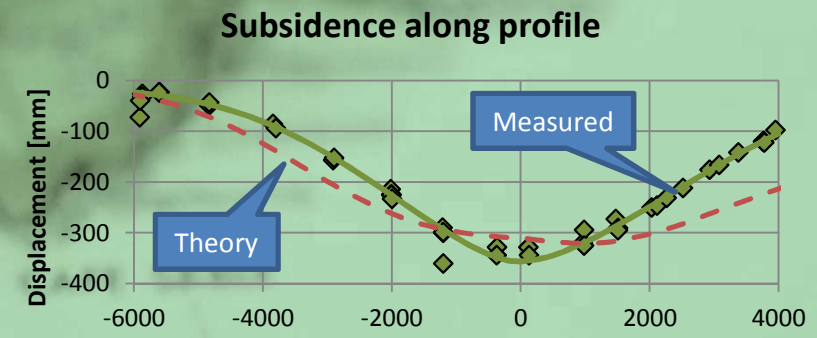
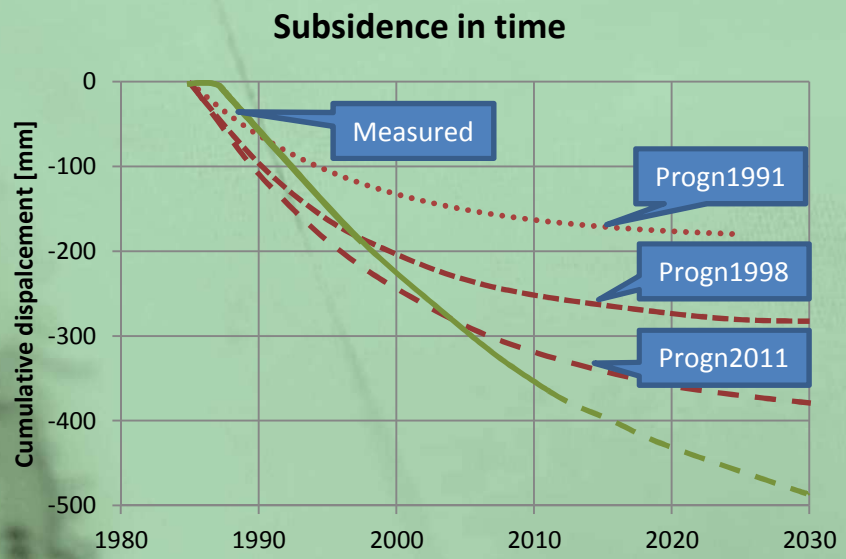
2nd Technical Meeting Steering Committee Long-term Subsidence Wadden Sea

Monday 28 and Tuesday 29 October

Waddenacademie, Leeuwarden

What's the problem?





- Wanted: reliable basis go/no go, damage control decisions
- Prognosis not fit for purpose
- Measured versus predicted
  - spatial: steeper & deeper
  - volume: far smaller
  - temporal: later
  - continues after end production
  - no rebound on injection
- Effectiveness 'Hand on the Tap' control mechanism?
- Shelf life predictions?
- Note: long wavelength discrepancies, regardless of detail

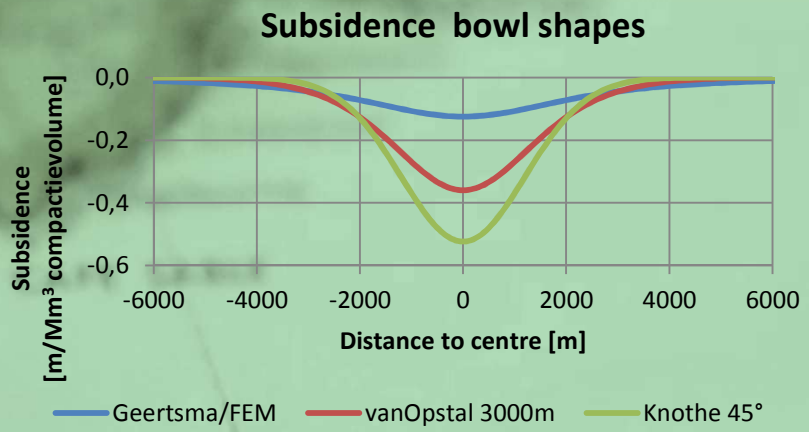
What's the cause?

