

## Autogenerering af hydrostratigrafiske modeller fra boreriger og SkyTEM

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# Autogenerering af hydrostratigrafiske modeller fra boringer og SkyTEM

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HydroGeophysics Group  
AARHUS UNIVERSITY



Niels Bohr Institutet



GEUS

**DTU Environment**

Department of Environmental Engineering

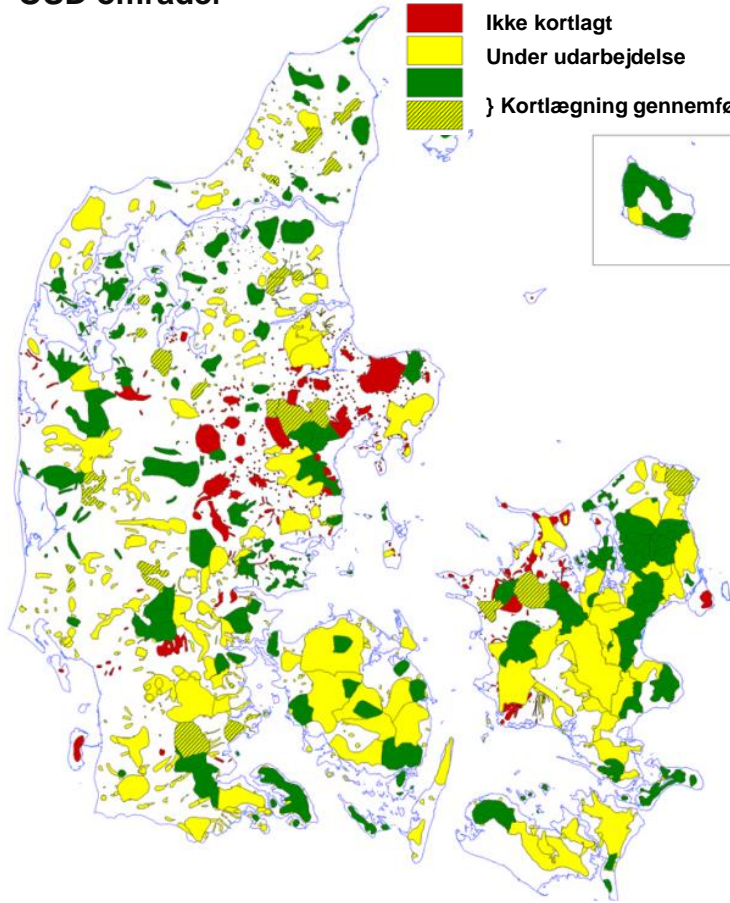


# EM data og grundvandsmodeller

OSD områder

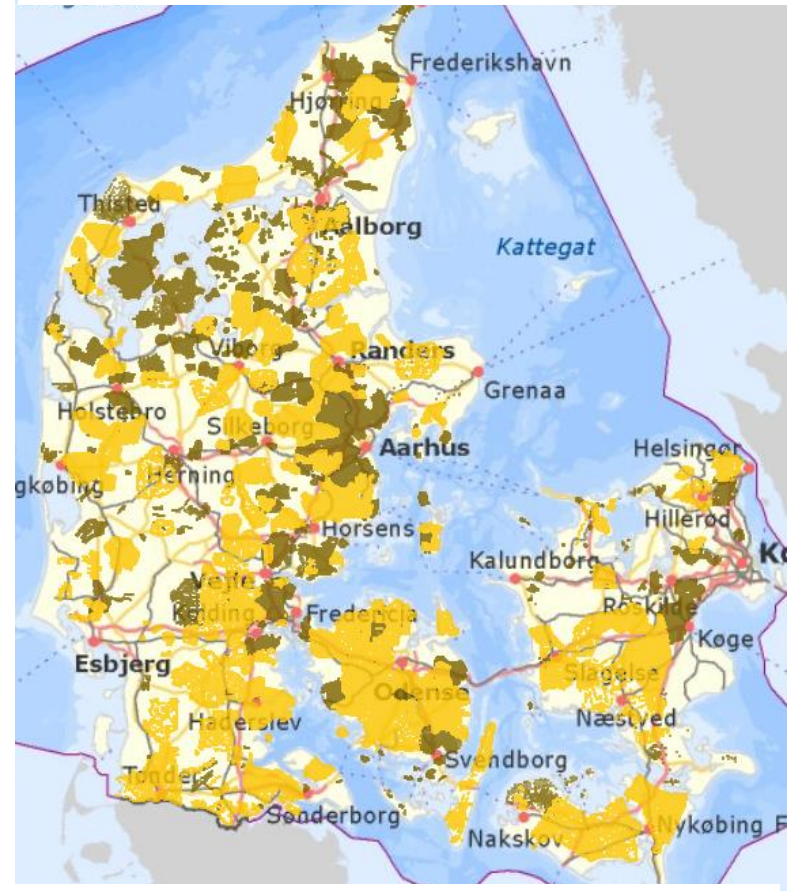
2011 status

- Ikke kortlagt
- Under udarbejdelse
- } Kortlægning gennemført



<http://gk.geus.info/xpdf/20110624-faglige-resultater-2010-med-omslag-enderlig.pdf>

TEM og SkyTEM sonderinger, GERDA 04 November 2014



Brun er TEM, gul er SkyTEM

# Motivation

- **Forvaltning af grundvandsressourcer**
  - Grundvandsudnyttelse
  - Forurening
  - Indvindingsoplande
- **Strukturel geologisk usikkerhed** er den dominerende usikkerhedskilde i grundvandsmodellering
- **Prædiktioner** fra grundvandsmodeller er følsomme overfor ændringer i den hydrostratigrafiske model
- Grundvandsmodeller er **non-unique'e** i forhold til hydrostratigrafien



