Den geotermisk ressource og modellering af langtidsudnyttelse

Niels Balling

Projekt-teamwork med

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Indhold

- Temperatur i undergrunden
- Den geotermiske ressource
- Modeller for energiudnyttelse

Temperatur

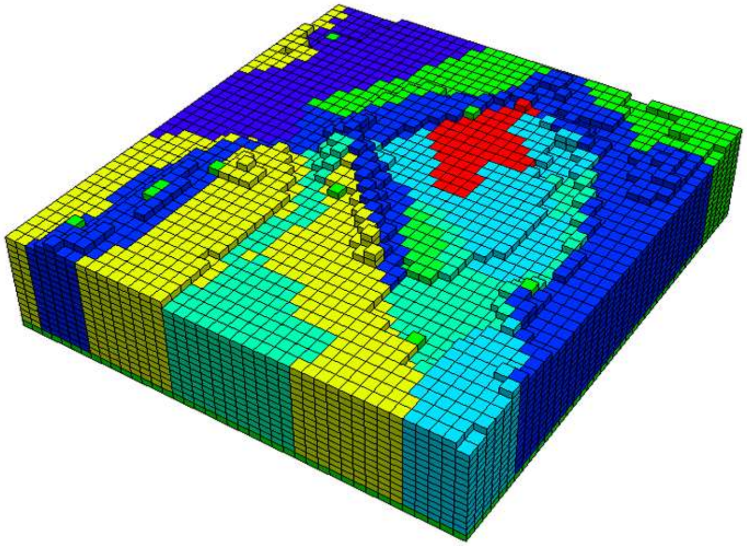
Varmeligningen

$$\frac{\partial}{\partial x}(k\frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(k\frac{\partial T}{\partial y})+\frac{\partial}{\partial z}(k\frac{\partial T}{\partial z})-\rho c\frac{\partial T}{\partial t}=-A$$

Temperatur

som numerisk
invers løsning i 3D grid

$$\mathrm{T(x,y,z=0)=T_s(x,y,t)}$$



$$k\frac{\partial T}{\partial z}(x,y,z=L)=Q_b(x,y)$$

Input information

- Målt temperatur i boringer
- Varmeledningsevne
- Varmeproduktion
- Varmestrøm
- Strukturel model fra GEUS

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Eksempler på modelresultater

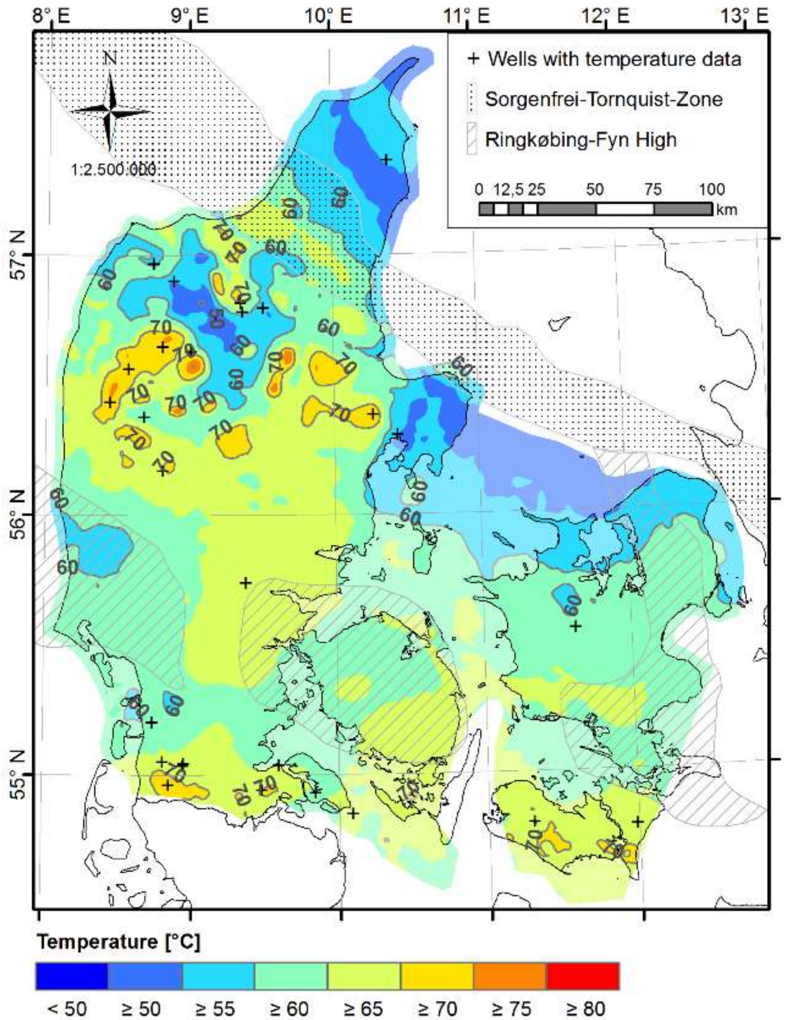
- Dybder 2000 og 3000 m

Geotermiske reservoirer:

