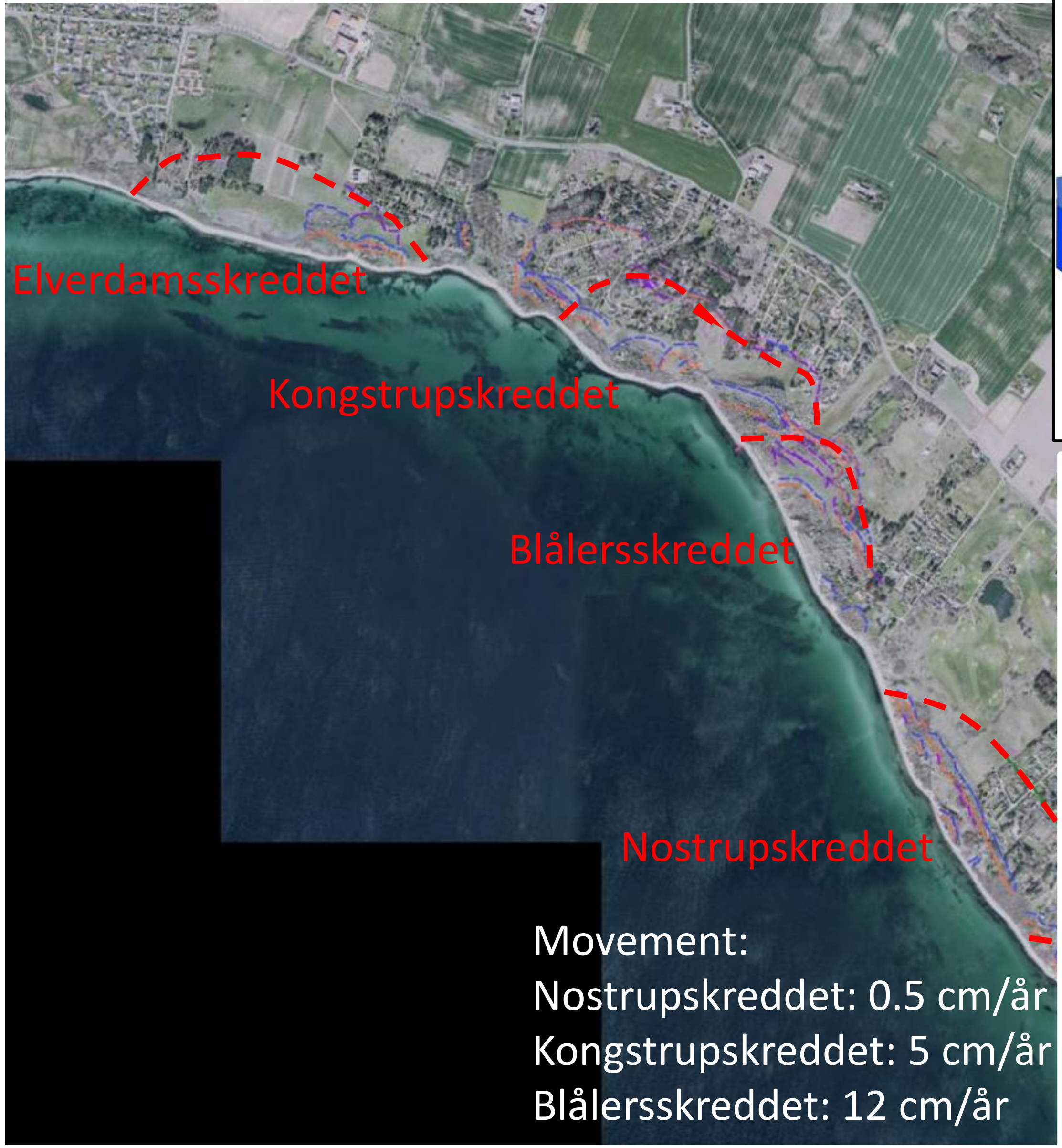


Landskred ved Røsnæs

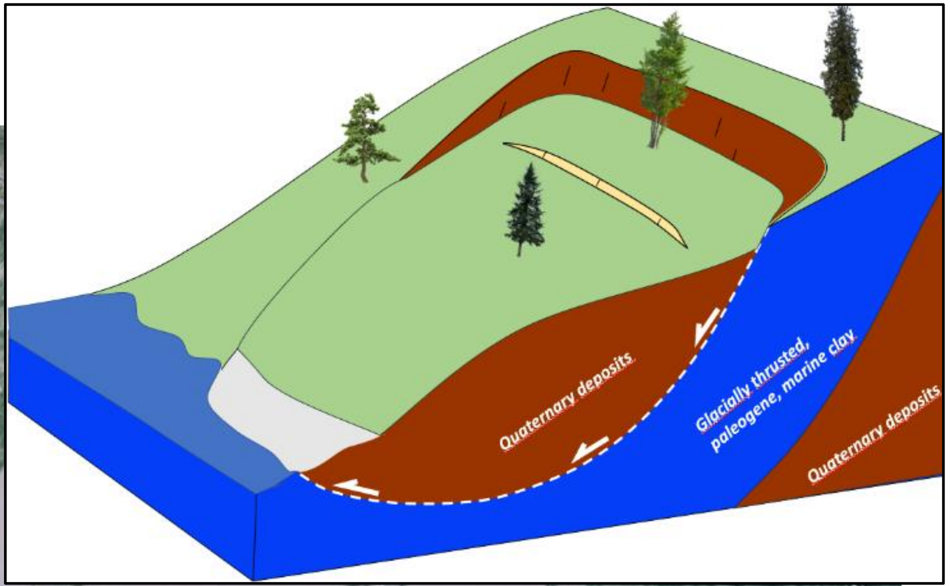


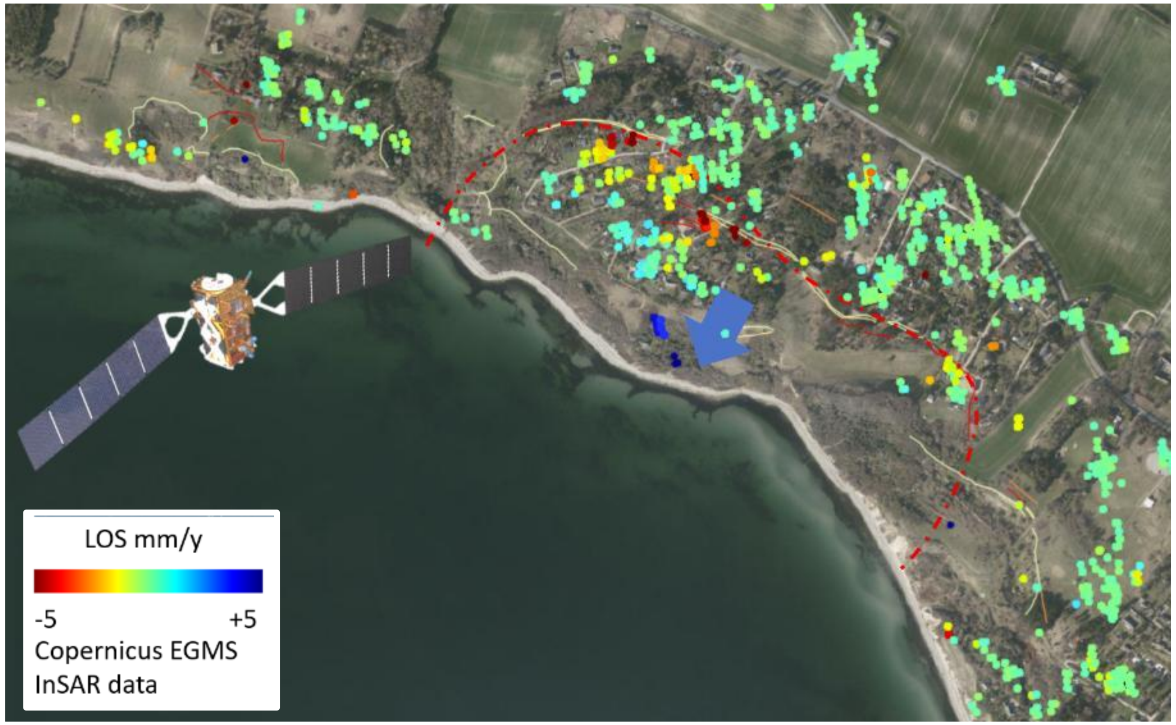
Movement:
Nostrupskreddet: 0.5 cm/år
Kongstrupskreddet: 5 cm/år
Blålersskreddet: 12 cm/år