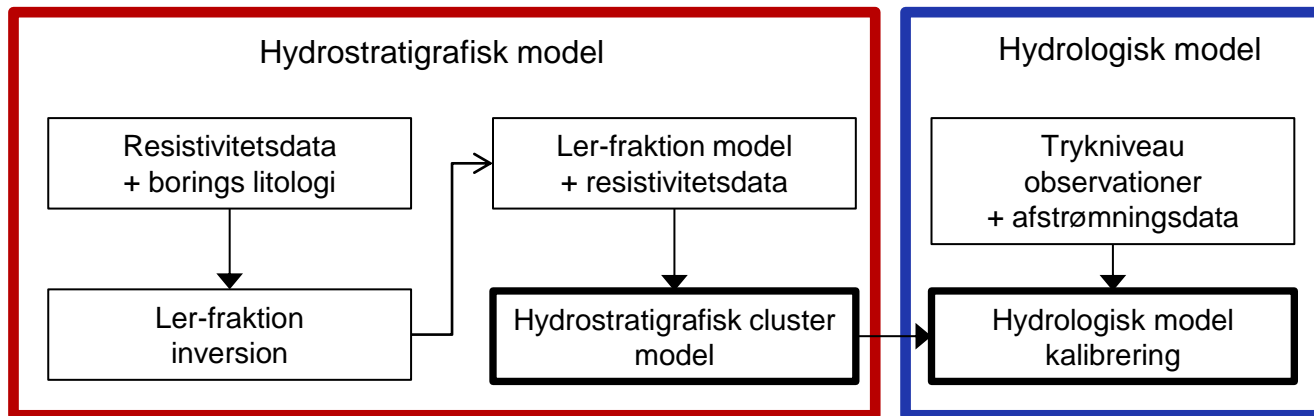
# Metode

**Geofysisk og lithologisk data**  **struktur**

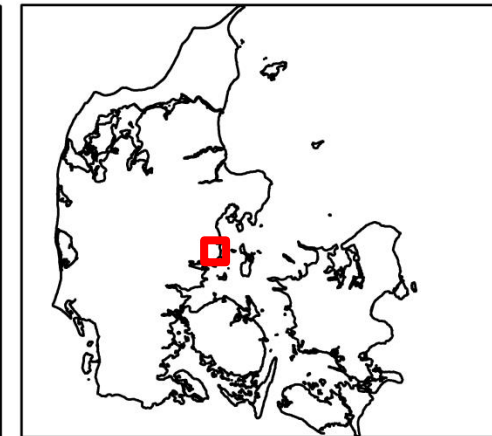
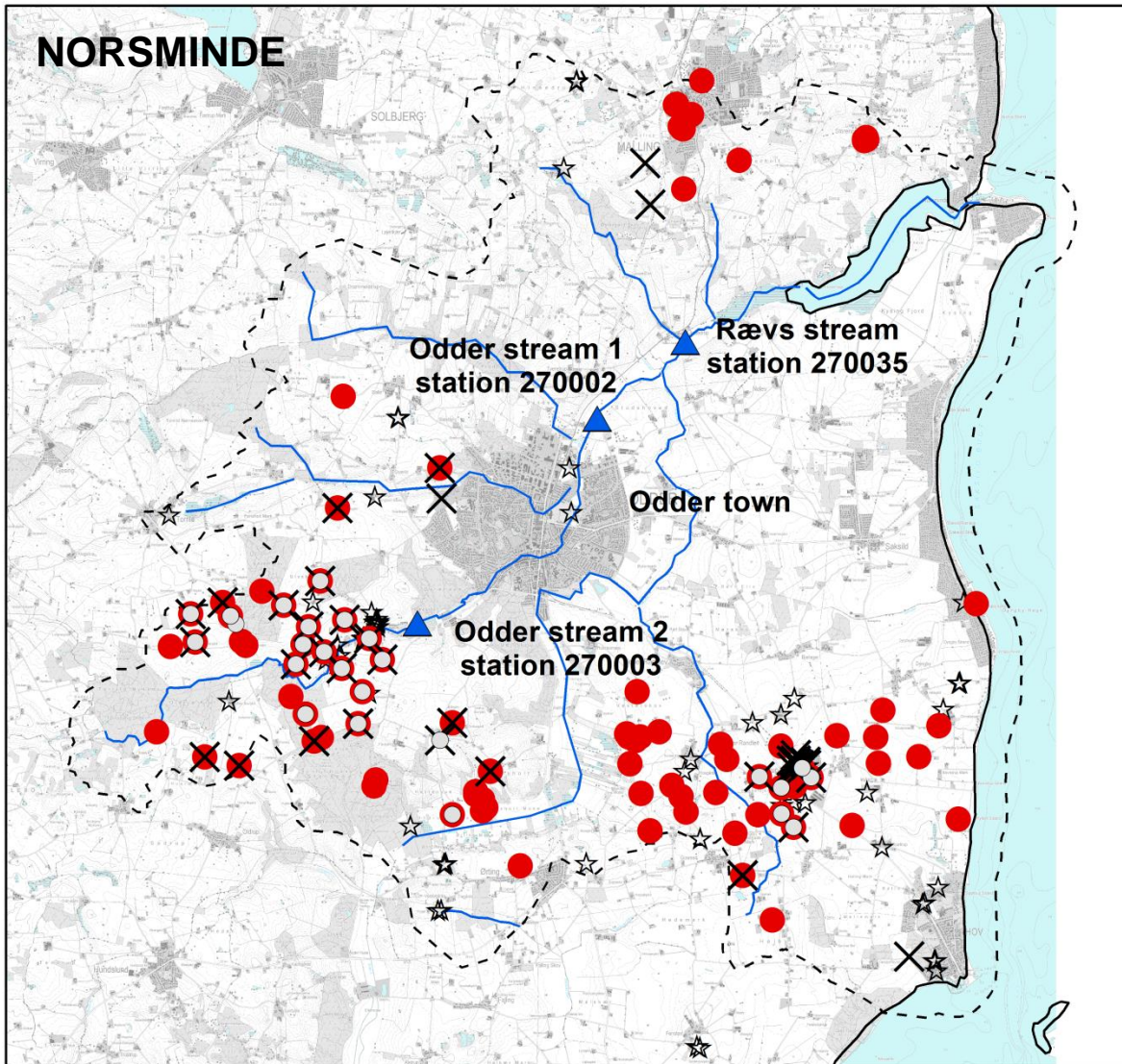
- Ler-fraktion inversion
- Cluster analyse

**Hydrologisk data**  **hydrauliske parametre**

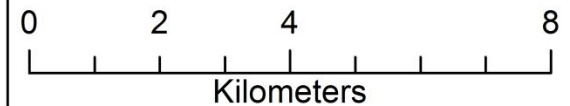
- Hydrologisk model kalibrering







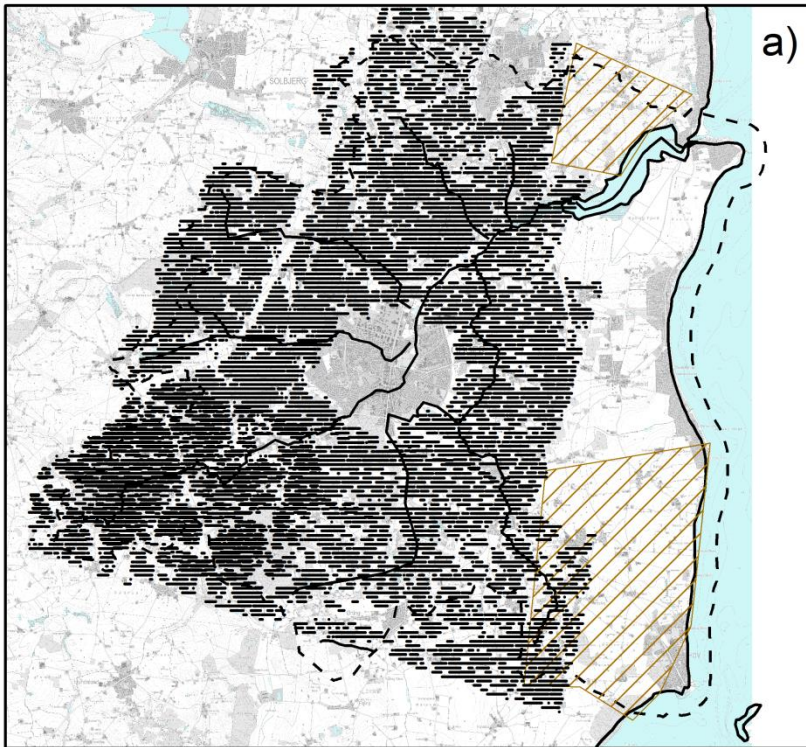
- Head observation 1995-1999
- ✕ Head observation 2008-2011
- Head observation 2000-2003
- ▲ Gauging station
- ☆ Abstraction well
- Stream
- - - Hydrological model domain