- Gassum
- Bunter/Skagerrak

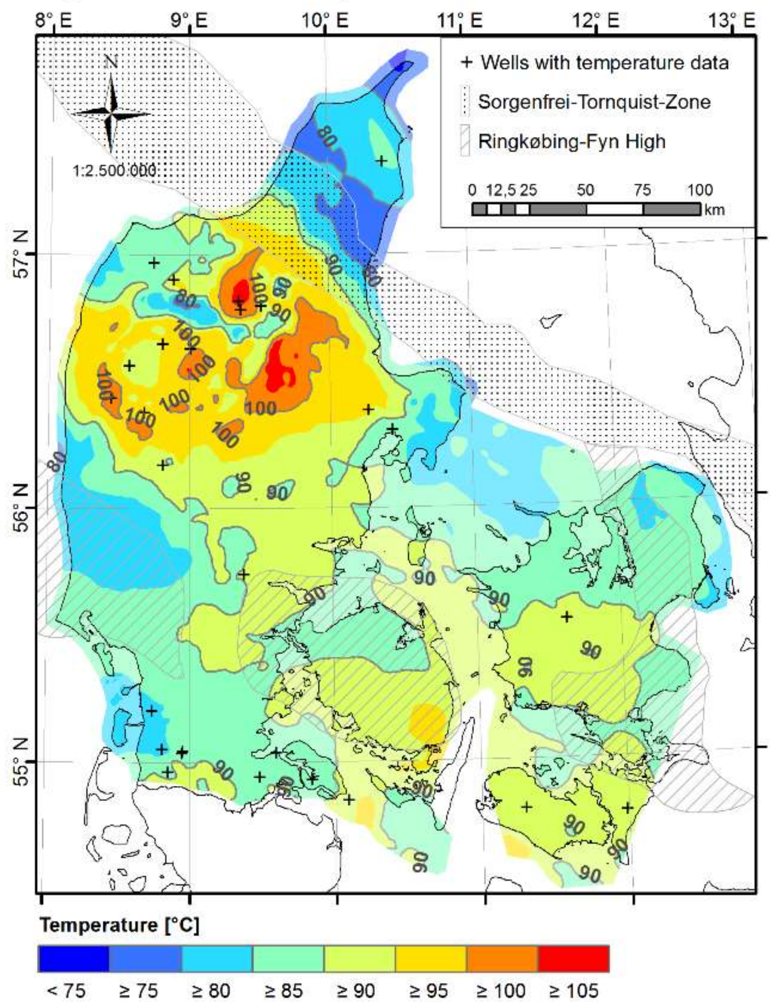
50 - 75°C

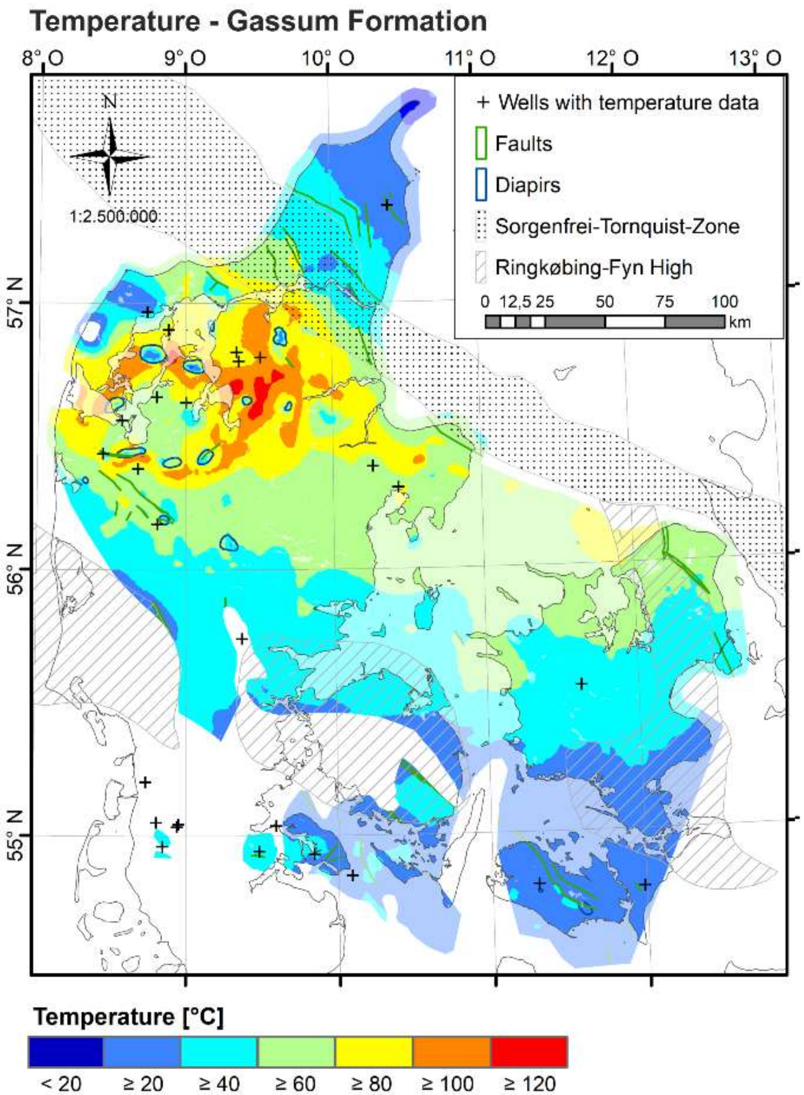
Temperature - 2000 m depth



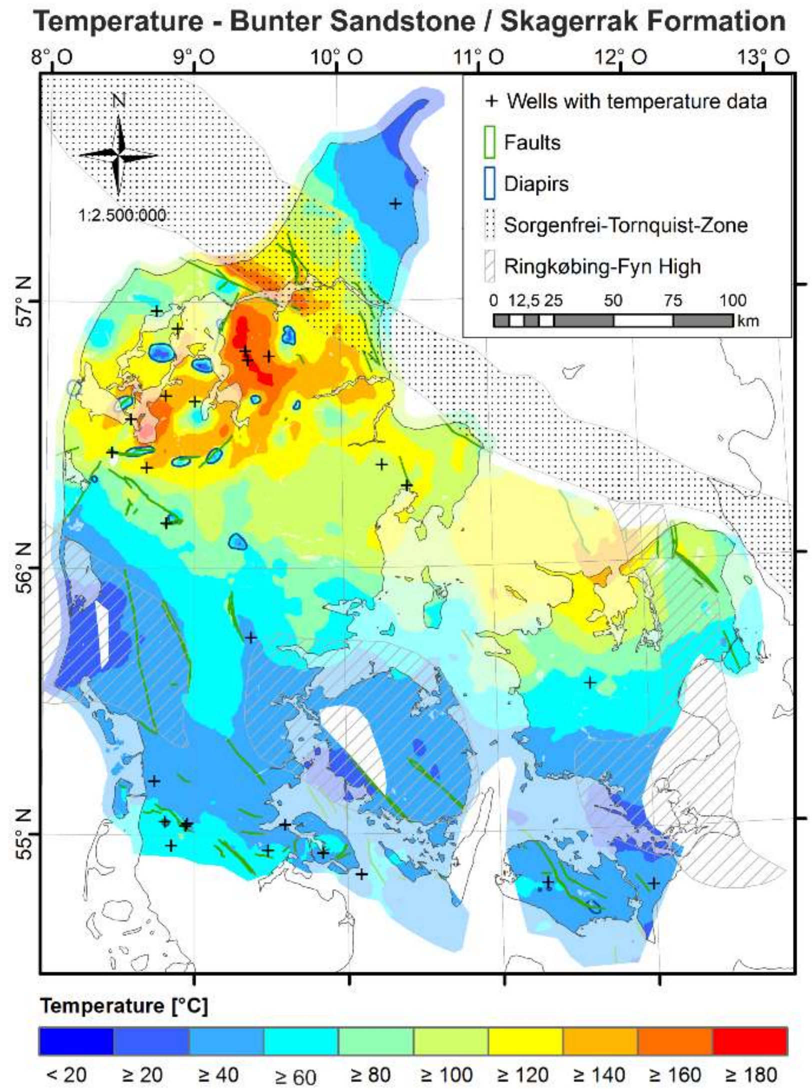
75 - 105°C

Temperature - 3000 m depth





Temperature - Gassum Formation
8° O
9° O
10° O
11° O
12° O
13° O
57° N
56° N
55° N
N
1:2.500.000
+ Wells with temperature data
Faults
Diapirs
Sorgenfrei-Tornquist-Zone
Ringkøbing-Fyn High
0 12,5 25 50 75 100 km
Temperature [°C]
< 20
≥ 20
≥ 40
≥ 60
≥ 80
≥ 100
≥ 120