Landskred ved Røsnæs

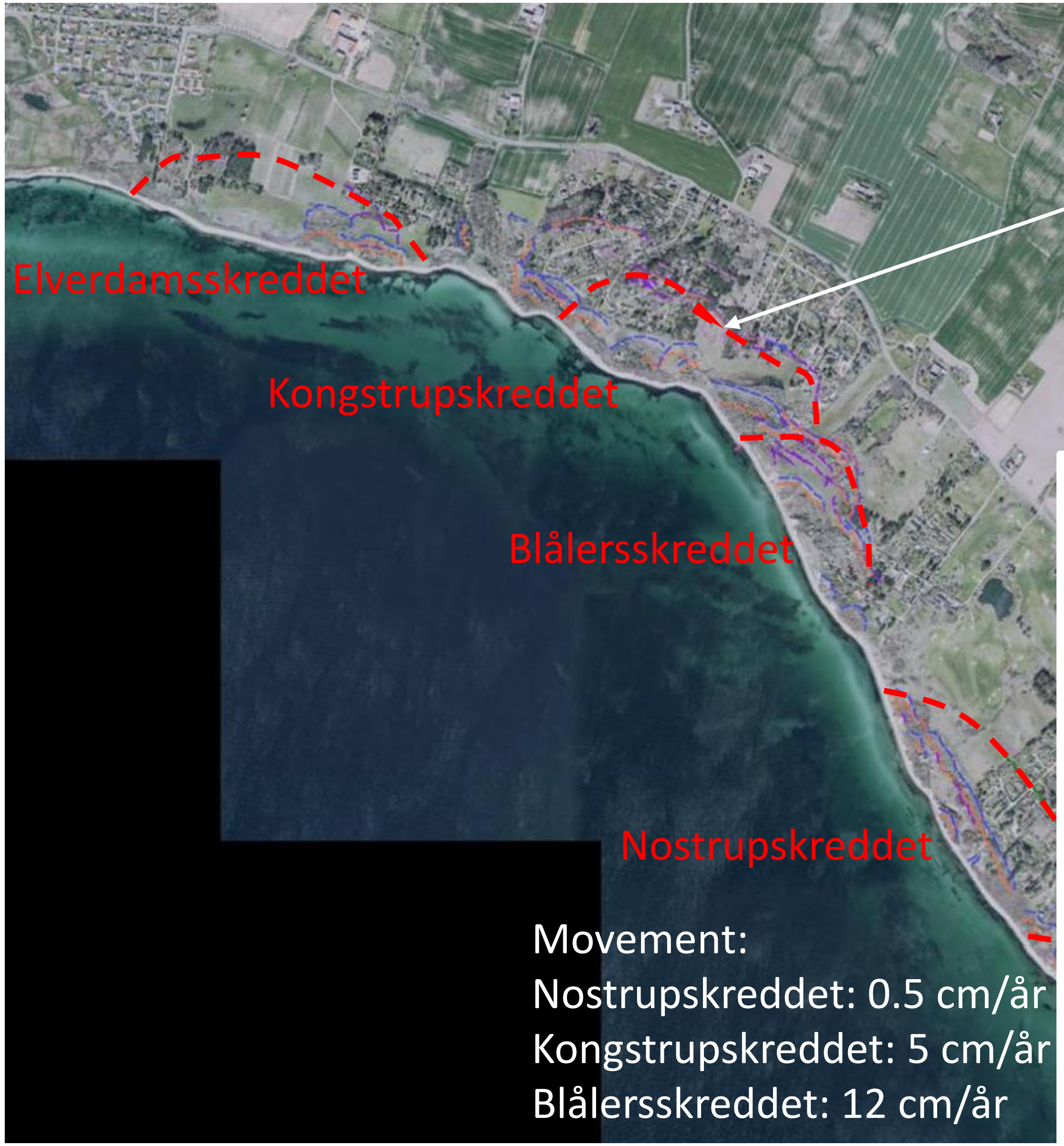


Movement:
Nostrupskreddet: 0.5 cm/år
Kongstrupskreddet: 5 cm/år
Blålersskreddet: 12 cm/år

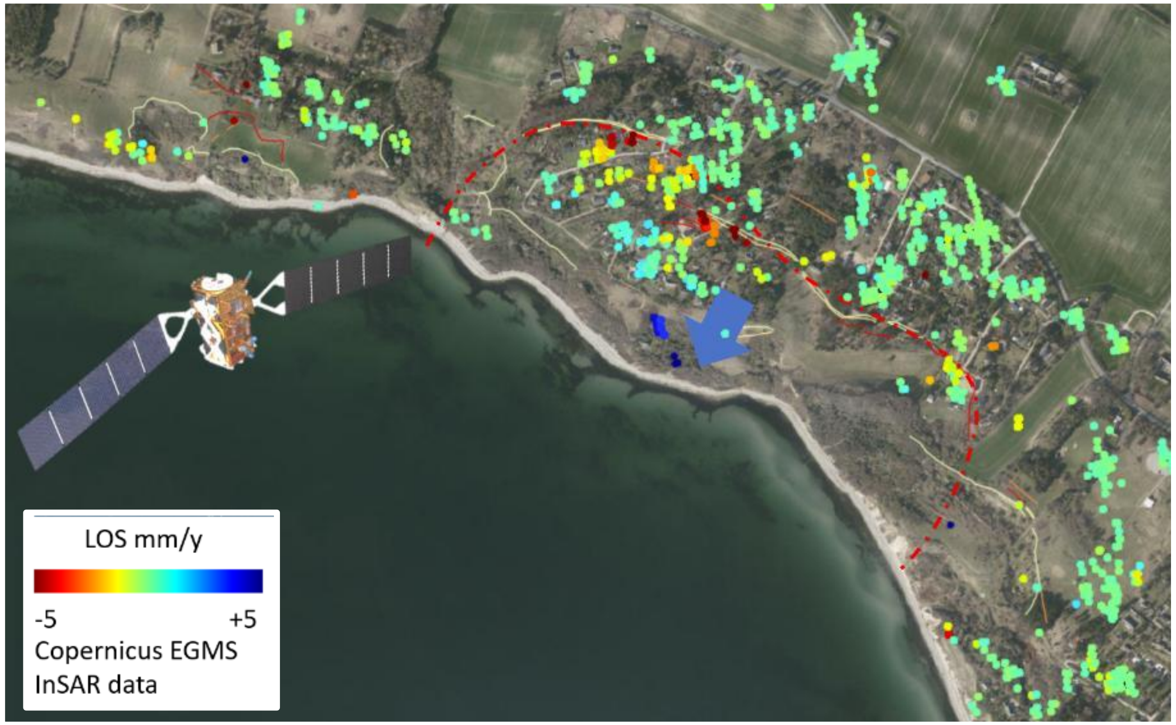




Landskred ved Røsnæs

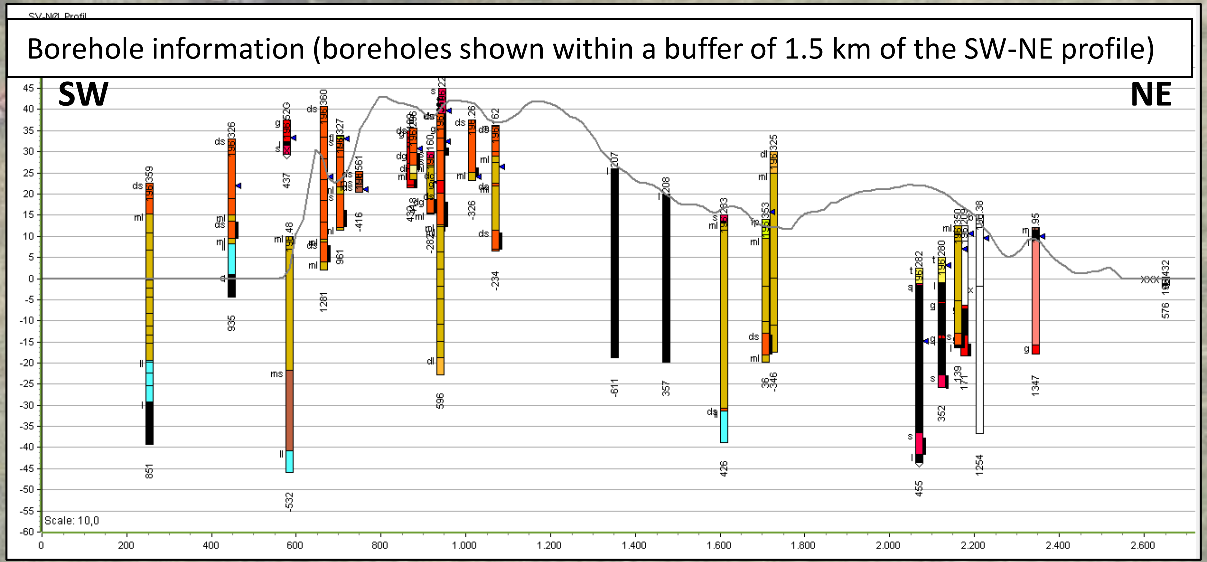


Movement:
Nostrupskreddet: 0.5 cm/år
Kongstrupskreddet: 5 cm/år
Blålersskreddet: 12 cm/år