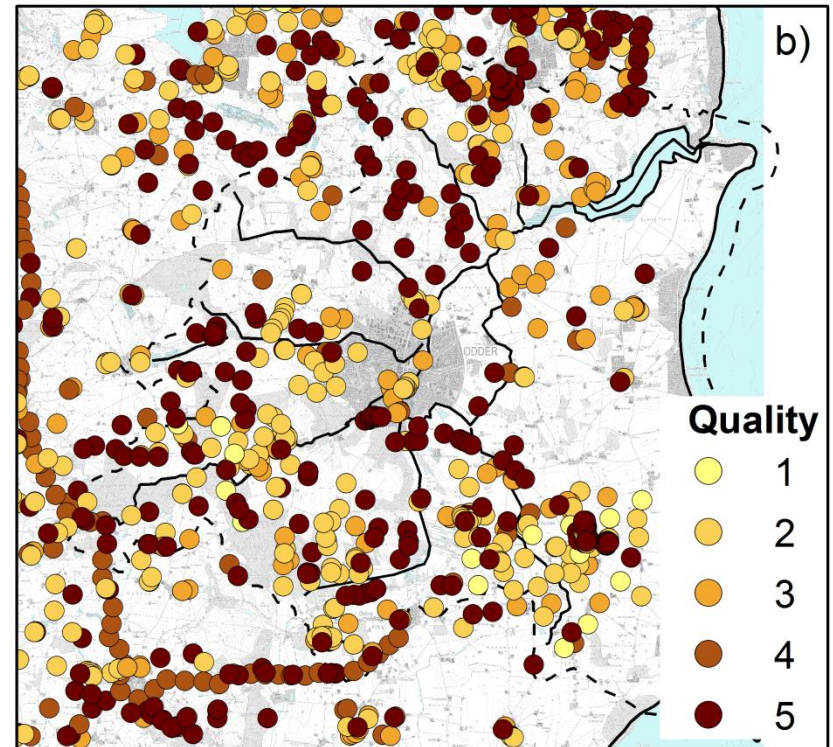


TEM (skraveret brun) og  
SkyTEM (sorte punkter)

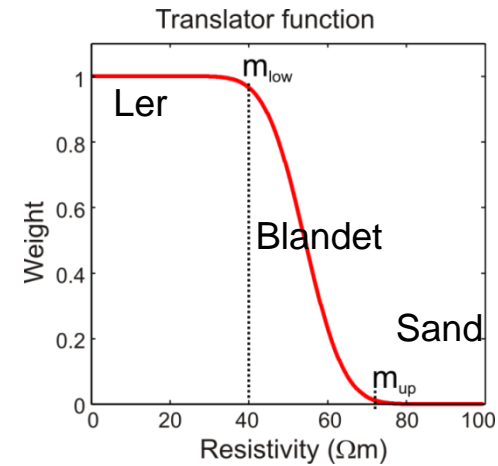
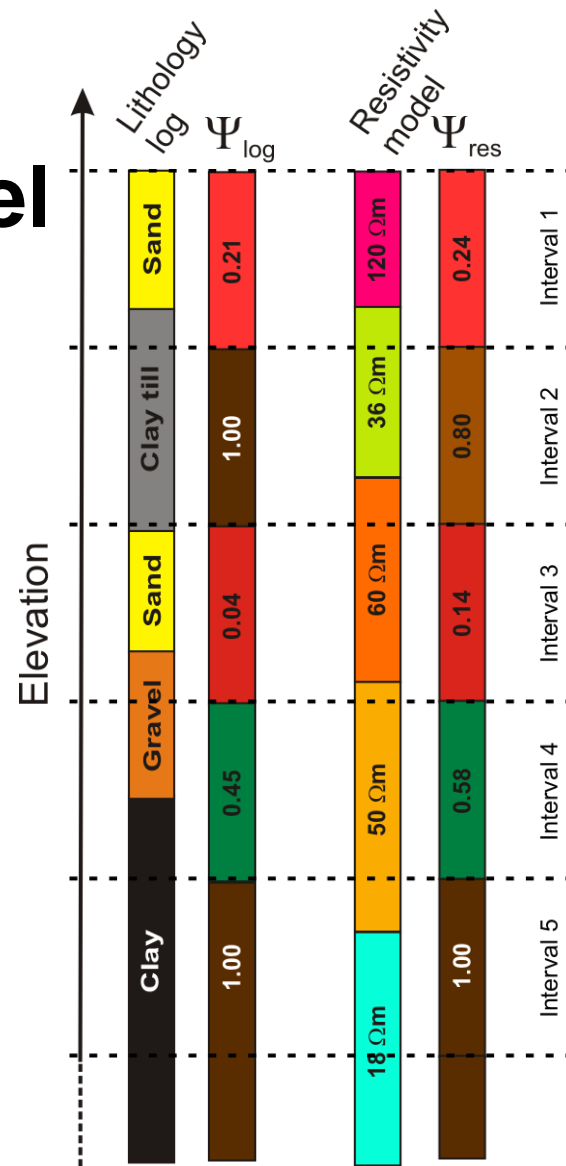
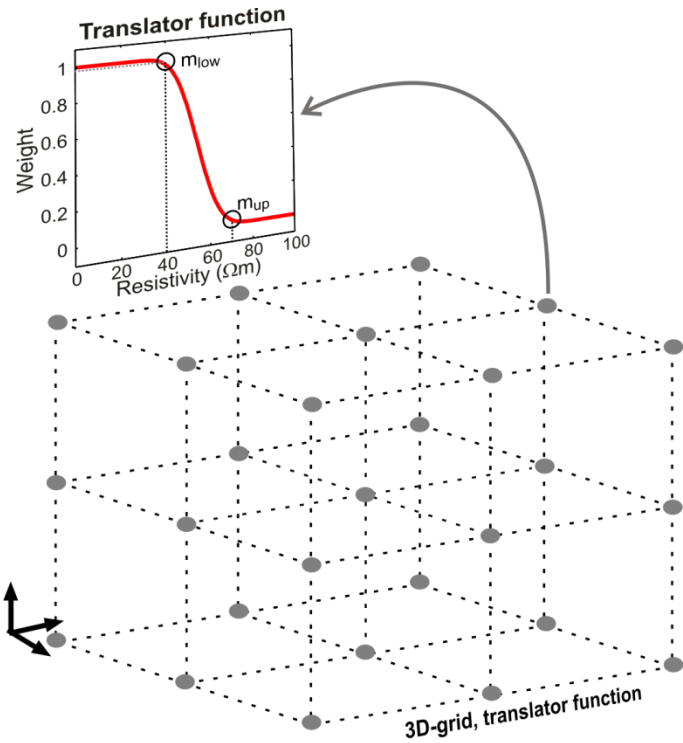
0 2.5 5 10 Kilometers

