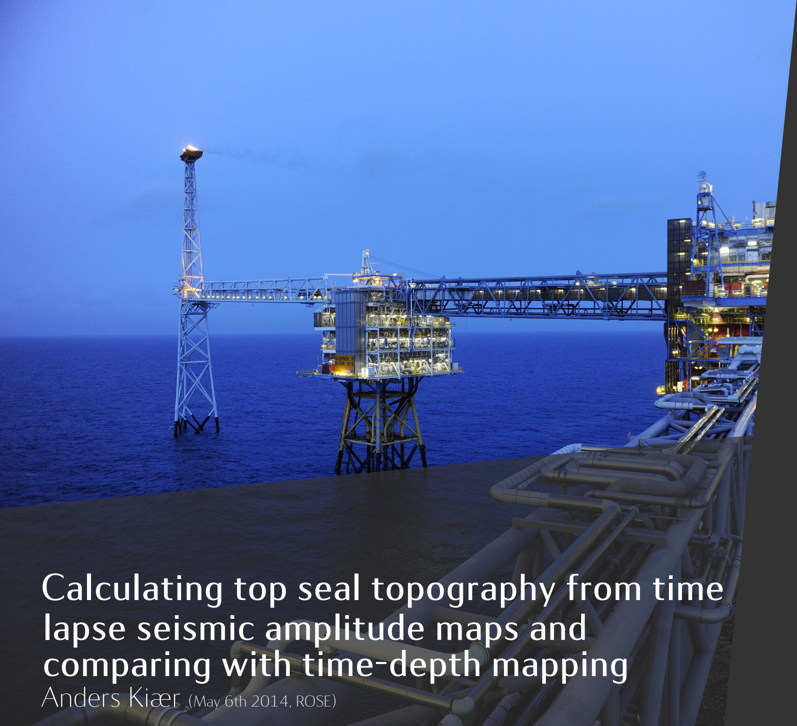

Calculating top seal topography from time lapse seismic amplitude maps and comparing with time-depth mapping

Anders Kiær (May 6th 2014, ROSE)

Statoil

NTNU
Innovation and Creativity

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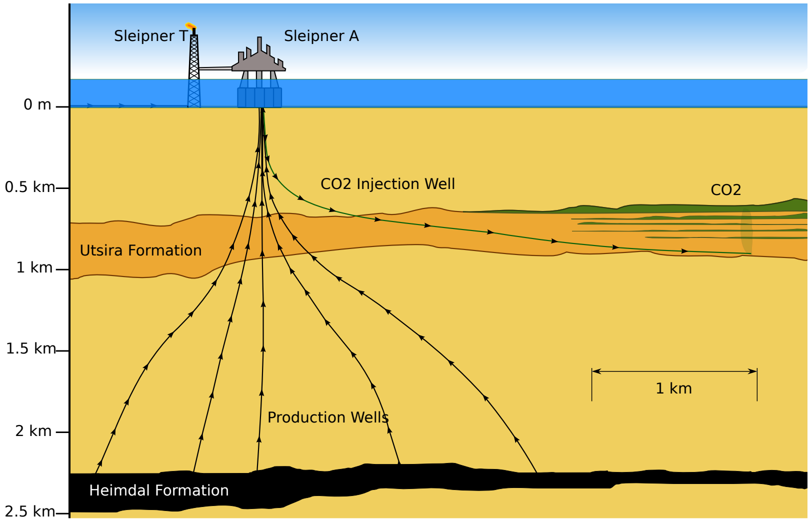
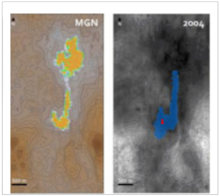
Sleipner CO_2 storage project



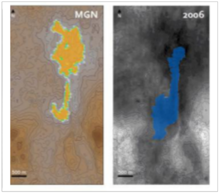
Motivation/goal

From Cavanagh (2013) - "Benchmark calibration and prediction of the Sleipner CO_2 plume from 2006 to 2012"