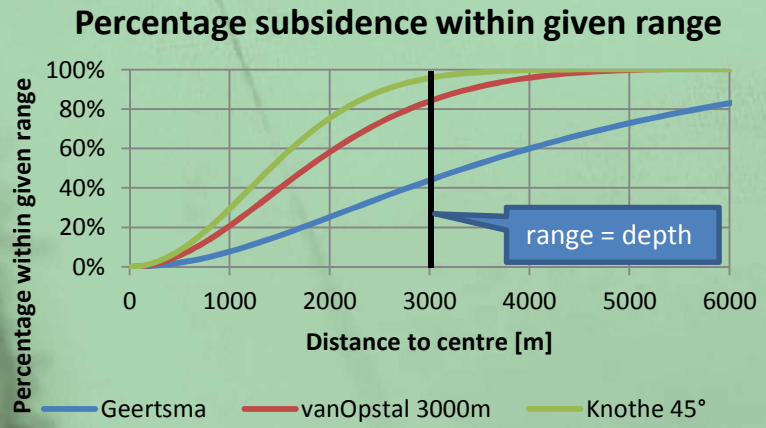
- without strict problem analysis > wasteful jumping to conclusions
- processes needing validation
  - geomechanics: from production to subsidence
  - geodesy: from measurements to subsidence
  - testing: predicted versus measured subsidence
- inversion and misconceived geodetic data
  - distorted cause and effect experiences
  - blurred distinctions between good & bad models

Geomechanics

- Poorly covered links in chain from production to subsidence volume
  - pore pressure decrease > matrix pressure increase
    - increased fault friction, arching, jerky compaction vs earthquakes
  - stress equalisation > reservoir, over-, underburden deformation
    - document NAM's FEM implementation,
    - validate Geertsma experimentally, incl. horizontal deformation
  - reservoir, over- & underburden deformation > subsidence
    - subsidence outside range = depth may differs by factor 12
- Subsidence volume per m^3 production
  - can differ by factor 10 depending on prognosis methodology
    - case analysis to extract lessons