Litologiske boringer

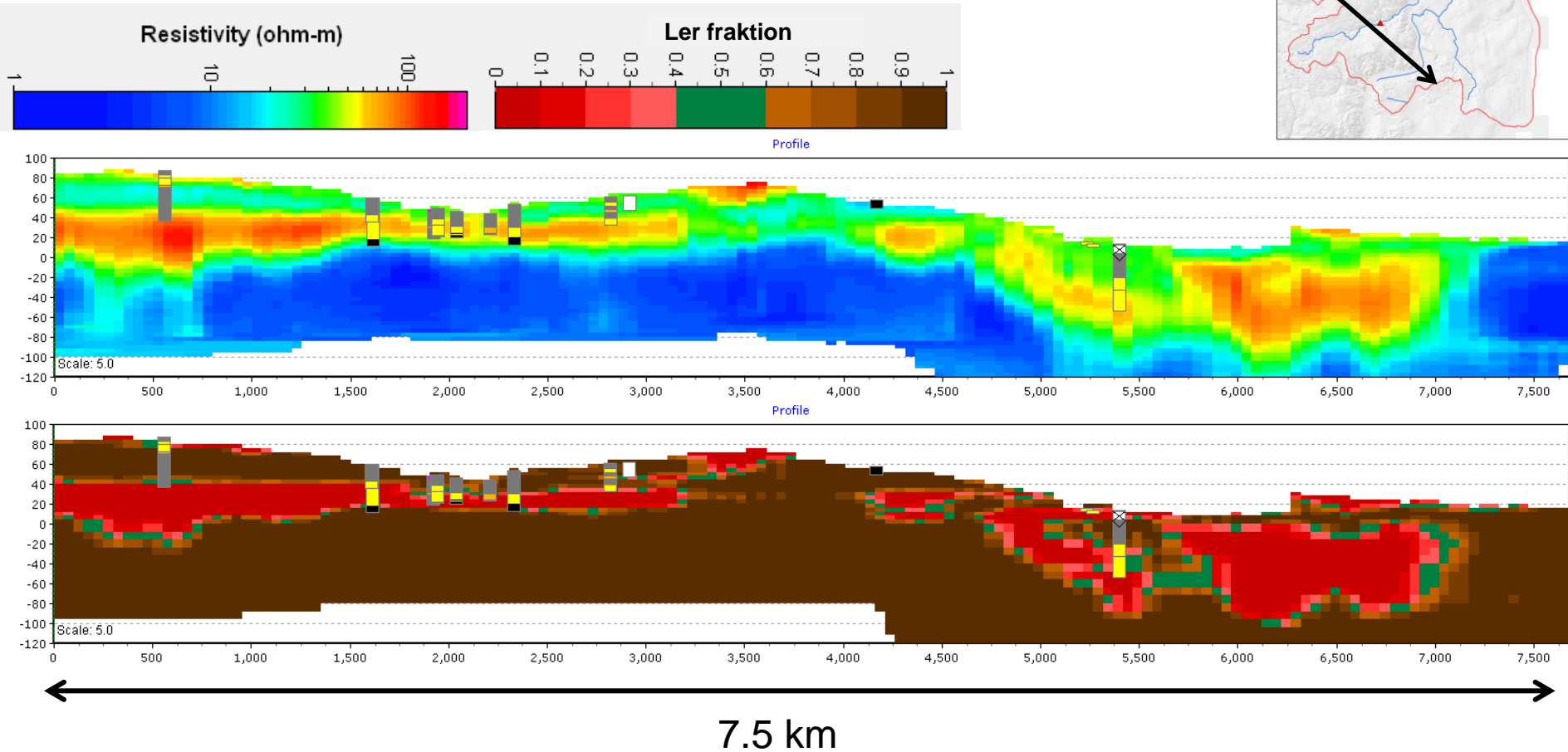
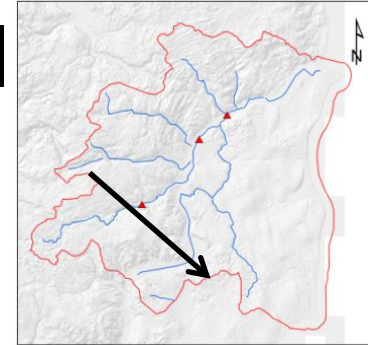


# Ler-fraction model

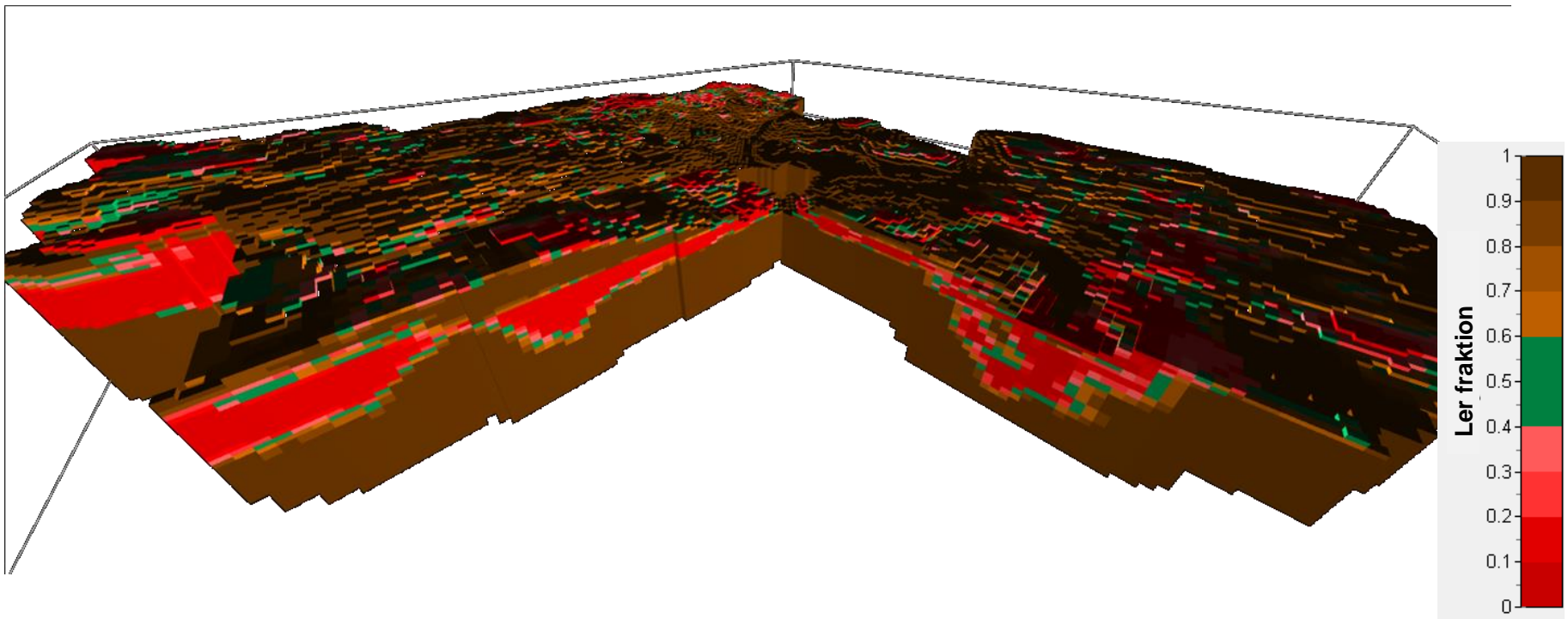


Foged, N., Marker, P. A., Christansen, A. V., Bauer-Gottwein, P., Jørgensen, F., Høyer, A.-S., and Auken, E.: Large-scale 3-D modeling by integration of resistivity models and borehole data through inversion, *Hydrol. Earth Syst. Sci.*, 18, 4349-4362, doi:10.5194/hess-18-4349-2014, 2014.