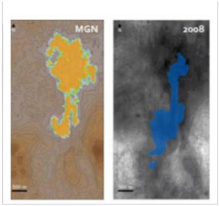
2004



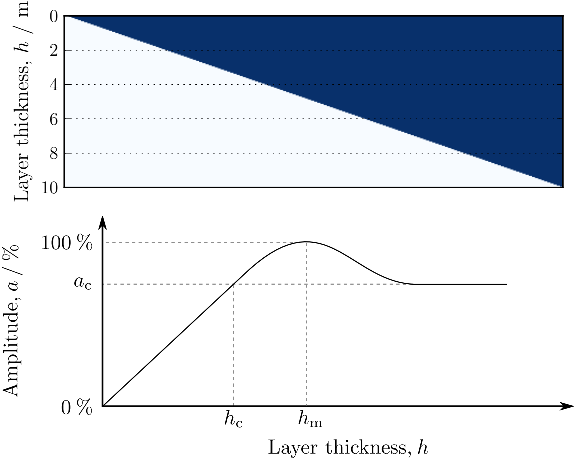
2006



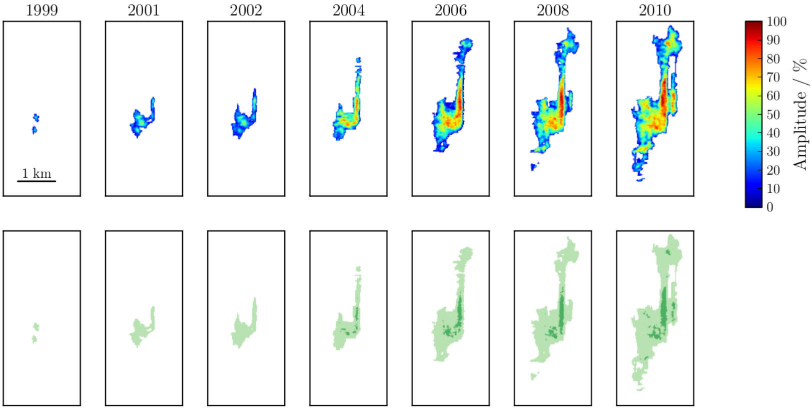
2008



Tuning relationship

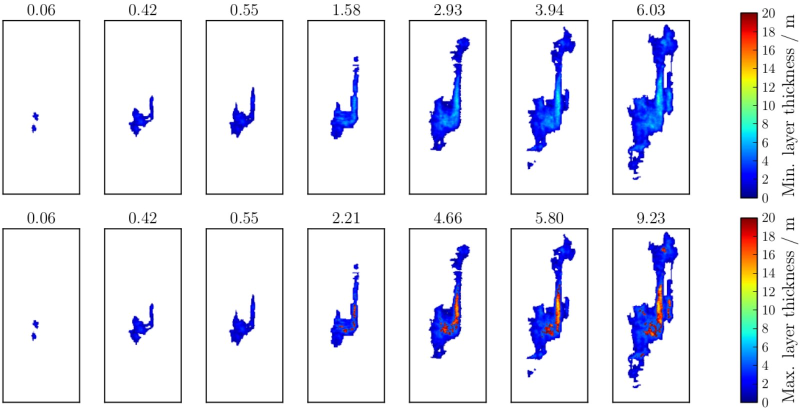


Seismic data sets



Min/max solutions

Numbers above each plot show rock volume (10^6 m^3) flooded by CO_2



Motivation/goal

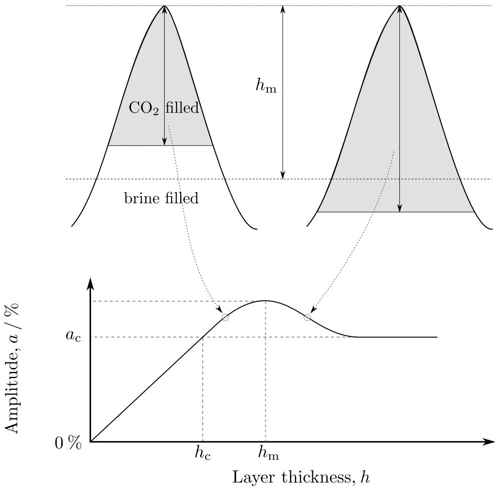
Earlier work

- Chadwick et al. (2005) - 4D seismic quantification of a growing CO_2 plume at Sleipner, North Sea