Temperature - Bunter Sandstone / Skagerrak Formation
8° O
9° O
10° O
11° O
12° O
13° O
57° N
56° N
55° N
N
1:2.500.000
+ Wells with temperature data
Faults
Diapirs
Sorgenfrei-Tornquist-Zone
Ringkøbing-Fyn High
0 12,5 25 50 75 100 km
Temperature [°C]
< 20
≥ 20
≥ 40
≥ 60
≥ 80
≥ 100
≥ 120
≥ 140
≥ 160
≥ 180

Den geotermiske ressource

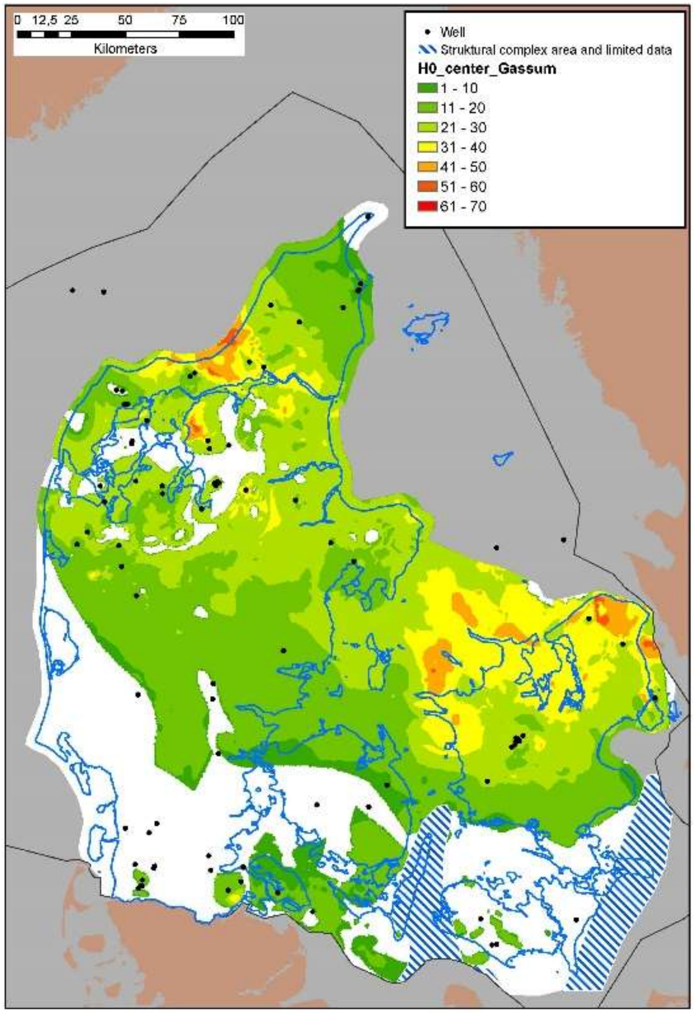
Varmeenergi = masse x varmefylde x temperaturforskel

Beregning af

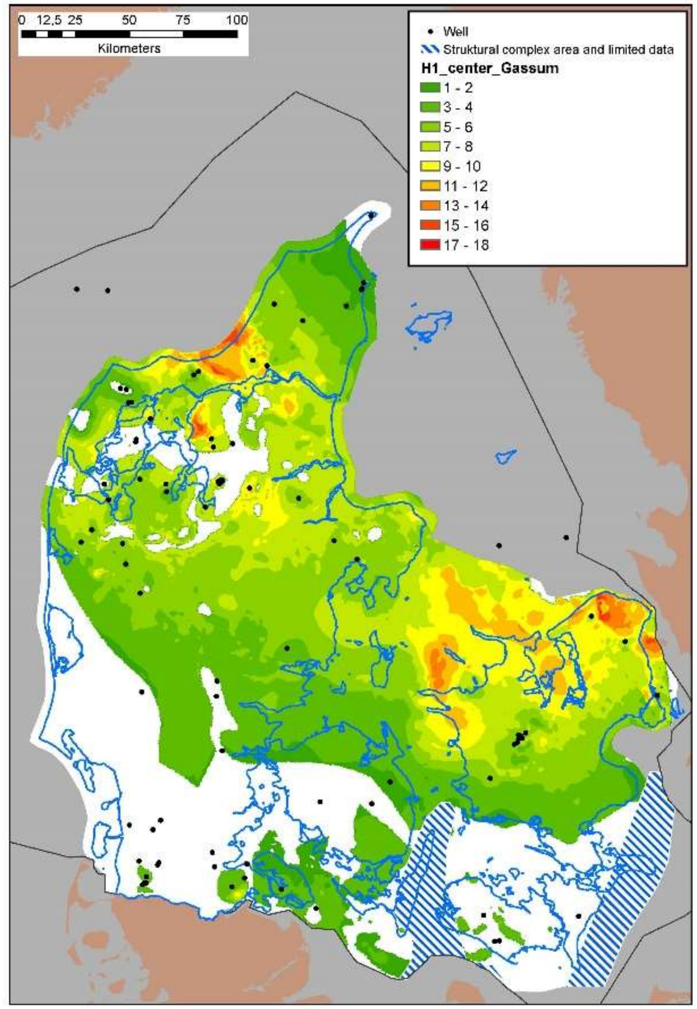
- 'Heat in place'
- 'Usable heat'/udnyttelig energi'