# Resistivitets- og ler-fraktion model

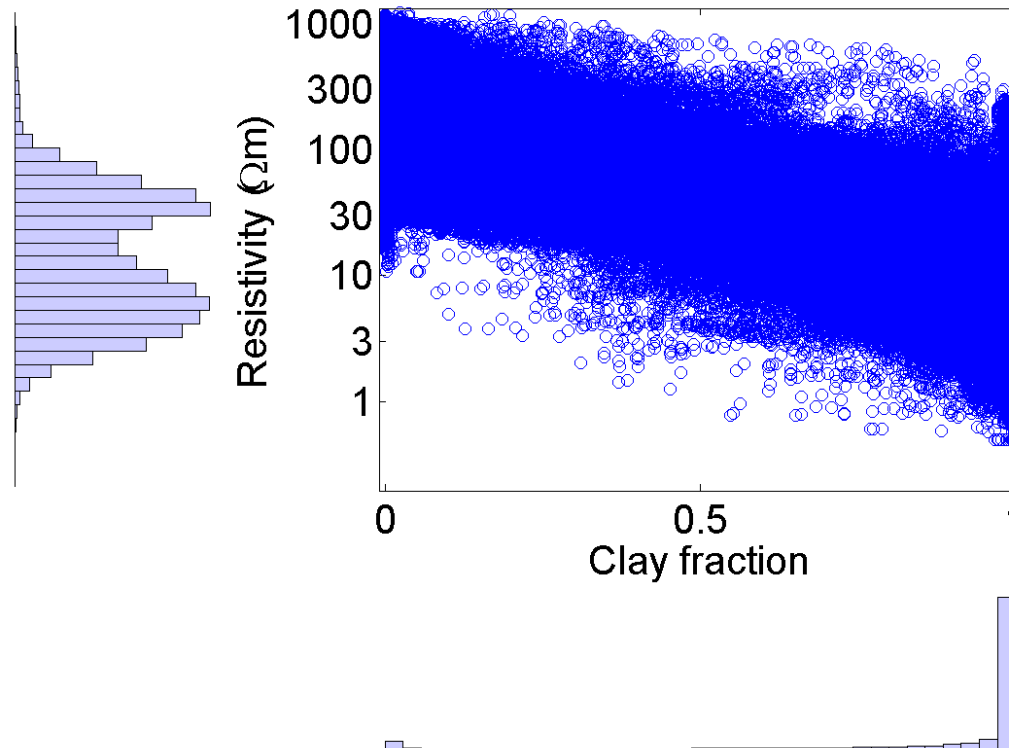


# 3D ler-fraktion model

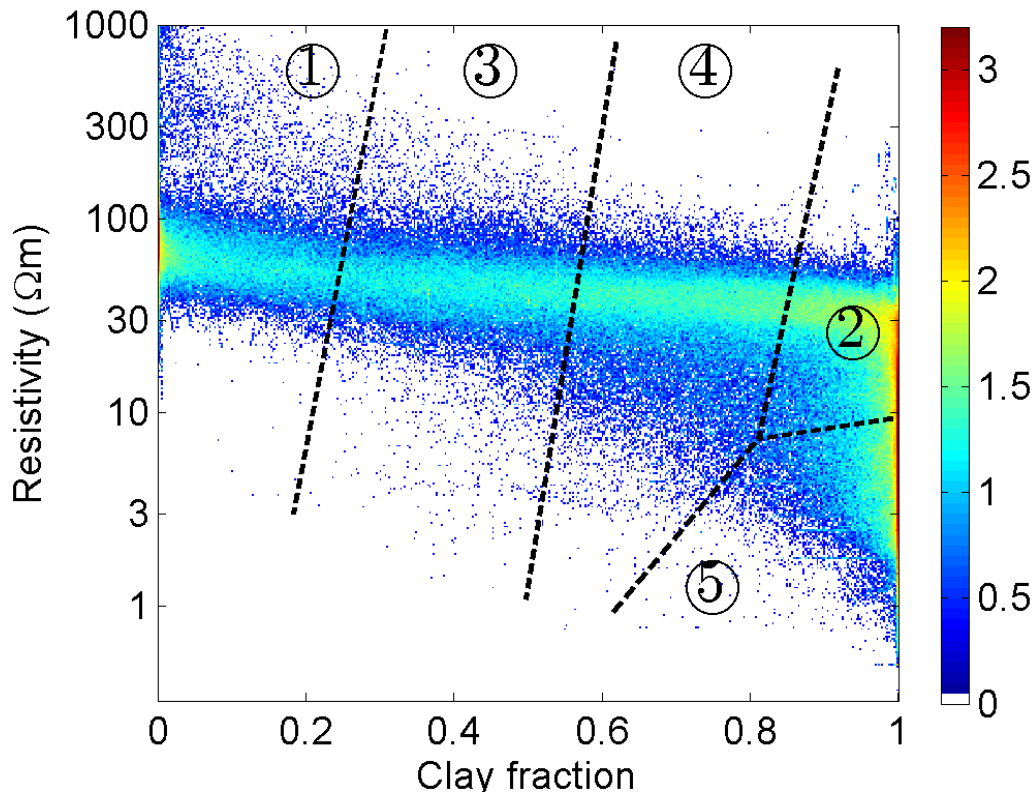


# K-means cluster analyse

- Inddeling af undergrunden i zoner
- Information i resistivitetsdata og ler-fraktion værdier

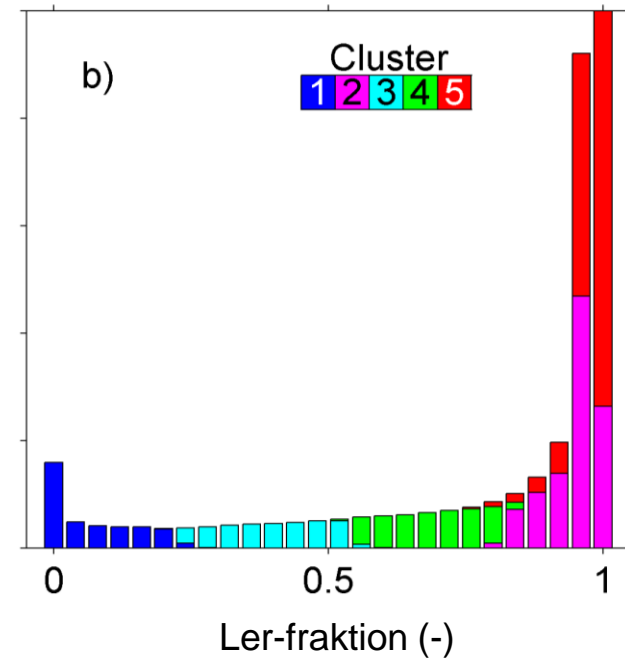
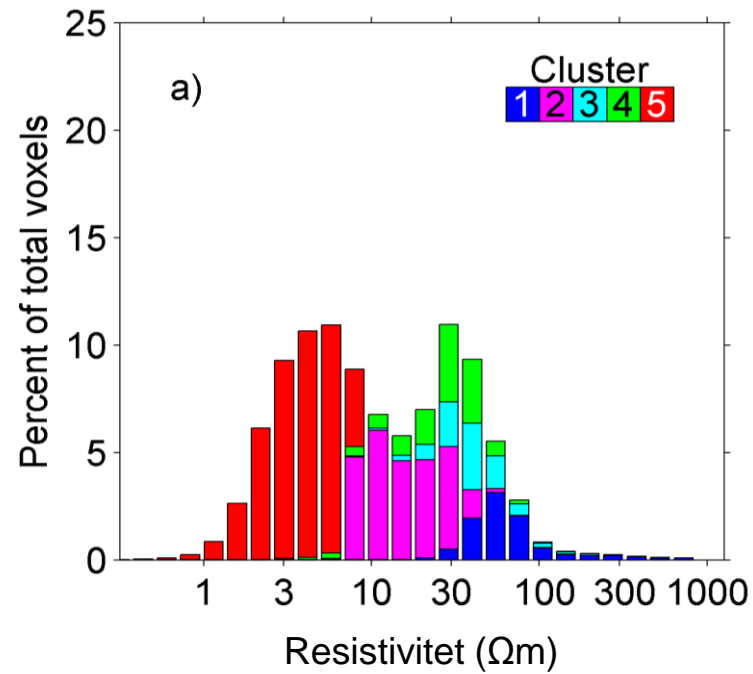