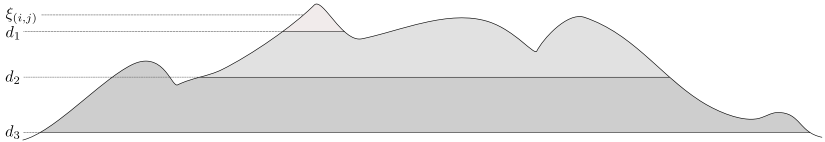
Goals

- Estimate thickness maps using seismic amplitude maps.
- Check the assumption of gravity dominated flow at Sleipner.
- Recalculate Top Utsira topography map.

Fundamental idea



Notation



- Positive direction downwards.
- $d_1 = 0$ taken as reference point.

Computational method

If a grid cell (i, j) is interpreted to contain CO_2 at time t_k, we would in the ideal gravity case have that the layer thickness is

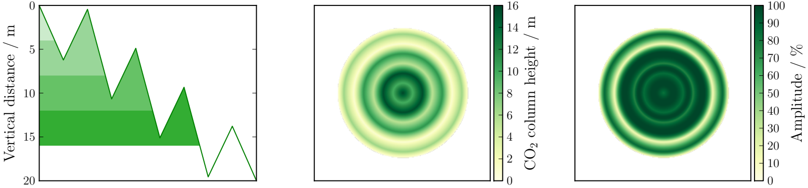
$$h_{(i,j,k)} = d_k - \xi_{(i,j)}. \quad (1)$$

However, in practice this can be far from true if the model assumptions are invalid or the data is noisy. To cope with this, Equation 1 is not required to be exact.

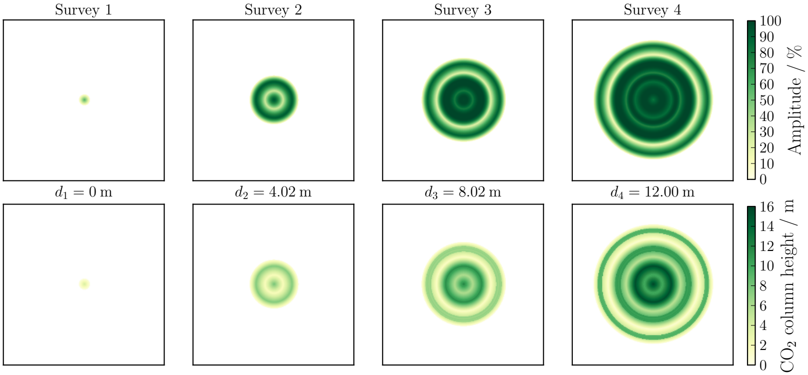
$$R \equiv \sum_{k=1}^{S} \sum_{(i,j)} \left[d_k - \xi_{(i,j)} - h_{(i,j,k)} \right]^2. \quad (2)$$