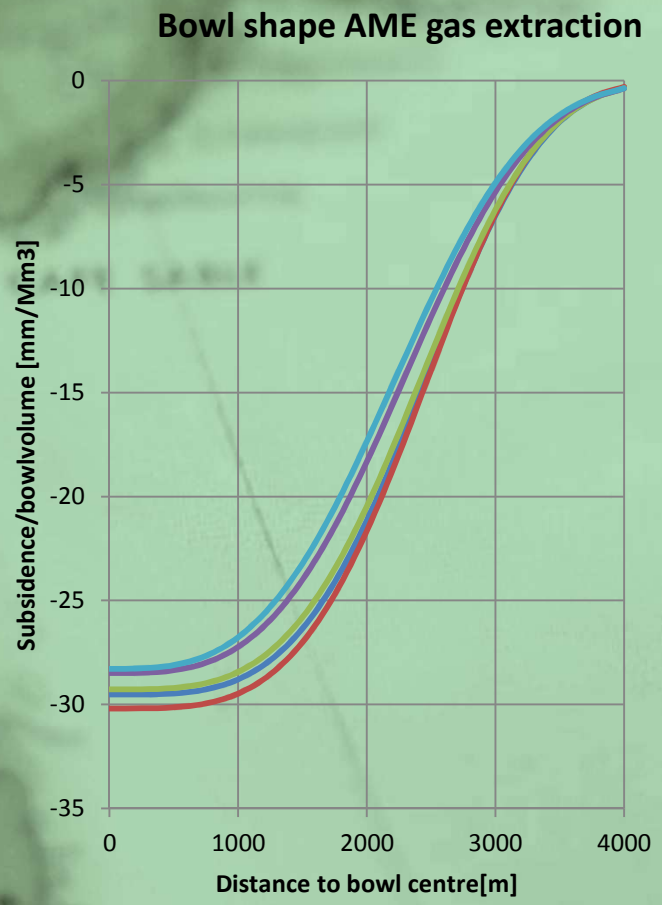
Spatial distributions

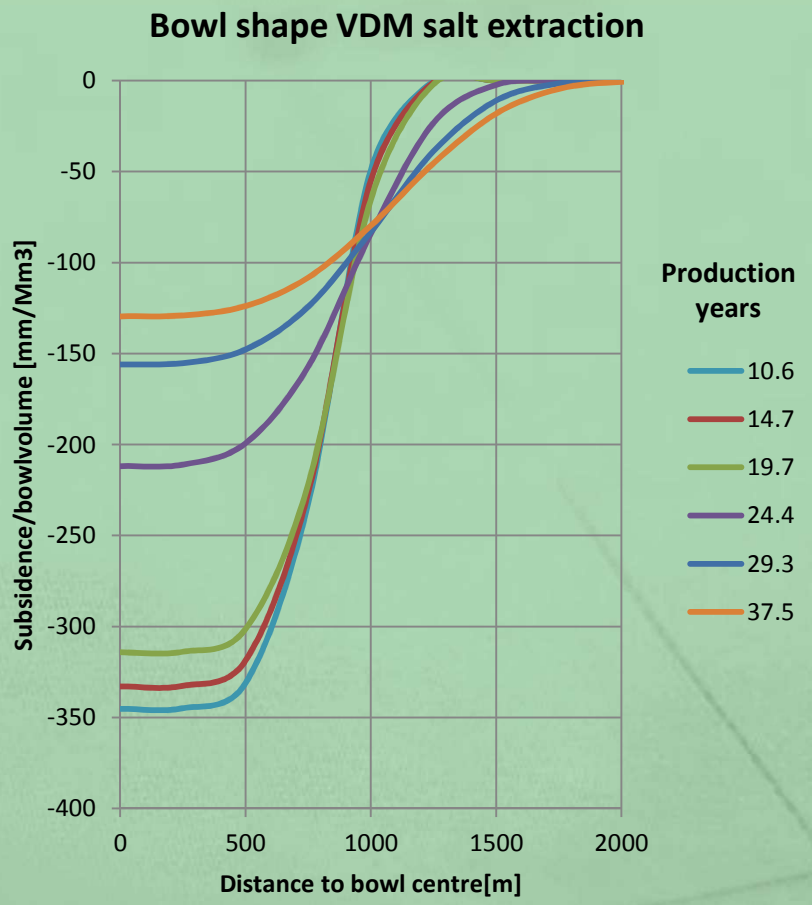




- Model choice: spatial distribution
- Comparing subsidence for same nucleus volume loss
- Subsidence volume may be 100 or 150% compaction
- Subsidence percentage outside range=depth varies by factor 13
- i.e. life/death Wadden banks