# Inddeling af datarum

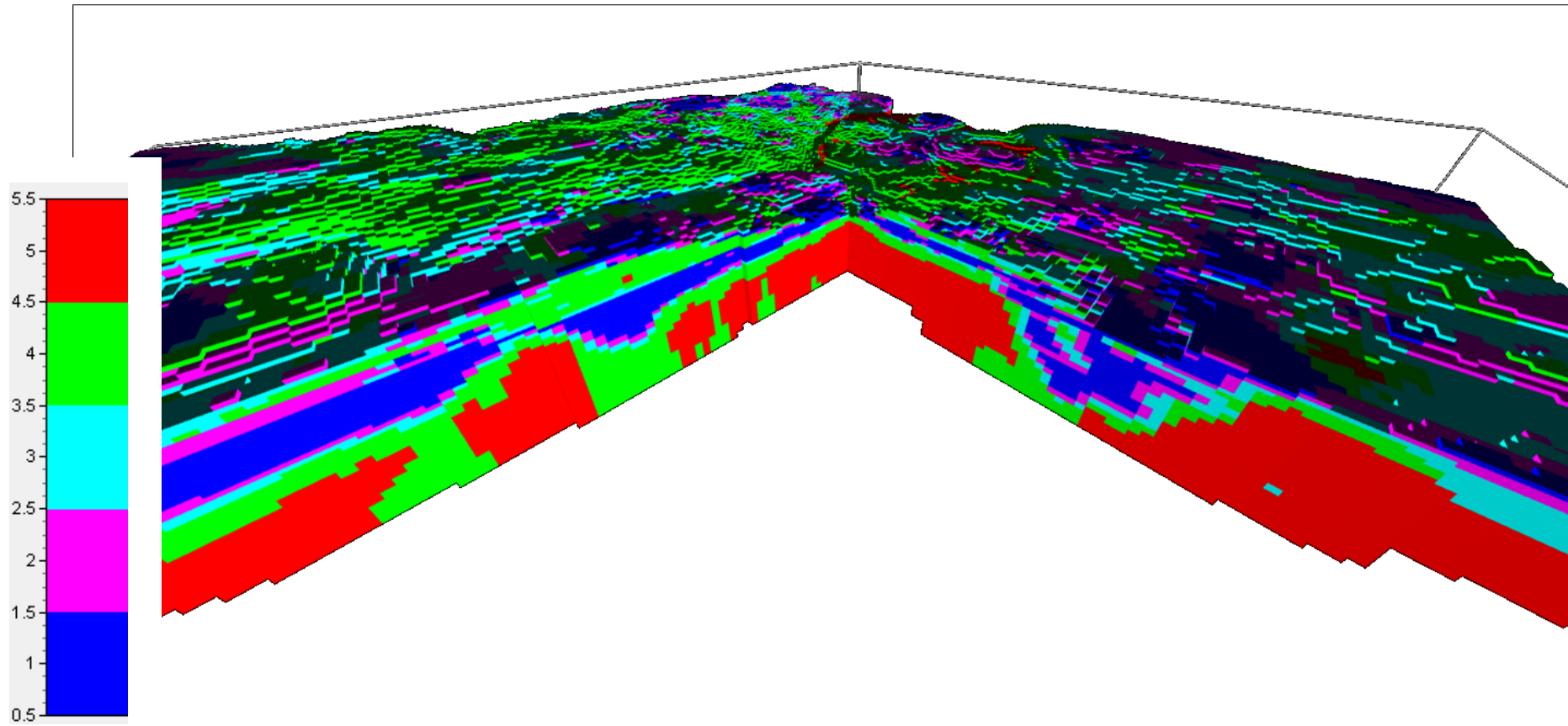


Farveskala angiver antal datapunkter (logaritmisk)

# Cluster-model



# 3D cluster-model





# Integreret hydrologisk model

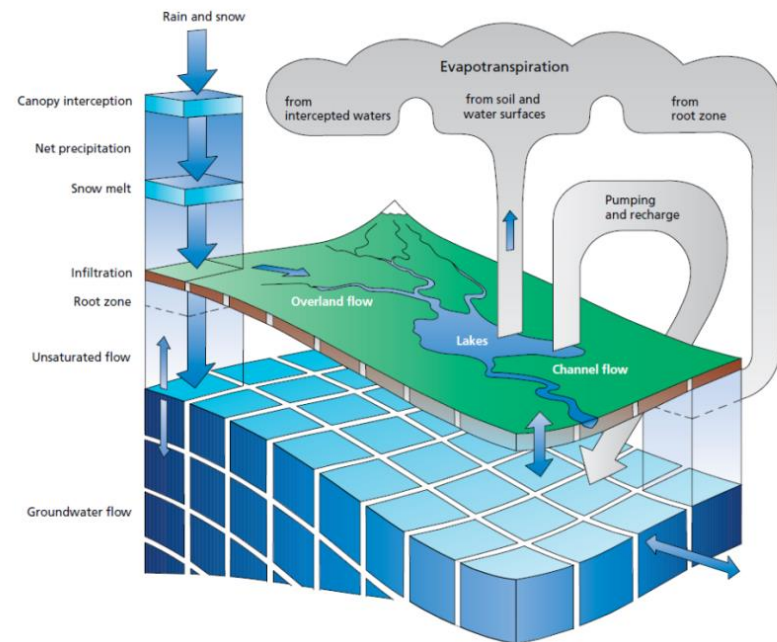
MIKE-SHE model

## Hydrologisk forcing

- Daglig klima data
- Grundvandsindvinding

## Observationer

- Trykniveau
- Vandføringer



# Kalibrering af hydrologisk model

$$\Phi = \Phi_{head} + \Phi_{discharge} = w_{H,i} \sum_{i=1}^{N_H} \left( \frac{obsH_i - simH_i}{\sigma_H} \right)^2 + w_{D,i} \sum_{i=1}^{N_D} \left( \frac{obsD_i - simD_i}{\sigma_{D,i}} \right)^2$$

$\sigma_H$	std dev trykniveau
$\sigma_{D,i}$	std dev vandføring
$w_{H,i}$	subjektiv vægt, trykniveau
$w_{D,i}$	subjektiv vægt, vandføring
$N_H$	antal trykniveau observationer
$N_D$	antal vandføring observationer
obs	observeret
sim	simuleret

# Performance kriterier

$$\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^N (\text{obs}_i - \text{sim}_i)^2}$$

Spredningen på residualerne

$$\text{RMSE}_w = \sqrt{\frac{1}{N} \sum_{i=1}^N \left( \frac{\text{obs}_i - \text{sim}_i}{\sigma_i} \right)^2}$$