$$d_1 \leq d_2 \leq \cdots \leq d_S. \quad (3)$$

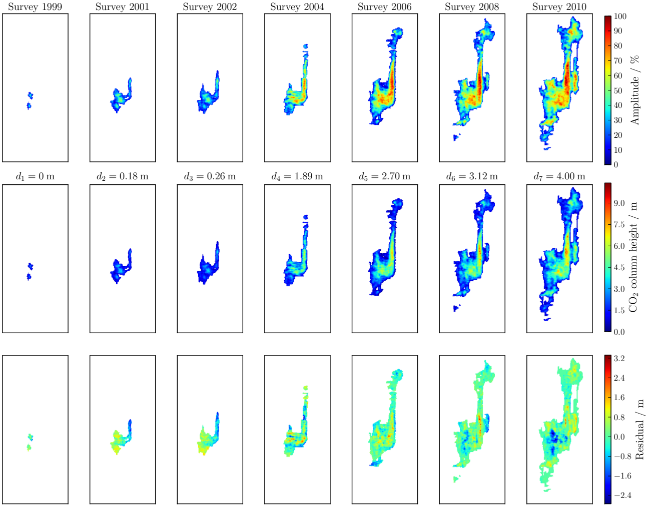
Synthetic case



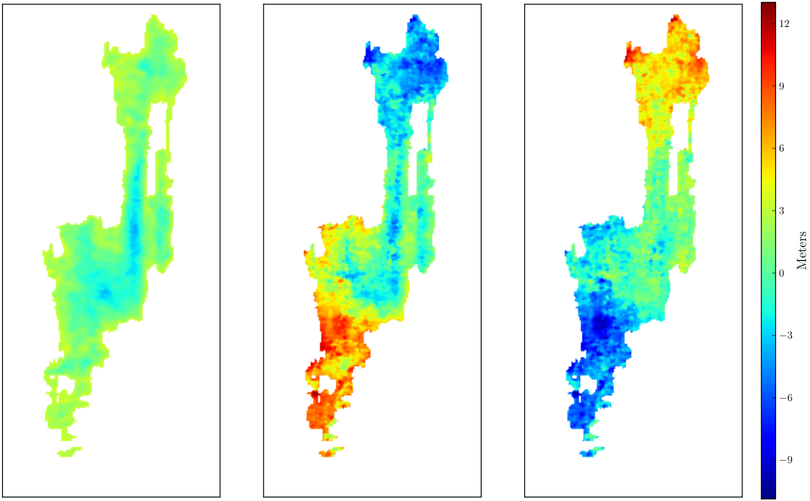
Result


Survey 1
Survey 2
Survey 3
Survey 4
Amplitude / %
100
90
80
70
60
50
40
30
20
10
0
$d_1 = 0$ m
$d_2 = 4.02$ m
$d_3 = 8.02$ m
$d_4 = 12.00$ m
CO_2 column height / m
16
14
12
10
8
6
4
2
0

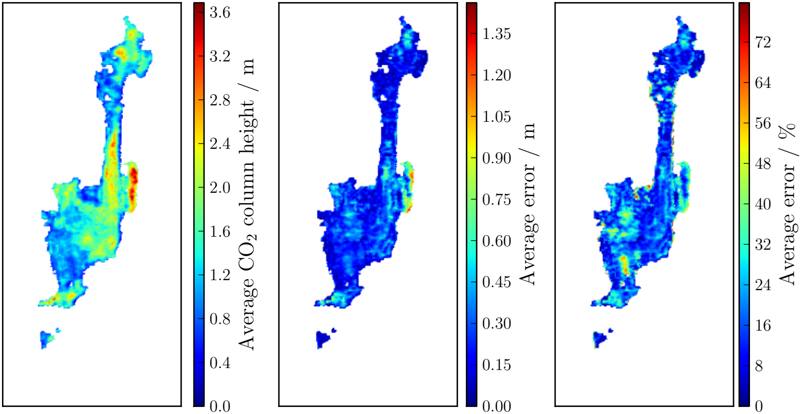
Real case


Survey 1999
Survey 2001
Survey 2002
Survey 2004
Survey 2006
Survey 2008
Survey 2010
Amplitude / %
$d_1 = 0$ m
$d_2 = 0.18$ m
$d_3 = 0.26$ m
$d_4 = 1.89$ m
$d_5 = 2.70$ m
$d_6 = 3.12$ m
$d_7 = 4.00$ m
CO_2 column height / m
Residual / m

Real case (topography)



Average error



Conclusions

- A method for estimating CO_2 layer thickness maps is developed and presented for gravity dominated cases.
- CO_2 layer thickness for the topmost layer found to be below the tuning thickness h_m everywhere for surveys up to and including 2008. This results supports the assumption done in Chadwick et al. (2005).
- (At least) 85% match between the amplitude maps and a pure gravity model.
- Inverted topography map of Top Utsira is flatter than the depth converted time map, but mutual agreement within uncertainty range.

Acknowledgements

- Statoil and the license partners (ExxonMobil and Total) for relasing information on the CO_2 storage project at Sleipner.
- Statoil for financing my PhD.
- Ola Eiken (QuadGeometrics, former Statoil) and Martin Landrø (NTNU) for helpful comments and suggestions.
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