Gassum reservoir som eksempel

Heat in Place – ca. 10-40 GJ/m²



Usable heat - ca. 3-12 GJ/m²



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Nogle få tal

Udnyttelig energi - individuelle reservoirer

Typisk 4–10 GJ/m^2 - op til 20 GJ/m^2

1 GJ/m^2 = 1 PJ/km^2 eller

ca. 24.000 ton olieækvivalent/km^2 (toe/km^2)

Udnyttelig varmeenergi

svarende til 100.000–250.000 toe/km^2

Modeller for udnyttelse

Numerisk reservoirsimulering

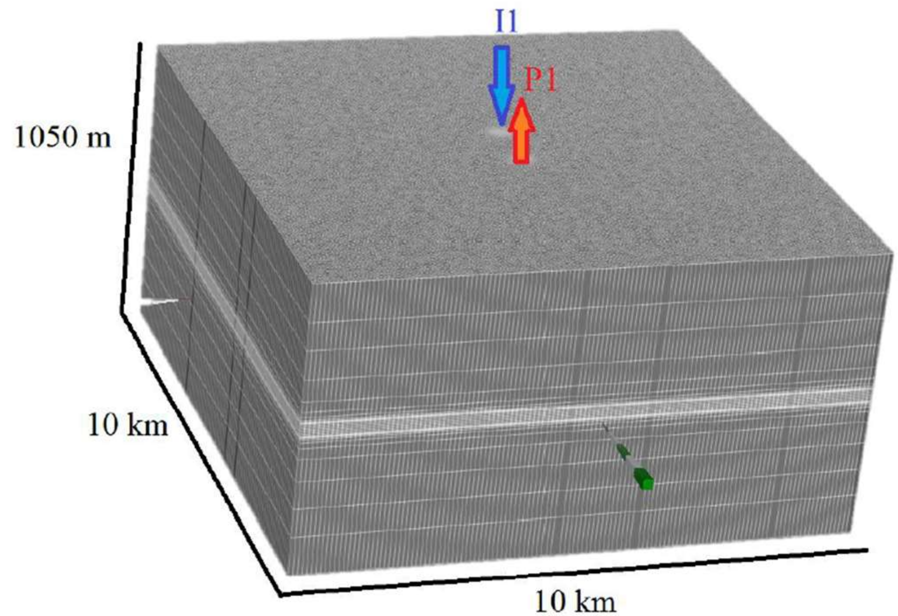
- Konceptuelle modeller
- Danske anlæg - Thisted

Numerisk reservoirsimulering

- **Parametrisering** af undergrunden
- Numerisk løsning af koblede ligninger for varme- og vandstrøm
- Givne flow-rater

- Software: FEFLOW

To boringer- produktion og injektion

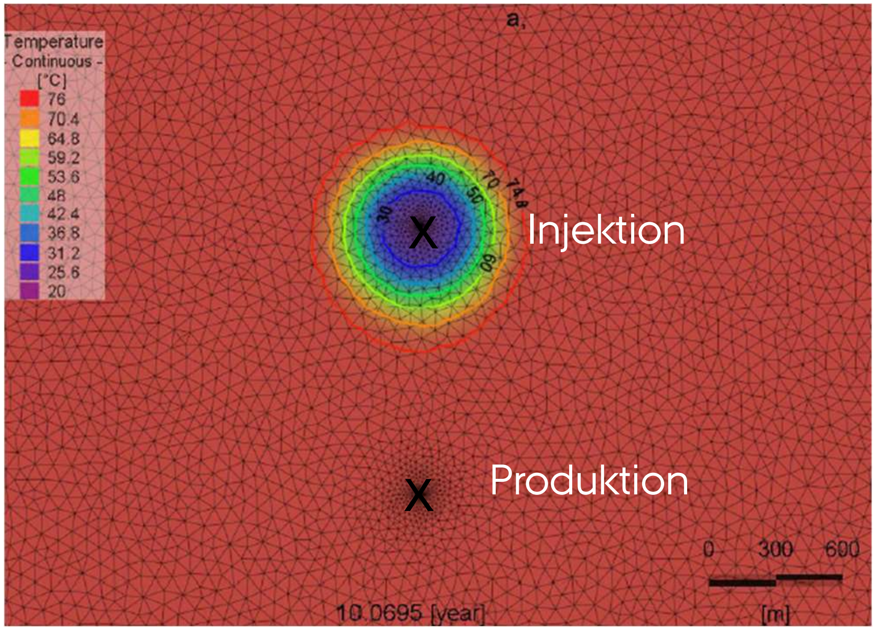


Basismodel

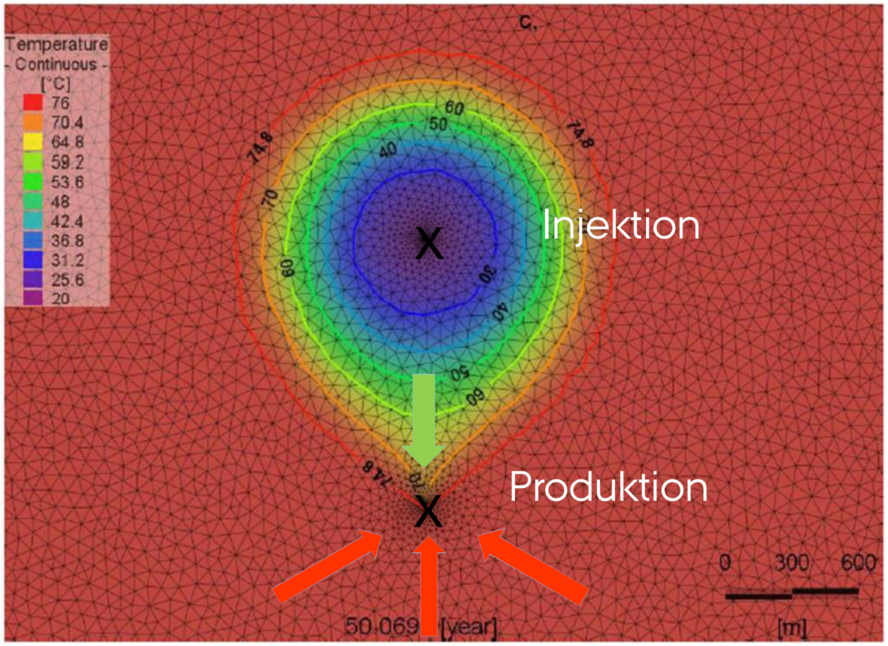
- To boringer- afstand: 1200 m
- Produktionsrate: 150 m^3/time
- Reservoirtemperatur: 75 °C
- Reservoirtykkelse: 50 m
- Injektionstemperatur: 20 °C