Vægtet RMSE; hvis = 1 er data fitted til én standardafvigelse

$$\text{ME} = \frac{1}{N} \sum_{i=1}^N (\text{obs}_i - \text{sim}_i)$$

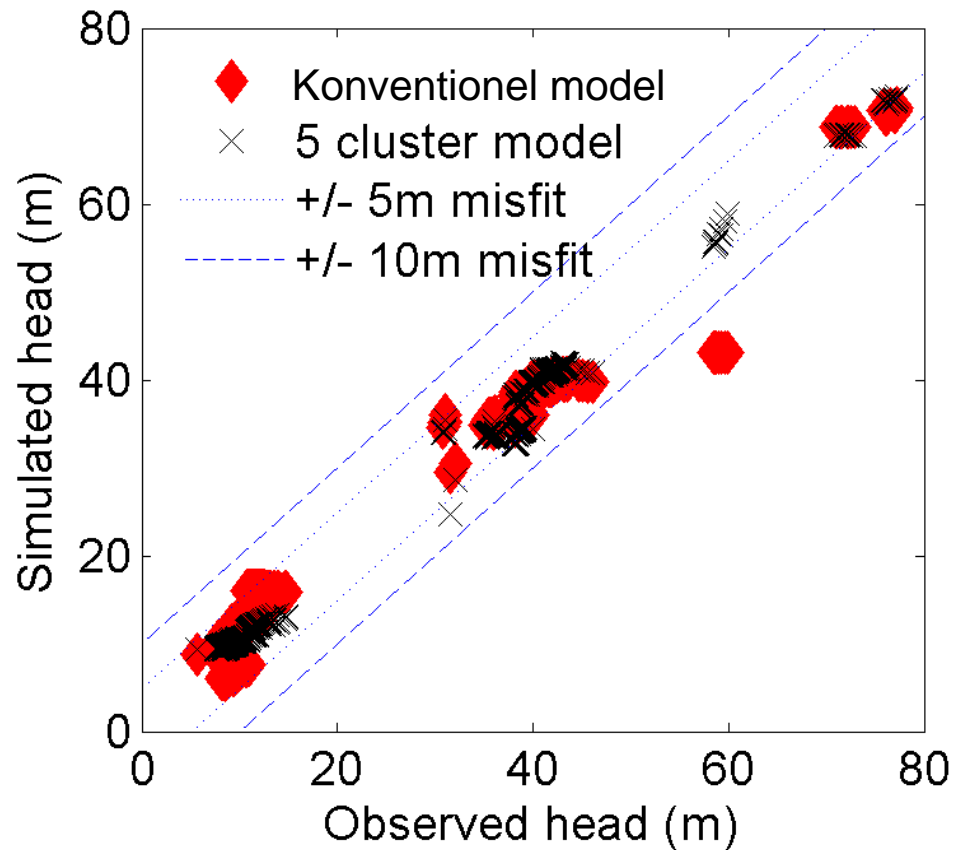
Middelfejl; mål for bias

# Benchmarking

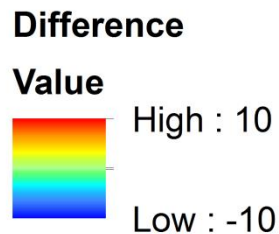
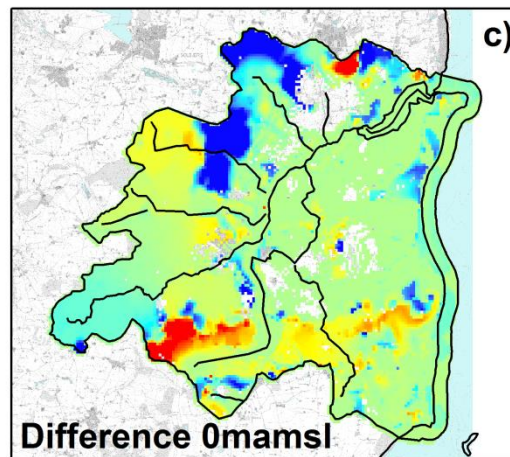
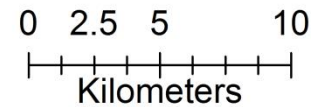
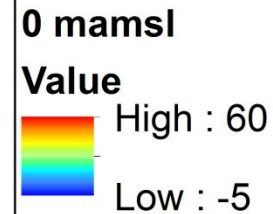
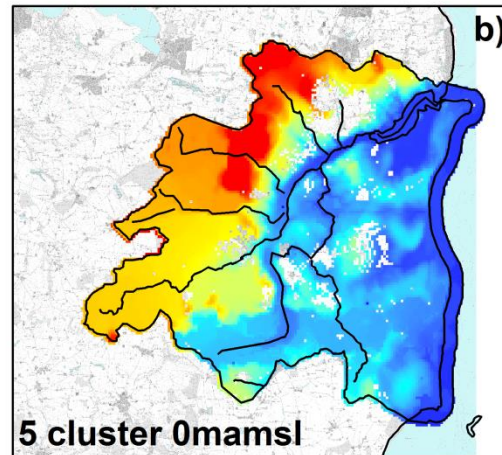
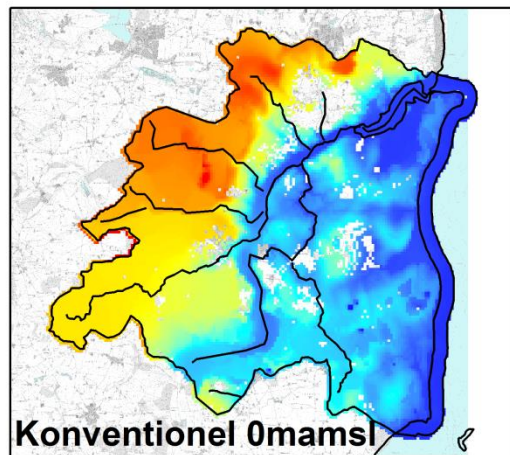
- 5-cluster model performance sammenlignet med konventionel hydrostratigrafisk model

		Konventionel model			5-cluster model		
		Weighted RMSE (-)	RMSE	ME	Weighted RMSE (-)	RMSE	ME
Calibration 2000-2003	Head (m)	<b>2.81</b>	<b>3.27</b>	<b>-0.0762</b>	<b>2.14</b>	<b>2.57</b>	<b>0.00310</b>
	Discharge (m <sup>3</sup> /s)	0.326	0.267	-0.0259	0.338	0.278	-0.0107
Validation 1995-1999	Head (m)	2.85	3.24	-0.926	1.76	2.19	-1.01
	Discharge (m <sup>3</sup> /s)	0.446	0.180	-0.0501	0.524	0.203	-0.0354
Validation 2008-2011	Head (m)	3.27	3.97	-0.899	2.64	3.34	-1.28
	Discharge (m <sup>3</sup> /s)	0.501	0.124	-0.0853	0.526	0.120	-0.0809