Data

Surveydetaljer:
Areal: ca. 2.5x2.5 km
tTEM sondering: 2406
Borehuller: 22 nærtliggende



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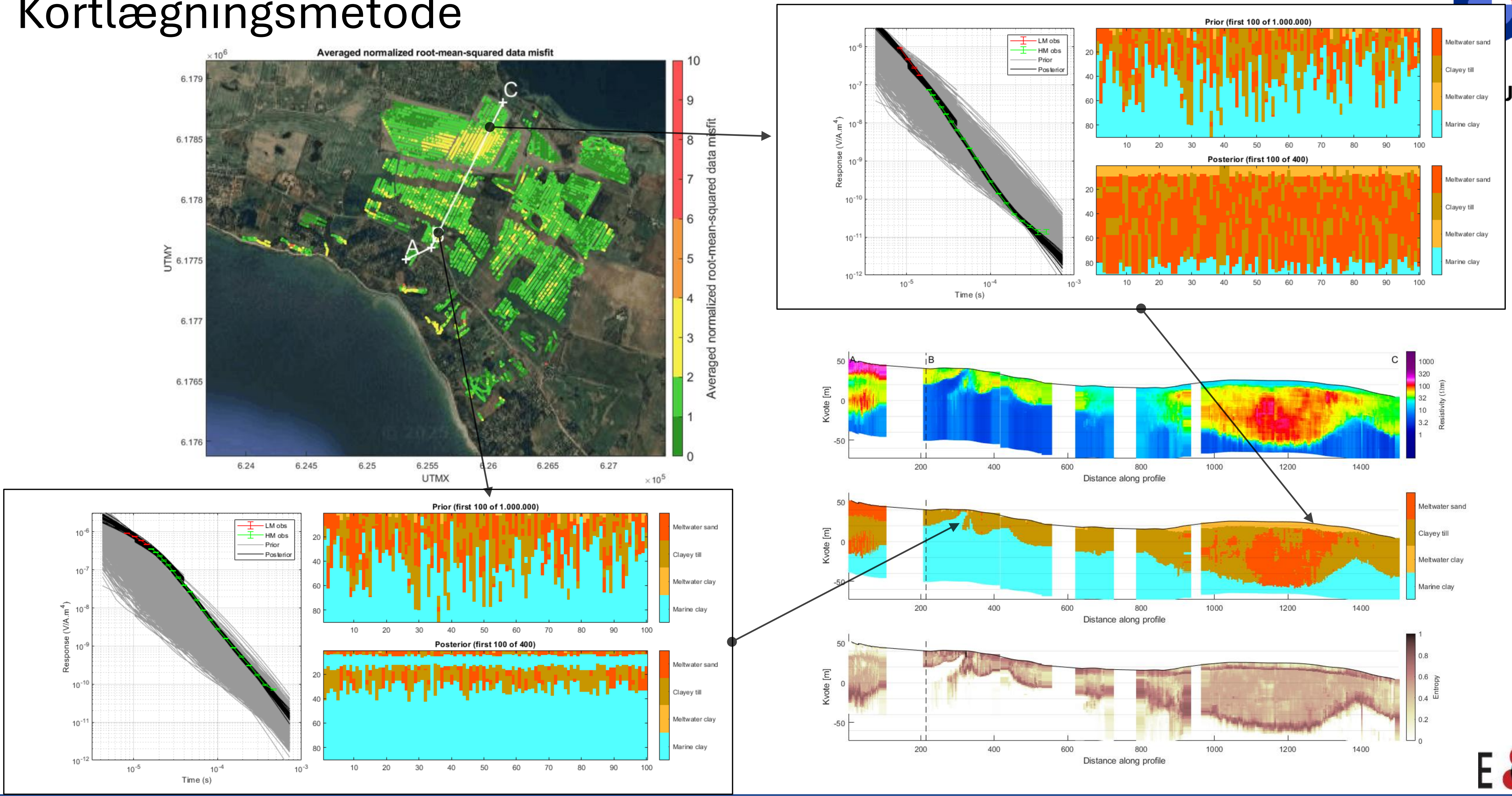
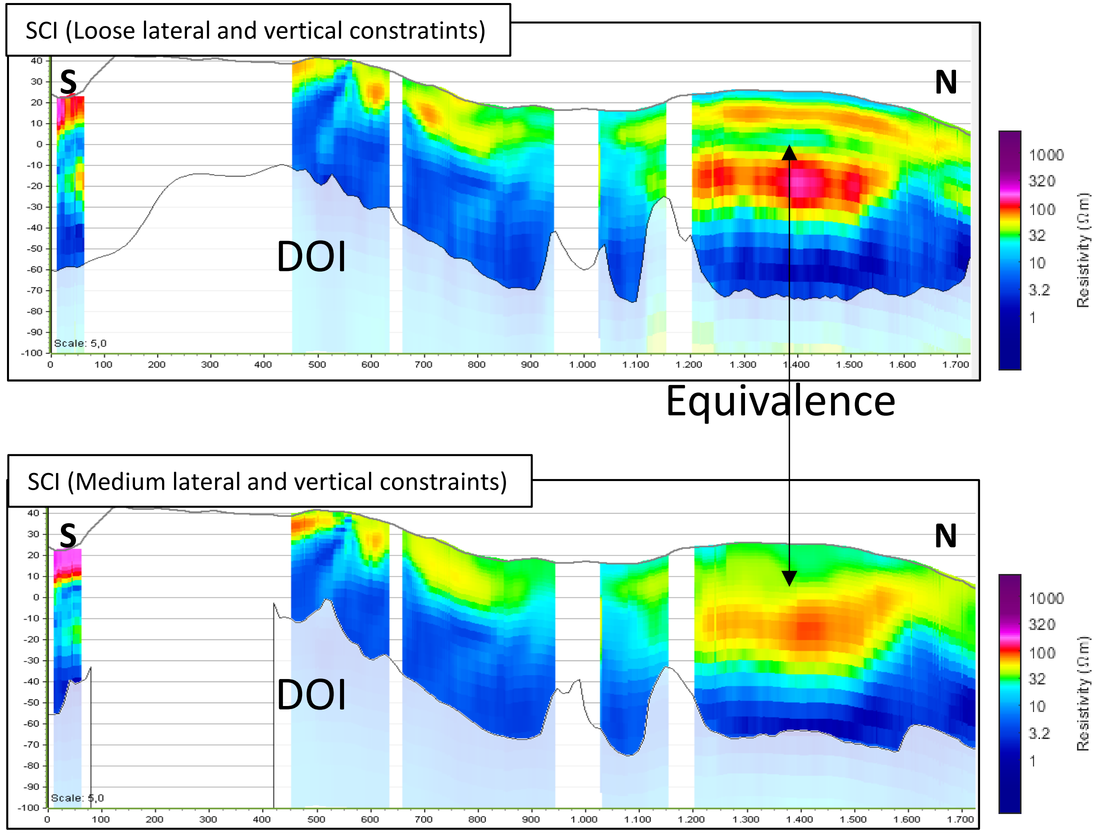
Kortlægningsmetode