Temperatur i midt reservoir

Efter 10 år



Efter 50 år



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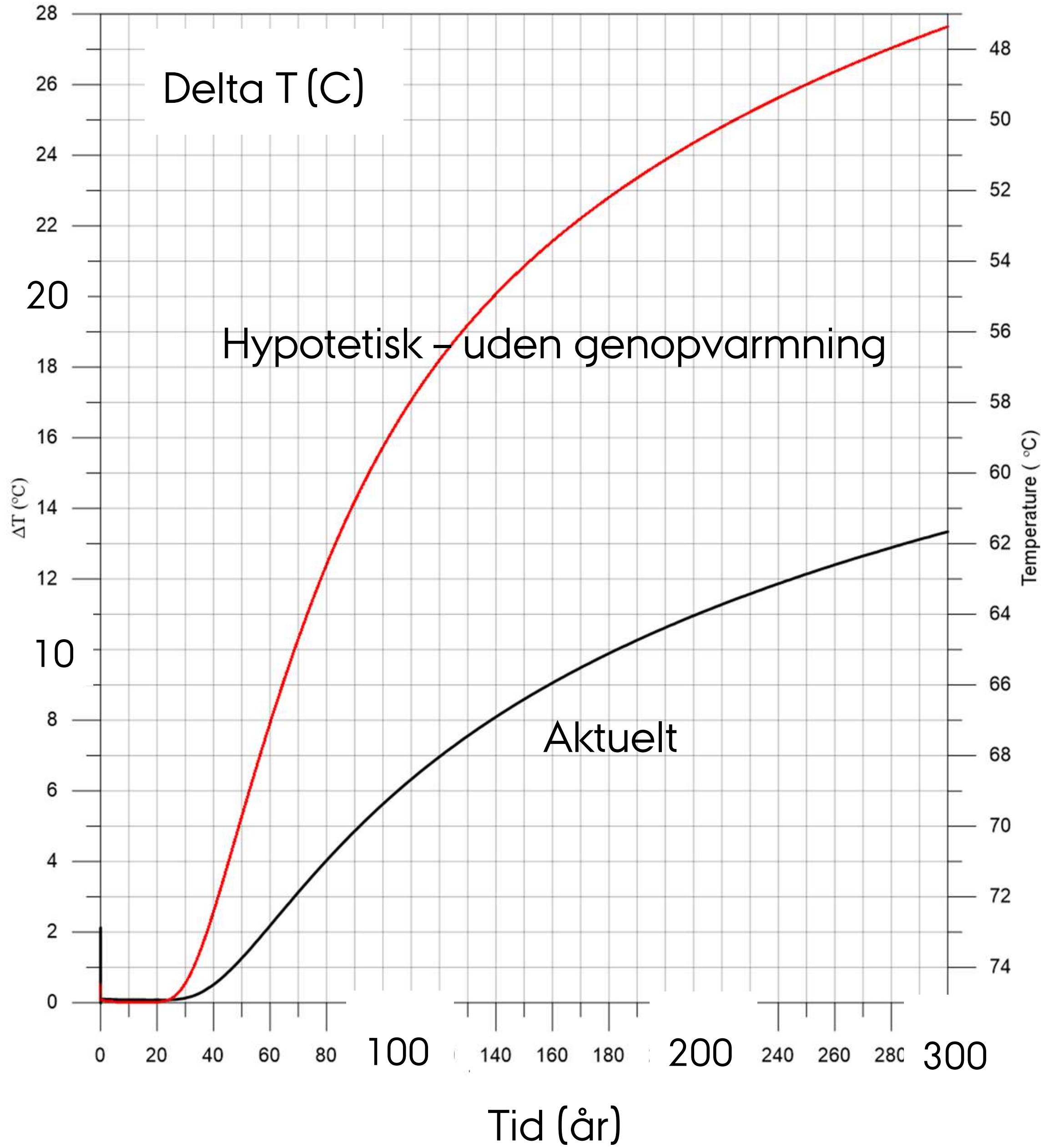
Temperaturudvikling

Produktion

Temperaturfald

ca. 5 -10 °C

efter 100-200 år



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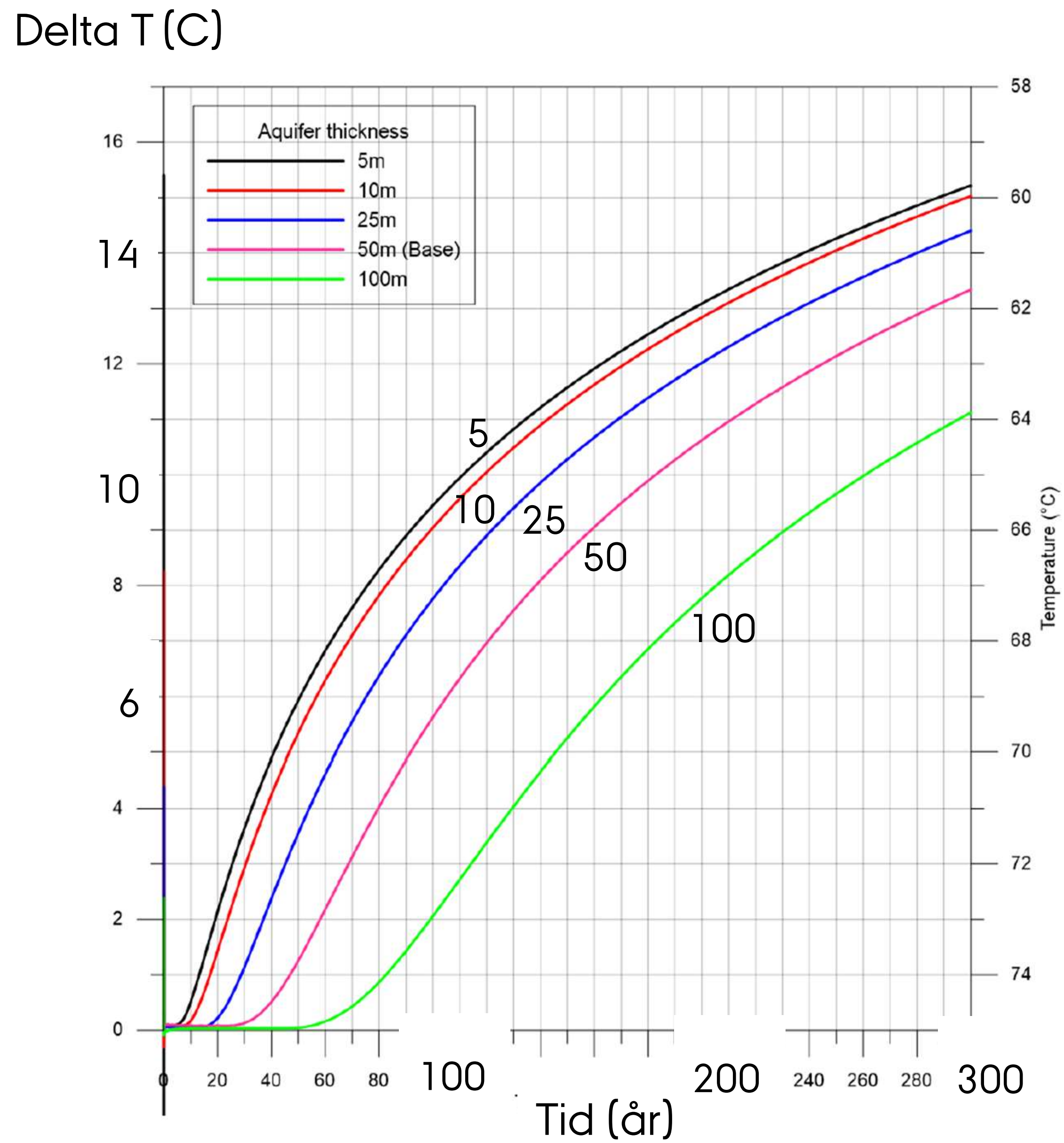
Temperaturudvikling