# Simuleret trykniveau, 1995-1999

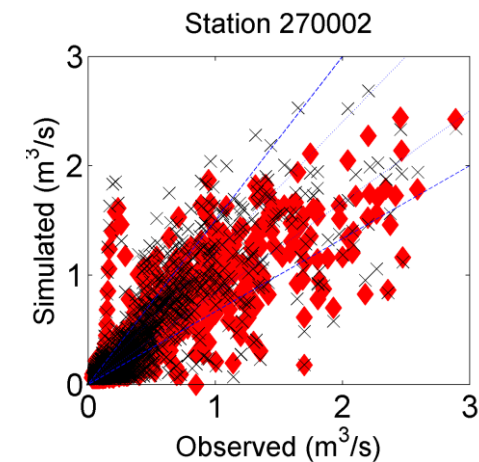
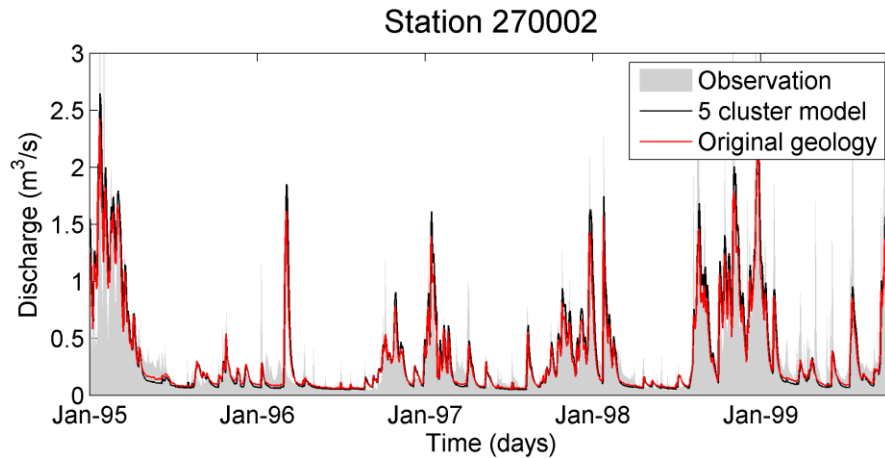
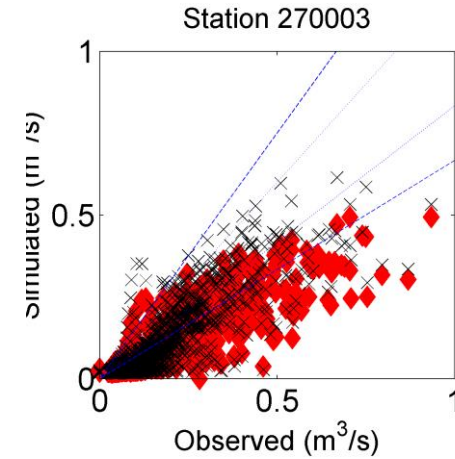
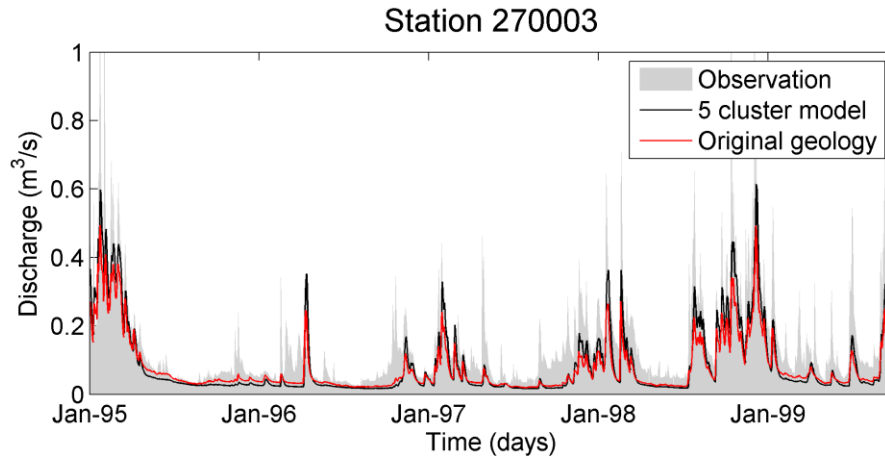
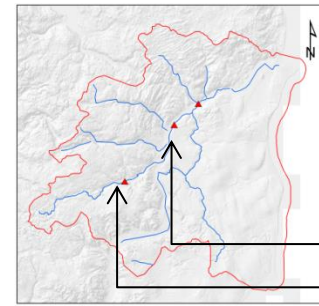


# Simuleret trykniveau, kote 0m

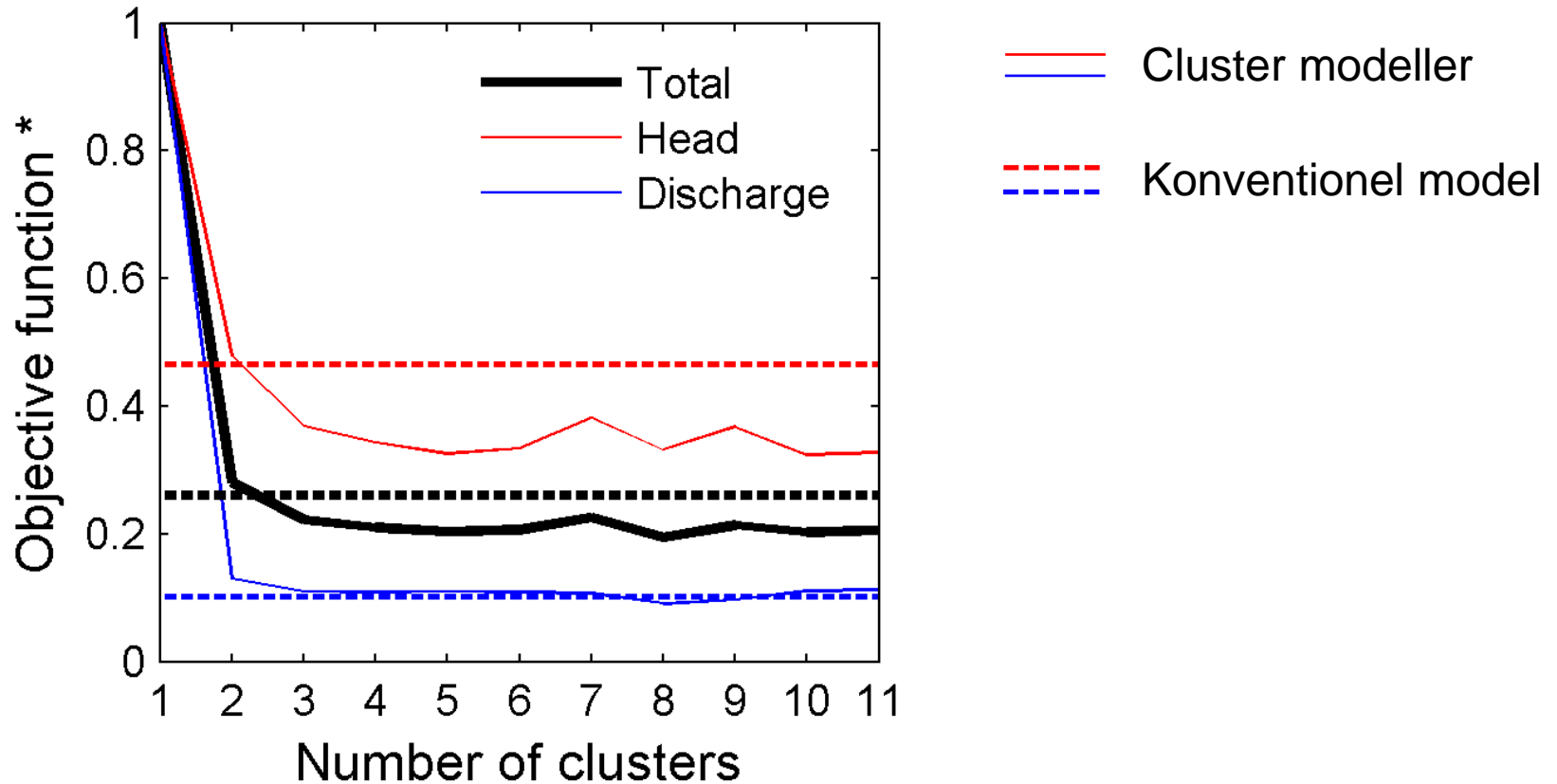


Forskellen på simuleret trykniveau fra de to modeller

# Afstrømningsdata 1995-1999



# Hvor mange zoner?





# Konklusion

- Vi kan ud fra geofysisk resistivitetsdata og ler-fraktion model inddele undergrunden i zoner, hvis hydrauliske ledningsevne kan estimeres i hydrologisk kalibrering
  - Resultat sammenligneligt med konventionel hydrostratigrafisk model
- Semi-automatisk og drevet af data → mindre ressourcekrævende
- Udnyttelse af rumlig information i geofysikken
- Mulighed for metodestandardisering i hydrostratigrafisk modelopbygning

## Fortsættelse

- Usikkerhedsanalyse ved generering af ensemble