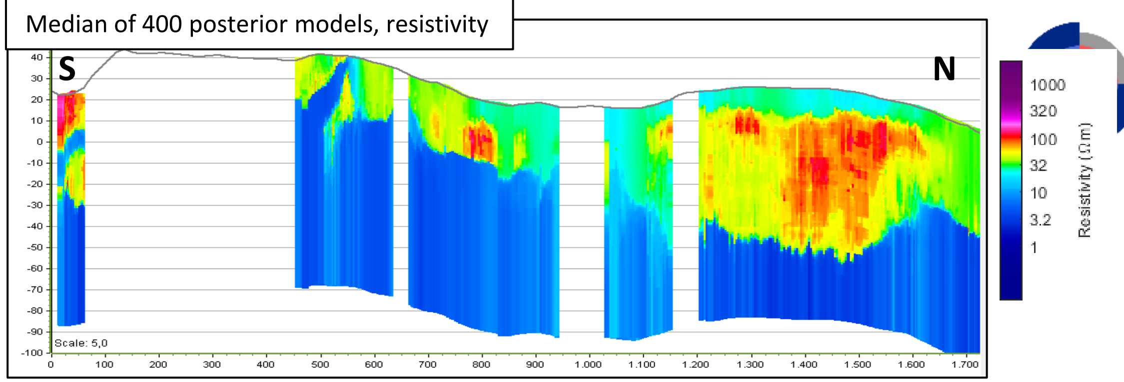


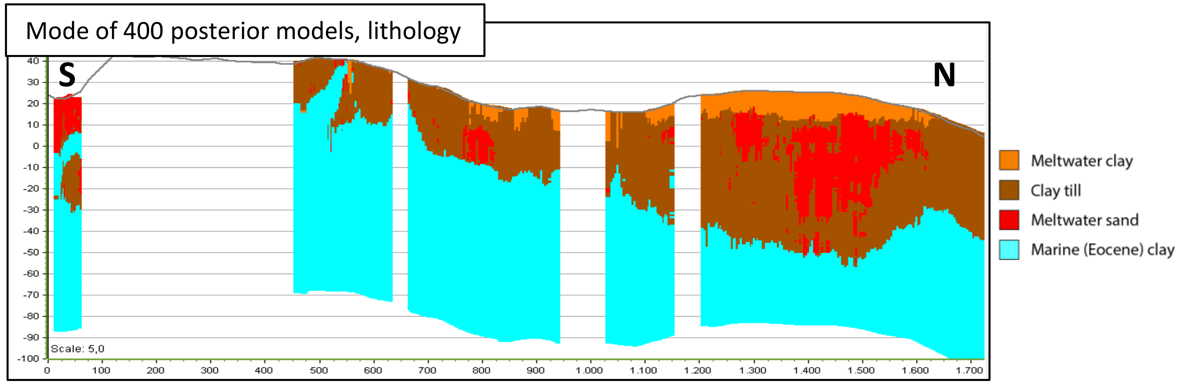
Metodesammenligning

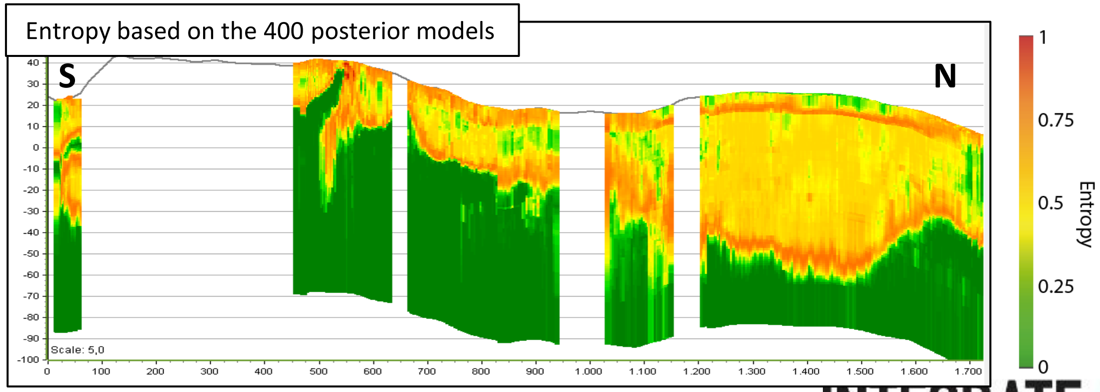
‘Traditionel’ deterministisk inversion med forskellige constraints:



Probabilistiske inversions resultater:



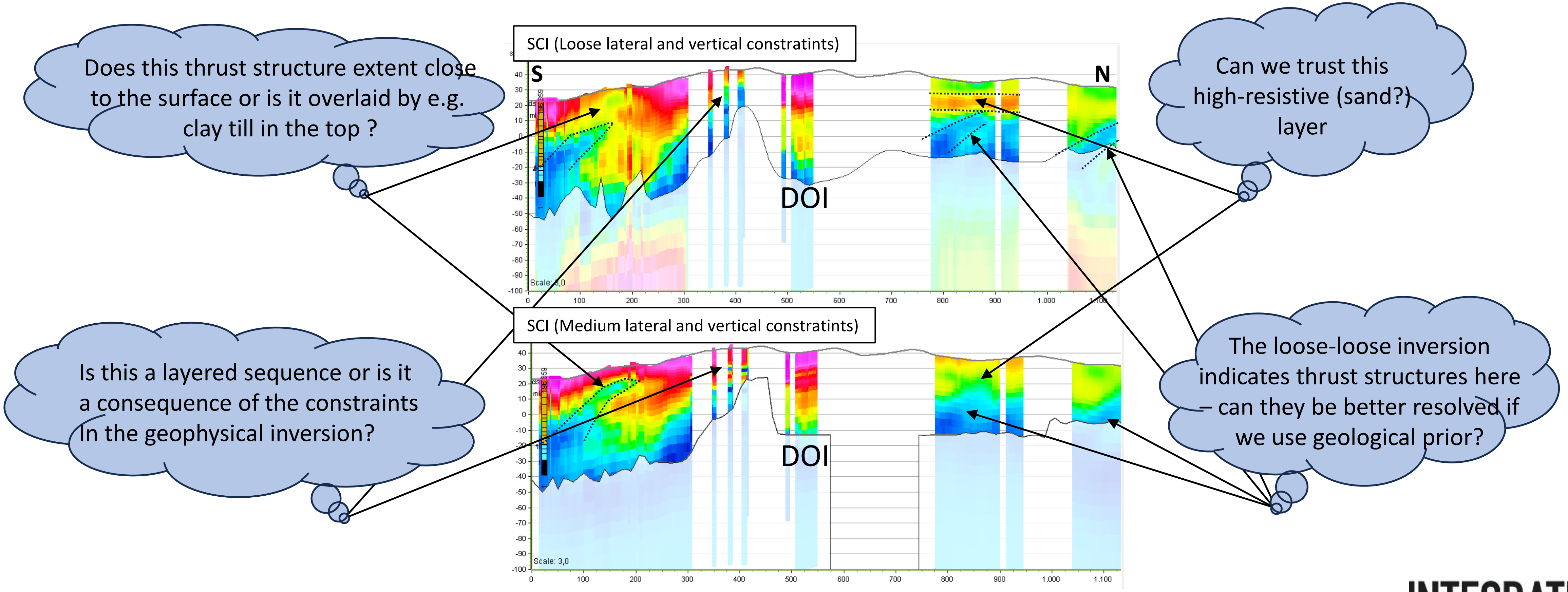




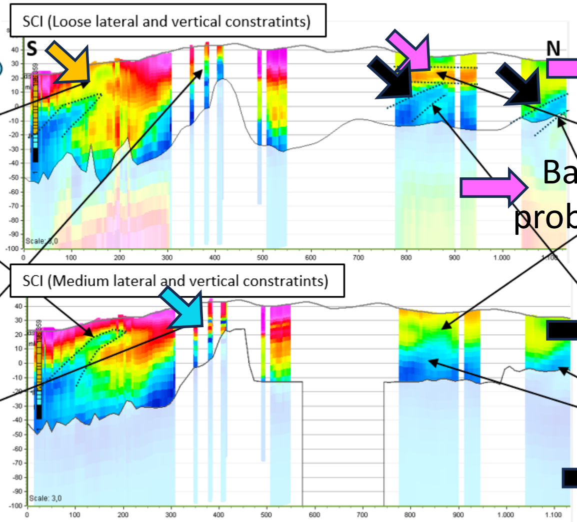
Uopklarede spørgsmål når man tolker resistivitetsmodeller

Når man tolker resistivitetsmodeller overvejer man ofte:

"Hvilke dele er data-drevne og hvilke dele er på grund af de valgte bånd?"



En mere fuldstændig forståelse kan opnås gennem de probabilistiske resultater



Does this thrust structure extent to the surface or is it overlaid by e.g. clay till in the top ?

Clay till is most probable here!

Is this a layered sequence or is it a consequence of the constraints In the geophysical inversion?