Variabel reservoirtykkelse

- 5–100 m

Begrænset temperaturfald
også ved
små reservoirtykkelser



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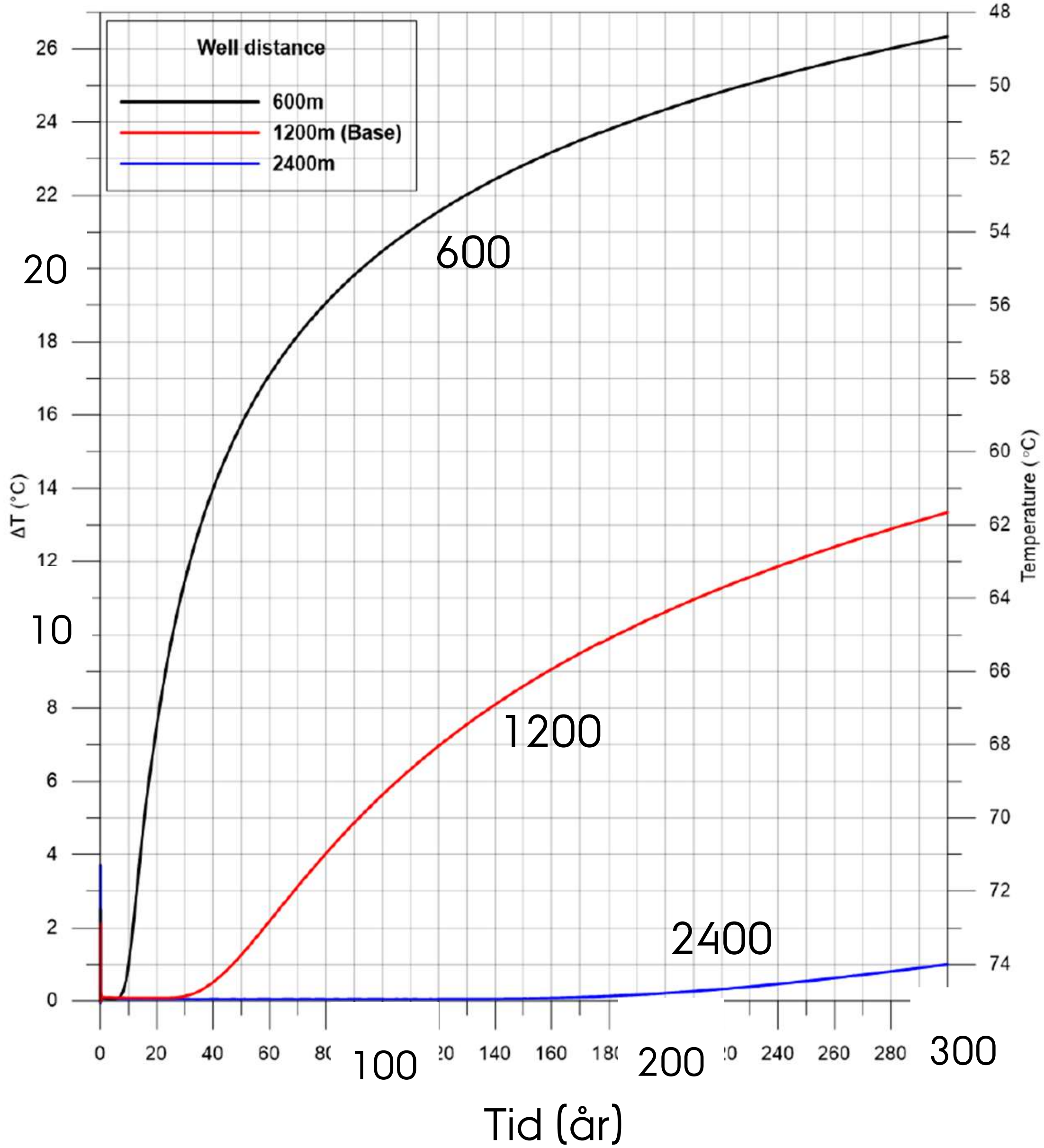
Temperaturudvikling