Time variant bowl shapes

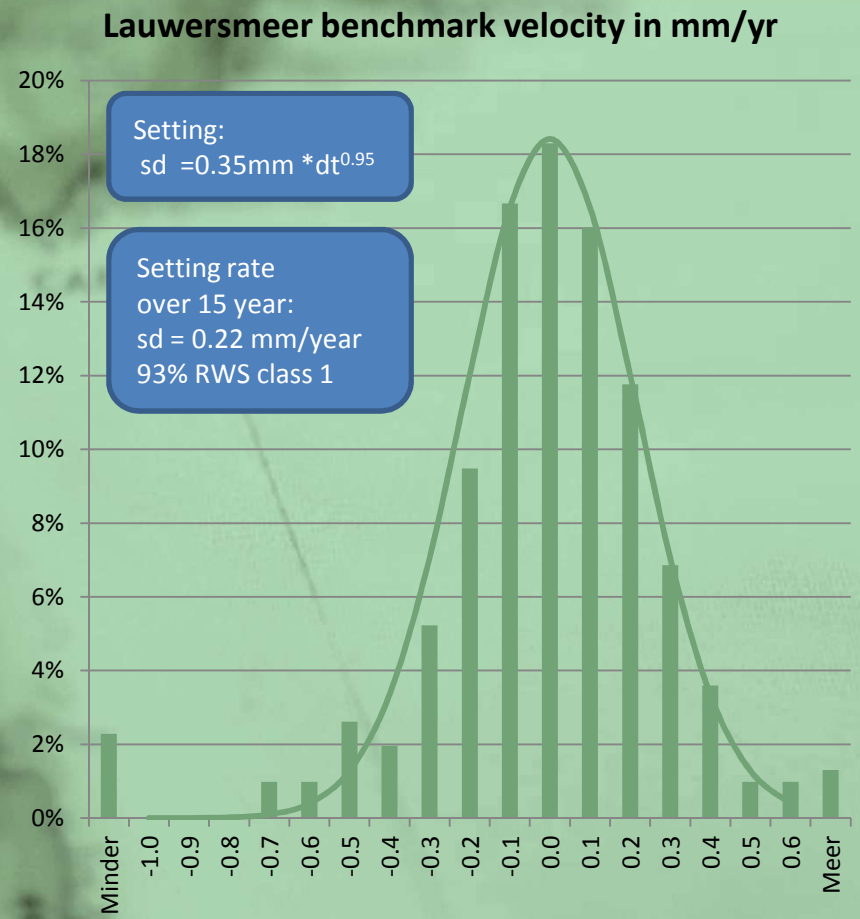




Geodesy

- Geodetic data suffer from misconceptions, not temporal noise
- The observables are spatial height differences, not heights
- Height differences between benchmarks, not ‘the surface’
- These benchmarks move with temporally correlated, but spatially uncorrelated speed w.r.t. the subsiding surface: temporal noise can't explain assumed, but not measured, spatially correlated bowl deepening
- Deformation is measurable, absolute subsidence is not
- Subsidence analysis is hampered by poor use of the spatial and temporal correlation in the deformation signal, not by poor spatial and temporal sampling

Relative benchmark stability



- Benchmarks set at logarithmically decreasing rates into surface
- Setting rates
  - not defined outside benchmarks, but continuous in time
  - rates of different benchmarks over same period uncorrelated
  - rate of same benchmark over different periods highly correlated
  - no time difference, no setting
  - different kind of benchmarks move the same, no bimodal distribution
  - ≈95% between +/- 0.5 mm/yr
- Conditional constraints address setting differences only
- Absolute displacement is irrelevant

Subsidence versus deformation

Subsidence: not measurable

$$z_i^{tu} = E\{h_i^u - h_i^t\}$$

$$D\{h_i^u - h_i^t\} = \left(2\sigma_h^2 + 2\sigma_t^2(u-t)^2\right).I$$

$$Test:$$

$$\left(z_i^{tu} - (h_i^u - h_i^t)\right)^T Q_{\Delta h}^{-1}\left(z_i^{tu} - (h_i^u - h_i^t)\right) = n$$

Deformation: measurable

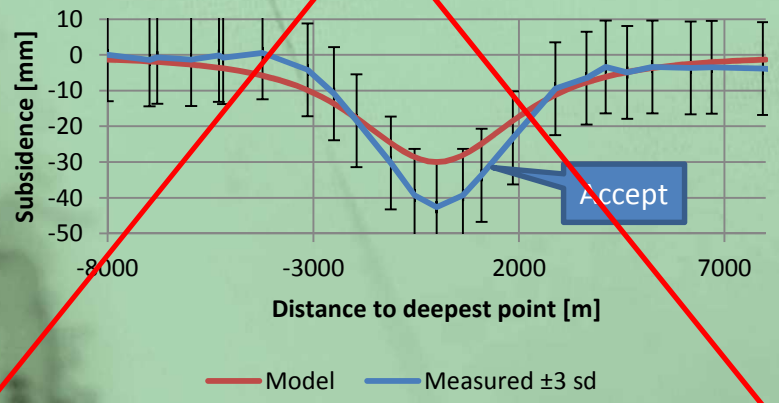
$$z_{ij}^{tu} = E\{h_{ij}^u - h_{ij}^t\} - E\{s_j^{tu} - s_i^{tu}\}$$