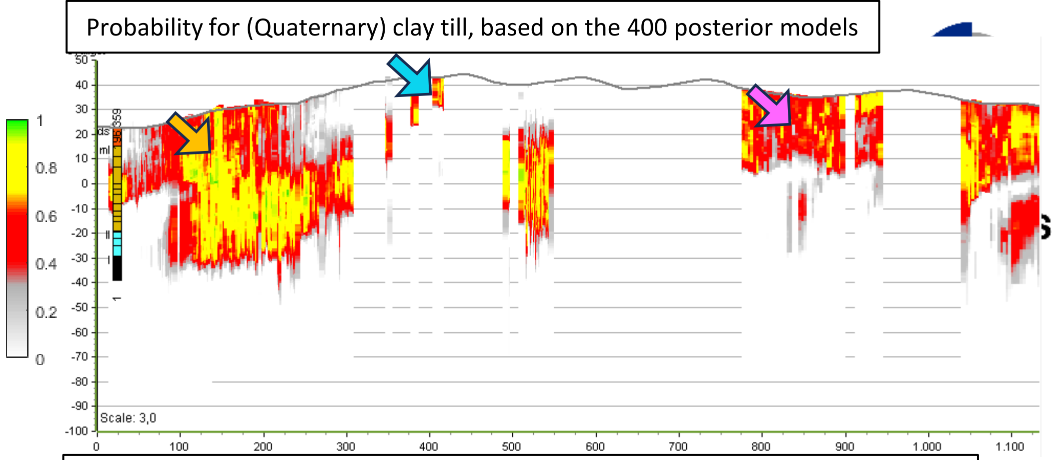
This cannot be ruled out

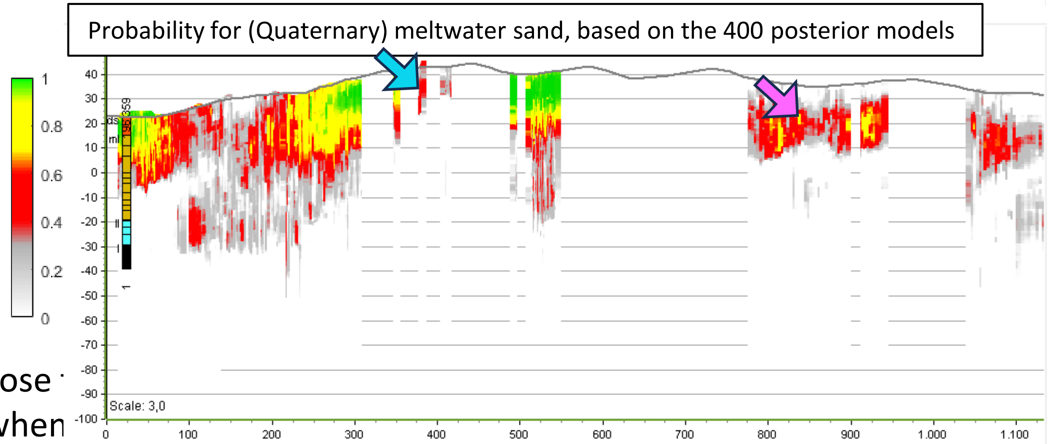
Can we trust this high-resistive (sand?) layer

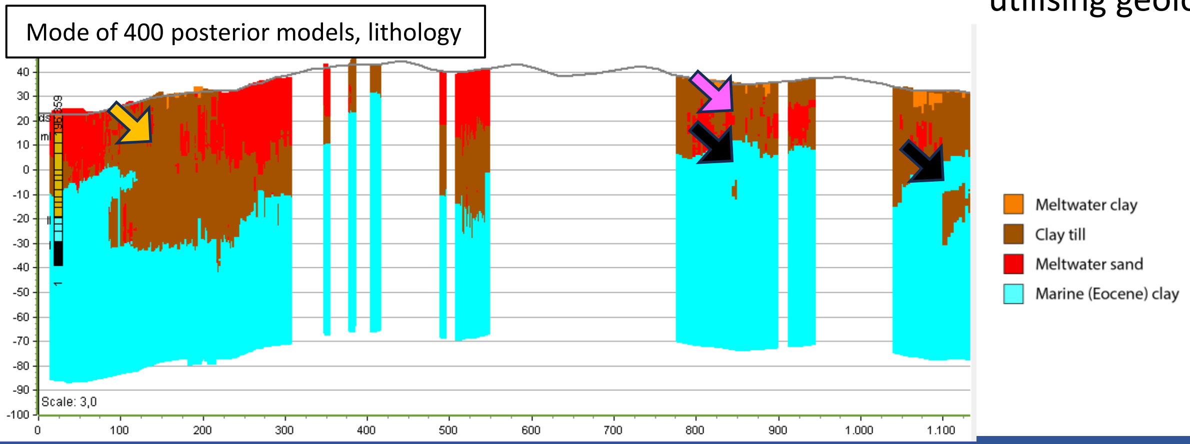
Based on 400 models, the probability is almost fifty-fifty

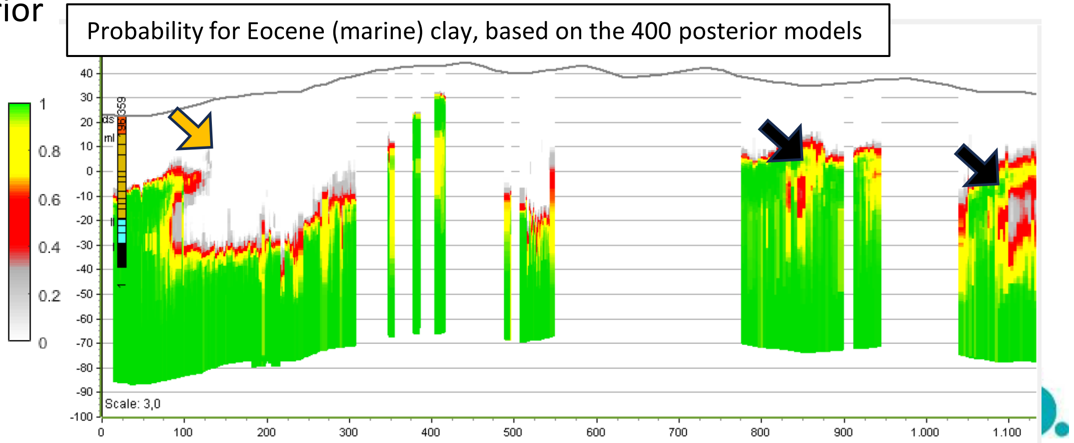
The loose-loose inversion indicates thrust structures here – can they be better resolved if we use geological prior?

The thrust structures close to the DOI are resolved when utilising geological prior