Variabel afstand mellem boringer

- 600 m
- 1200 m
- 2400 m

Signifikant effekt af afstand



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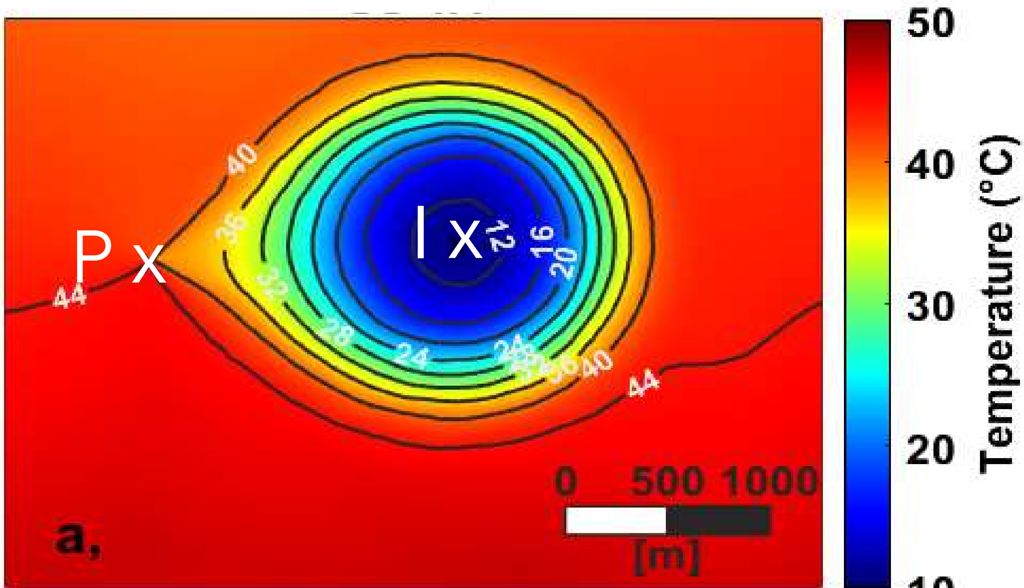
Modellering af danske anlæg

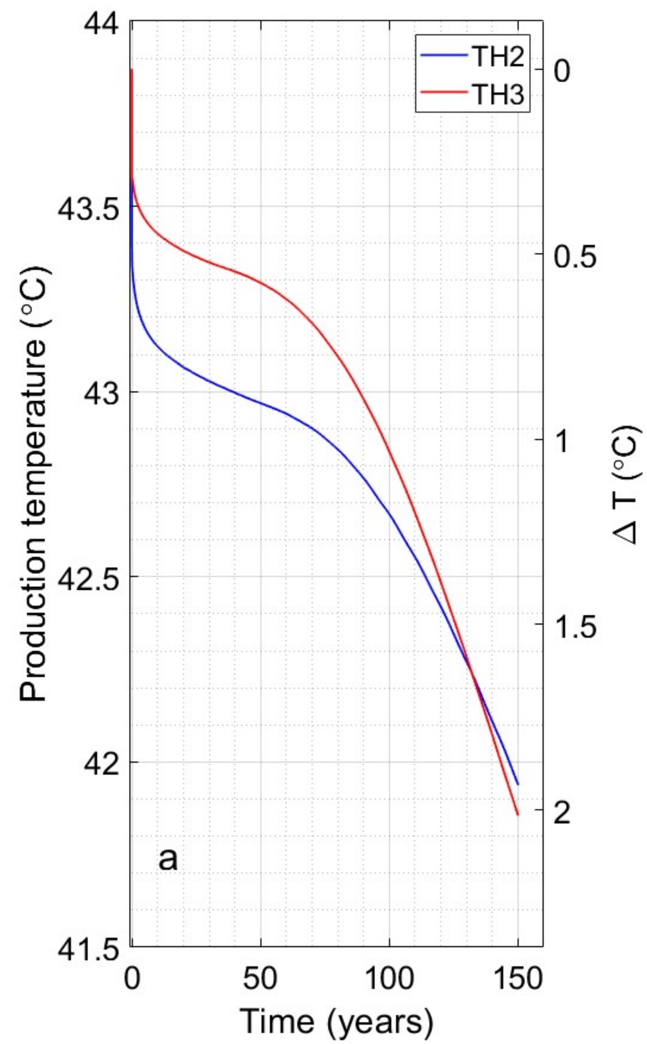
Eksempel Thisted

Thisted

Homogent reservoir
Tænkt konstant 150 m^3/time
i 150 år

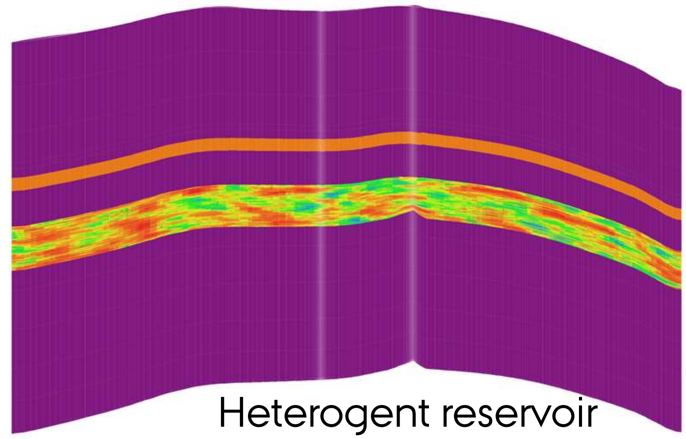


Produktionstemp.