$$D\{h_{ij}^u - h_{ij}^t\} = AQ_{dh}A^T;\ D\{s_j^{tu} - s_i^{tu}\} = BQ_sB^T$$

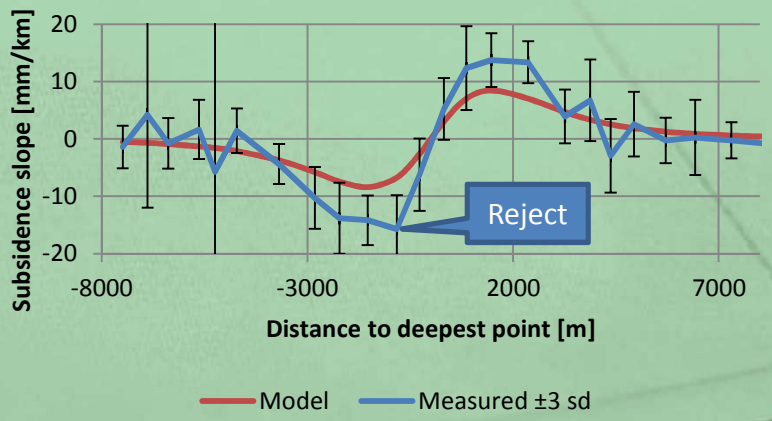
$$Test: \quad \left(z_{ij}^{tu} - \left(h_{ij}^u - h_{ij}^t\right)\right)^T.$$

$$.(AQ_{dh}A^T + BQ_sB^T)^{-1}.\left(z_{ij}^{tu} - \left(h_{ij}^u - h_{ij}^t\right)\right) = b$$

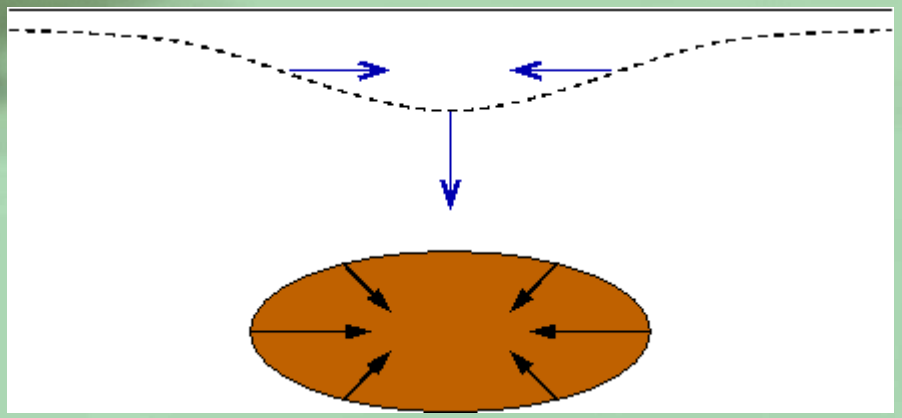
Testing subsidence



Testing deformation



Hypotheses versus distinctive experience



- Alternative hypothesis: Artifact of geodetic data sparsity and salt flow
  - Salt flow known to cause
    - deepening of subsidence in the centre (where geodetic SNR is high)
    - and shallowing at the edges (where geodetic SNR is low).
- Comments:
  - point subsidence not measurable, hence no SNR
  - only height difference between centre and edges measurable
  - data supports deepening in the centre rather than shallowing?
  - is phenomenon present with, absent without salt cover?

Steering whish list

- In situ compaction versus earthquakes
- Description of NAM's FEM
- Moddergat/Nes prognoses on SC website
- Experimental validation of Geertsma
- GPS survey of horizontal deformation
- Drop sparse geodetic data/salt flow hypothesis
- Support for Geertsma's neglected gravity effects, RTCM and slow aquifer depletion