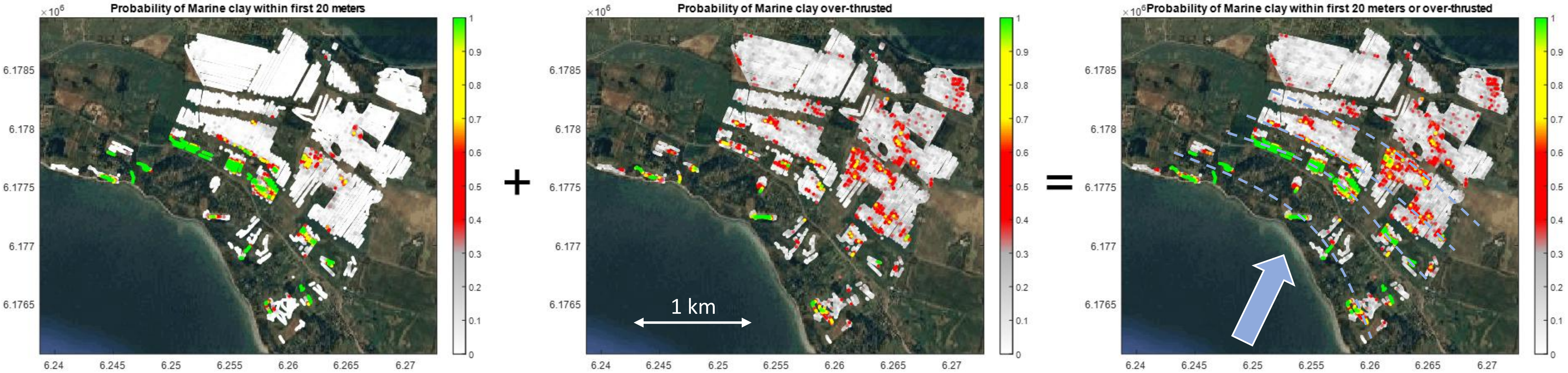


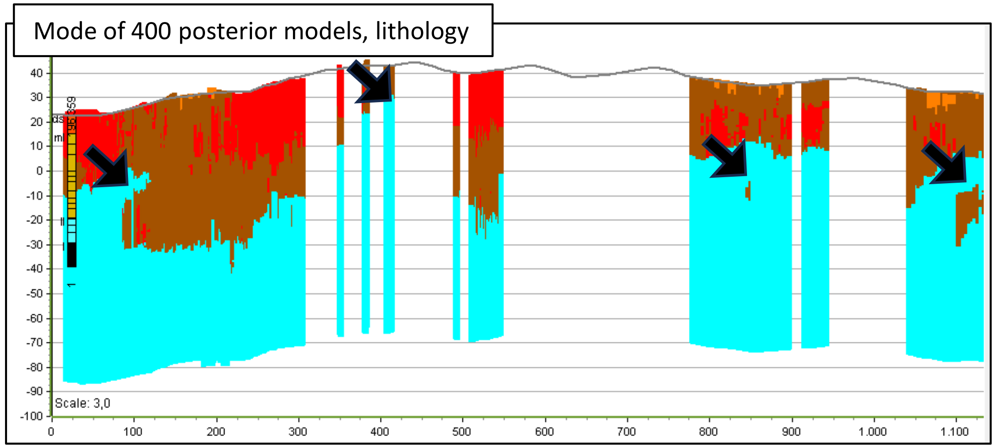


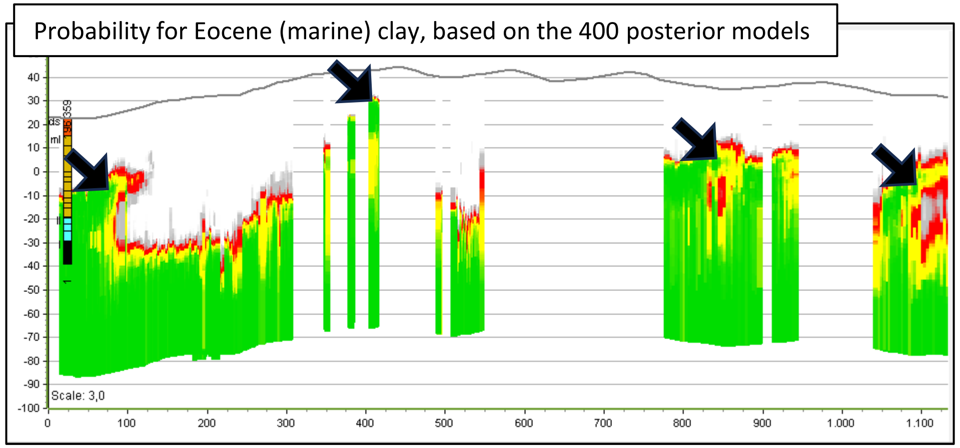




Kortlægning af overskydningszoner







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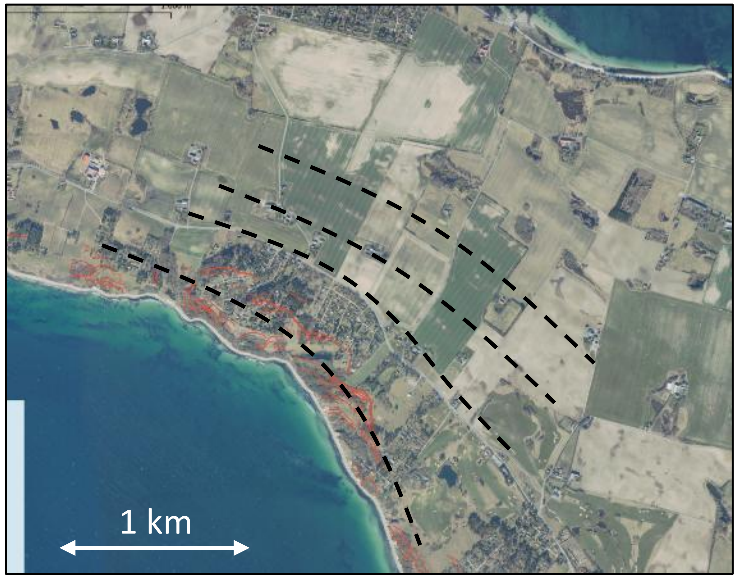
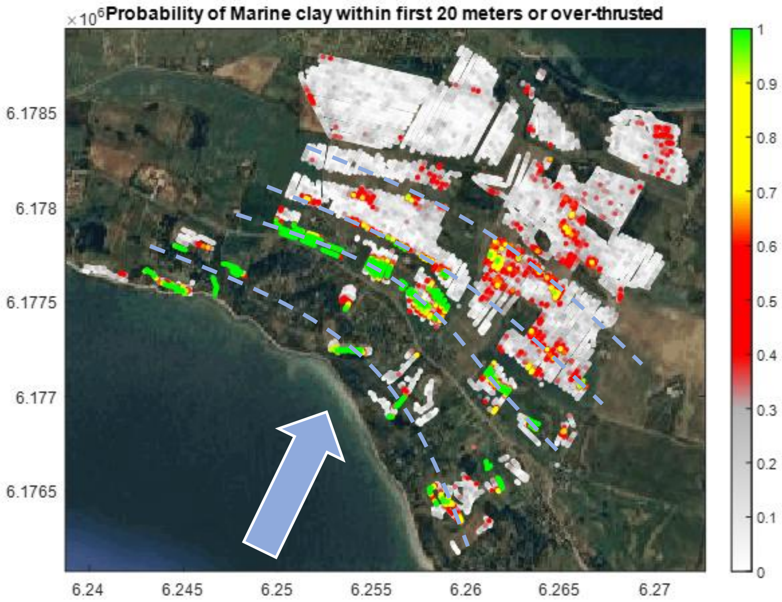
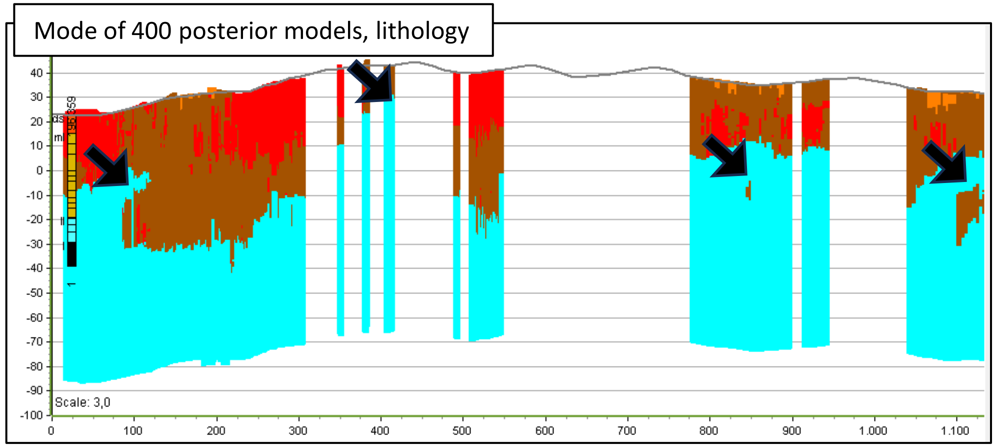
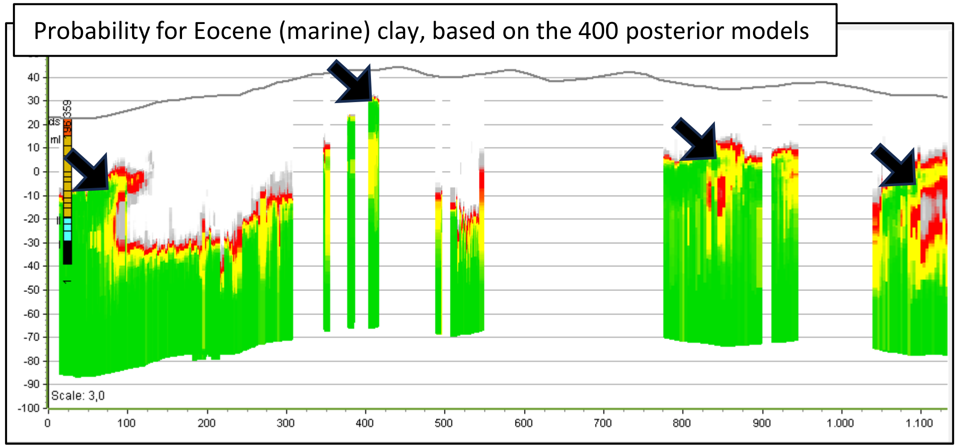
Kortlægning af overskydningszoner









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Kortlægning af kvikler i Sverige