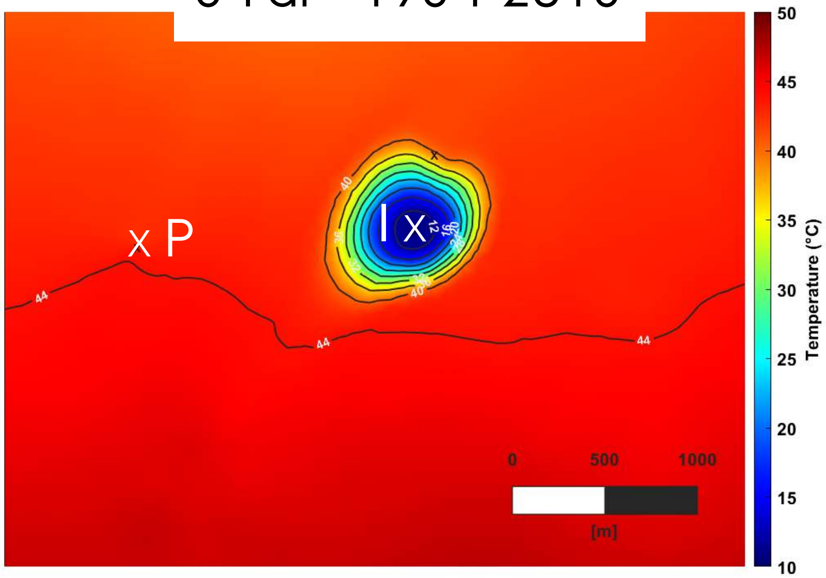
TH2 TH3

Gassum



Heterogent reservoir

34 år - 1984-2018



Historiske data

Heterogent reservoir

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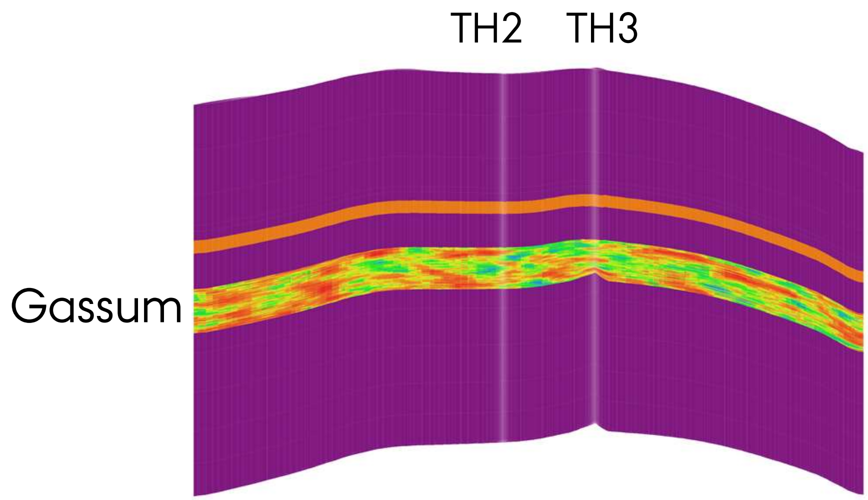
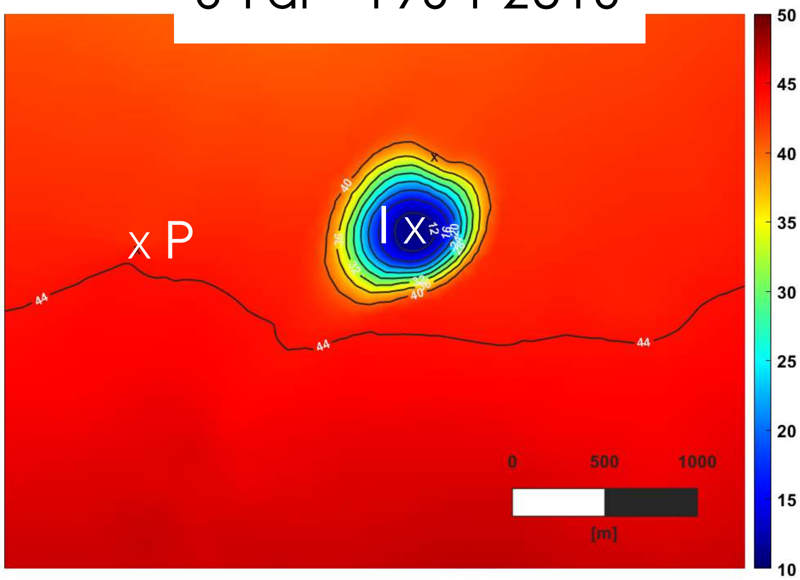
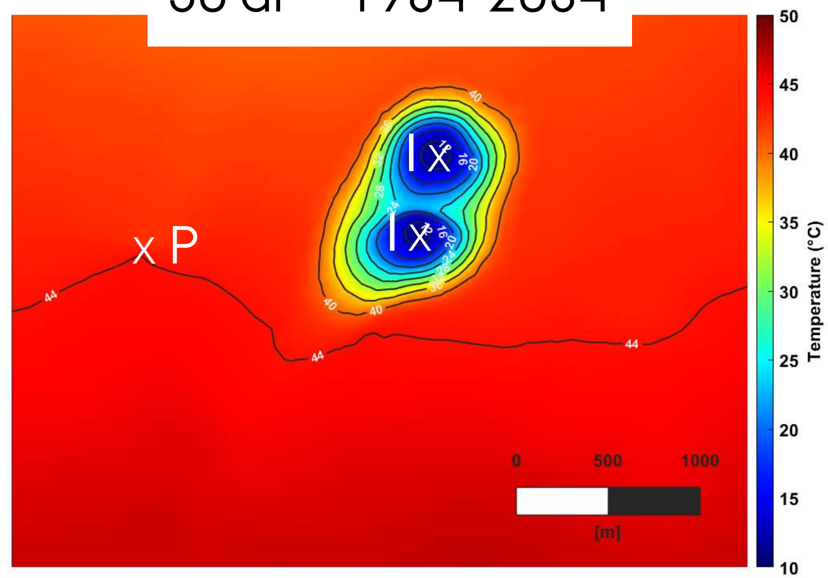


34 år - 1984-2018



50 år - 1984-2034



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Kort 'take home'

- Vi har et godt kendskab til temperatur i undergrunden
- Der findes enorme mængder tilgængelig bæredygtig varmeenergi i den danske undergrund
- Reservoirer har meget lang termisk levetid ved produktion

Nogle publikationer

- Balling, N., Major, M., Fuchs, S., Mathiesen, A., Nielsen, C.M., Hansen, T.M., Kristensen, L. and Förster, A., 2019. Geothermal reservoirs in the Danish area: temperatures, resources and models for long-term energy extraction. Scientific report, *Department of Geoscience, Aarhus University, 70 pp/https://dybgeotermi.geus.dk/wp-content/uploads/Final-report-M4.6_WP4.pdf*
- *Fuc*hs, S, Balling, N and Mathiesen, A., 2020. Deep basin temperature and heat-flow field in Denmark – new insights from borehole analysis and 3D geothermal modelling. *Geothermics, 83, 101722.*
- Major, M., Poulsen, S.E. and Balling, N., 2018. A numerical investigation of combined heat storage and extraction in deep geothermal reservoirs. *Geothermal Energy, 6:1, doi.org/10.1186/s40517-018-0089-0.*
- Poulsen, S.E., Balling, N. and Nielsen, S.B., 2015. A parametric study of the thermal recharge of low enthalpy geothermal reservoirs. *Geothermics, 53, 464-478.*

Tak for opmærksomhed