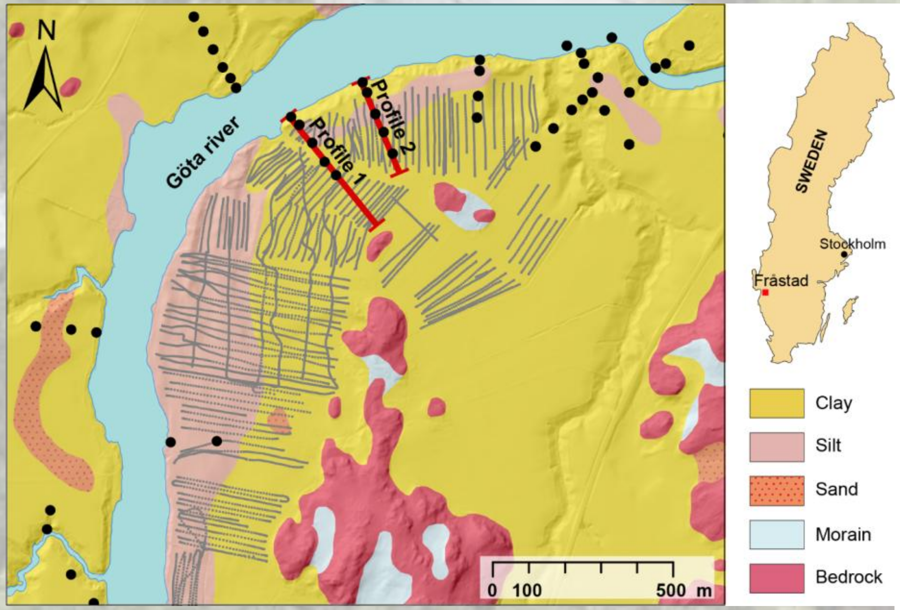
Figure 1. Photos from landslides in Sweden. (a) Landslide in Tuve, Gothenburg, Sweden on 30 November 1977. (b) Landslide in Småröd, Munkedal, December 2006.

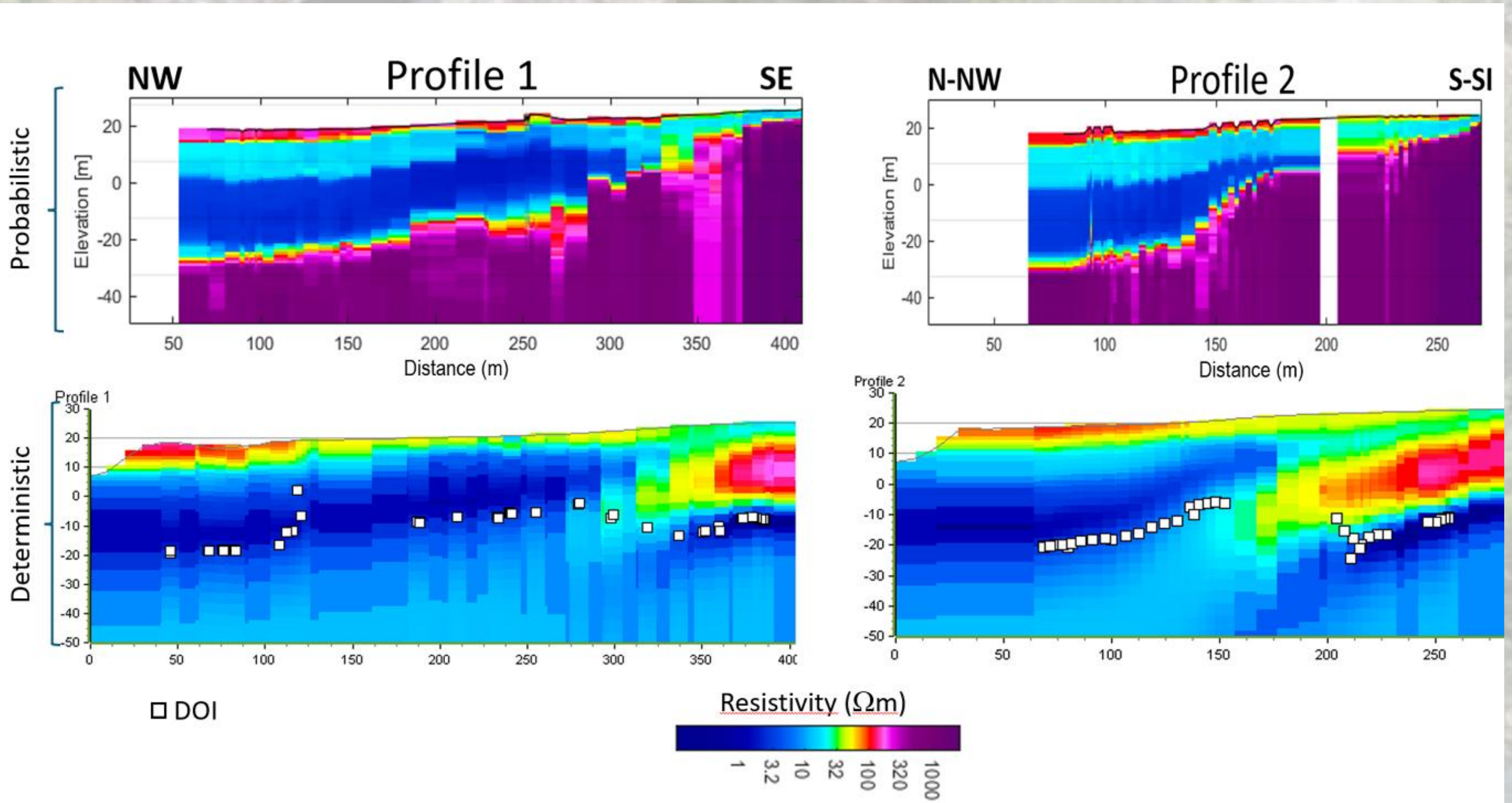
Kortlægning af kvikler i Sverige

Brugen af prior viden kan styre resistivitetsmodellerne i den rigtige retning.

Øverste: Probabilistisk inversion med priors

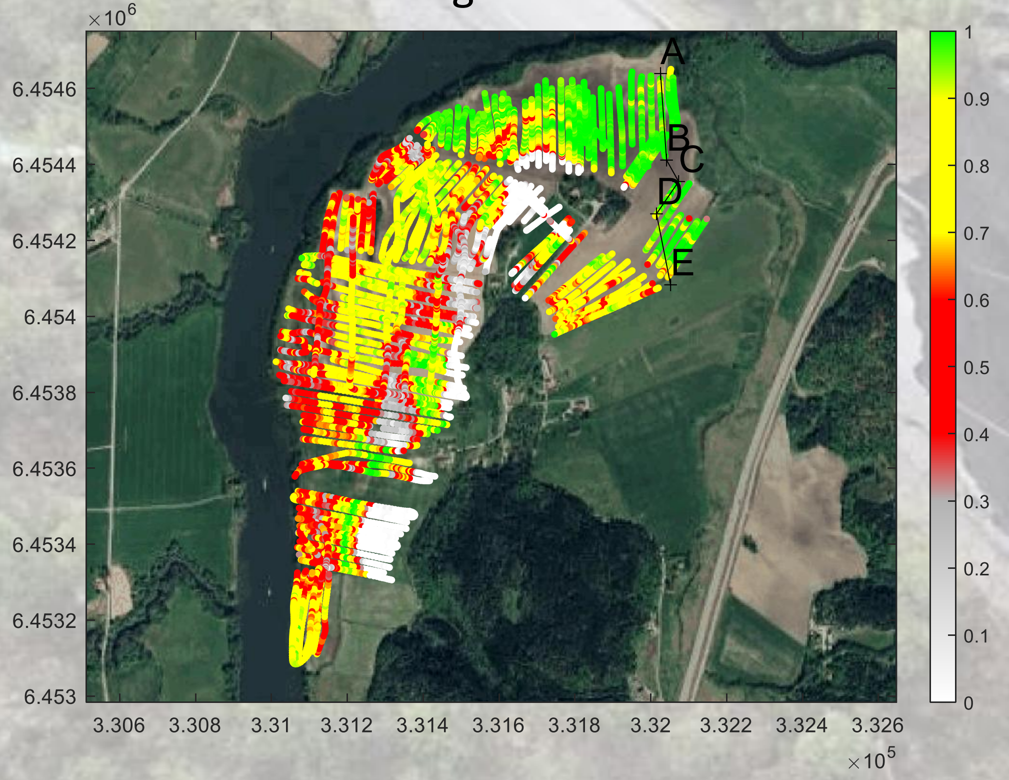
Nederst: Klassisk inversion med medium constraints

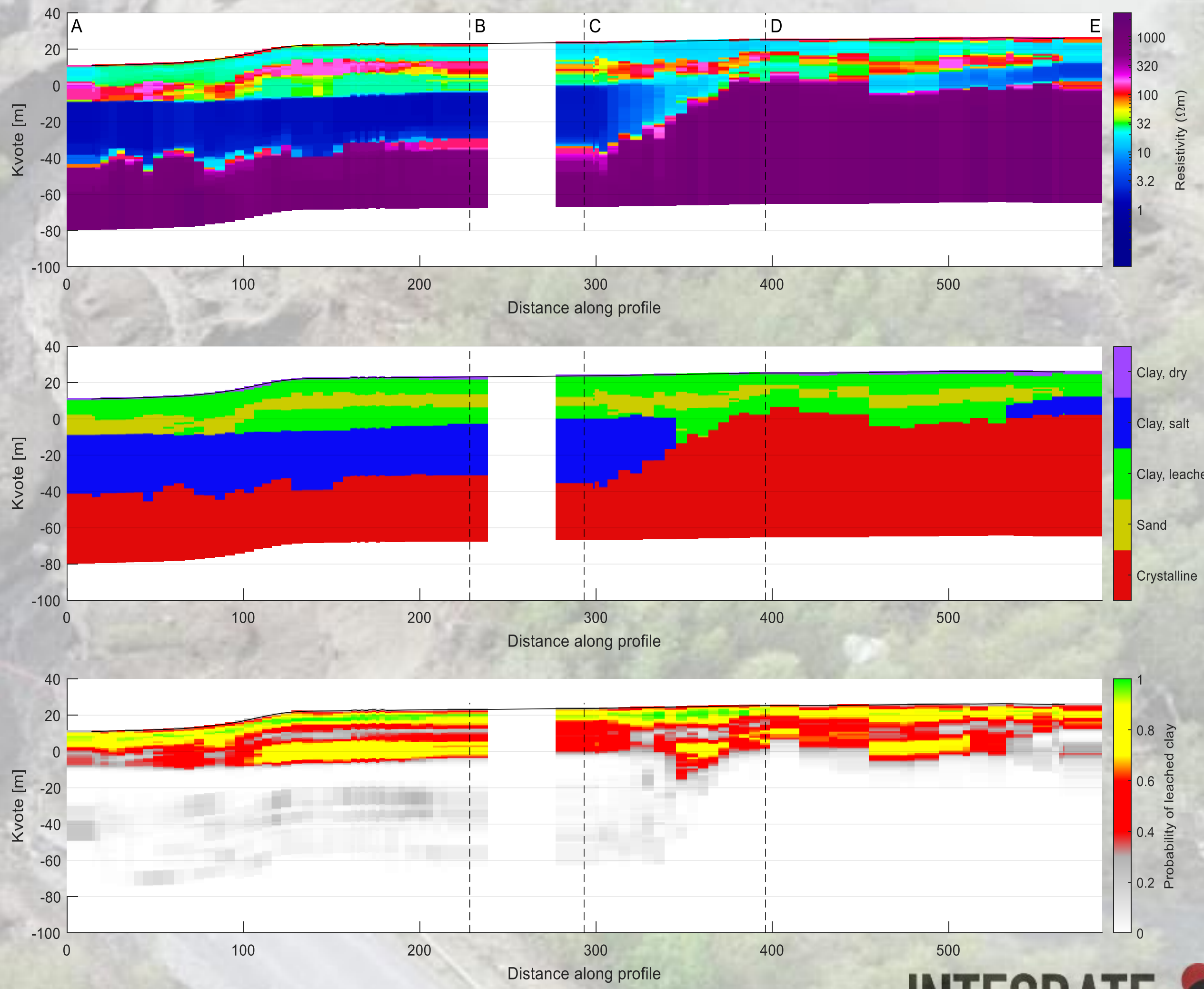




Kortlægning af kvikler i Sverige

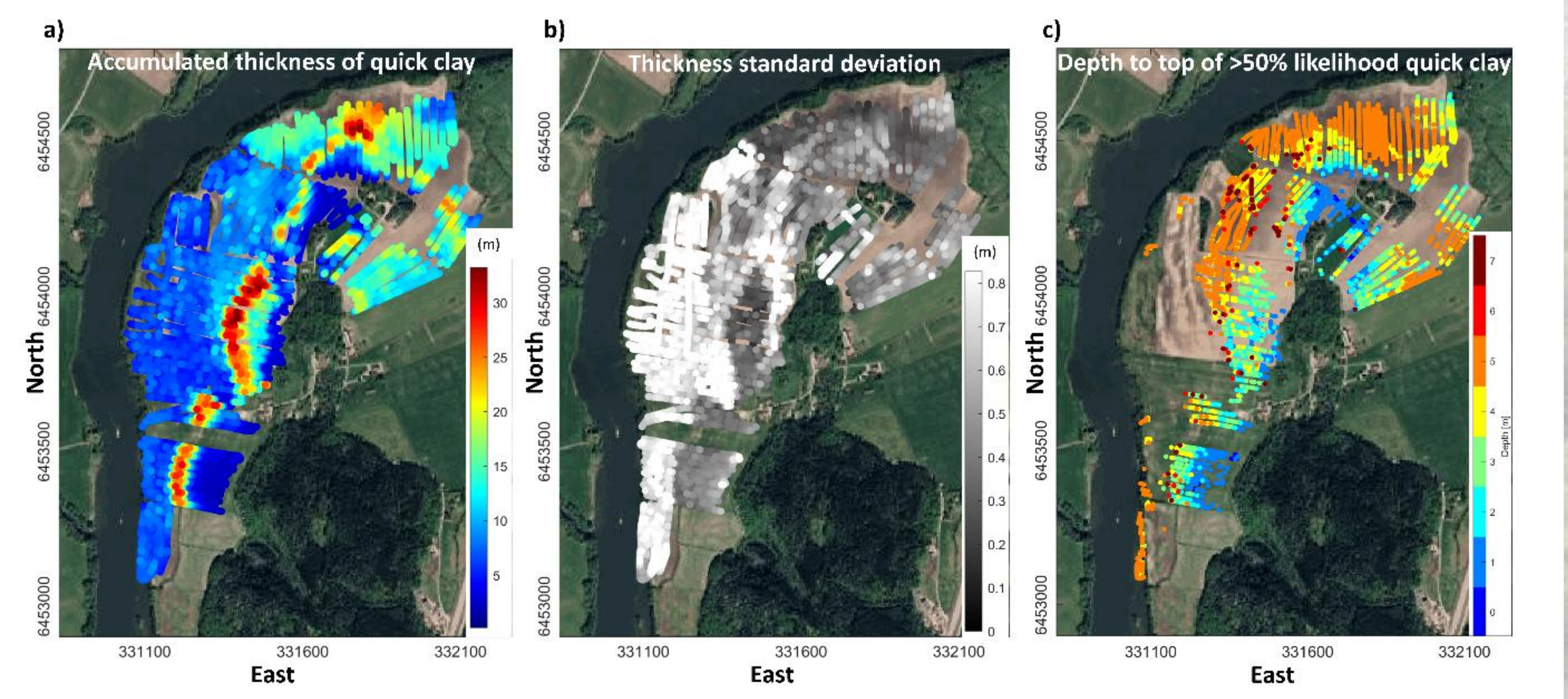
Sandsynlighed for at finde >5 m sammenhængende kvikler





Kortlægning af kvikler i Sverige

Andre eksempler på interessante udtræk i forbindelse med kvikler.



Hovedpointer:

- Forskellige geofysisk modeller kan fitte samme data (ækvivalenser).
- For at udregne den geofysiske og den geologiske usikkerhed arbejder vi med sværme af modeller.
- Ultimativt stærkere beslutningsgrundlag.

Perspektiver:

- Råstoffer
- Grundvand
- Forurening
- Geologisk kortlægning
- …

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For more information visit: http://integrate.nu/

Projekt understøttelse:

INTEGRATE: ”Informative mapping of construction aggregate recources through statistical data analysis”. Funding: Innovation Fund Denmark (2.8M EUR), 2023-2026, Grant #2081-00009B

Røsnæs data:

The Danish Landslide Project: Funding: Danish Research Reserve under the Ministry of Higher Education and Science, Denmark, 2025 (2.4M EUR)

Projektpartnere:

I•GIS AARHUS UNIVERSITY midt regionmidtjylland wsp Region Syddanmark sgu Sveriges geologiska undersökning

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