# Probabilistic Design

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# Introduction

## Fedor Baart

PhD thesis: Operational forecasts of morphological effects of storms

## Links

http://citg.tudelft.nl http://www.deltares.nl
http://www.openearth.nl http://www.micore.eu

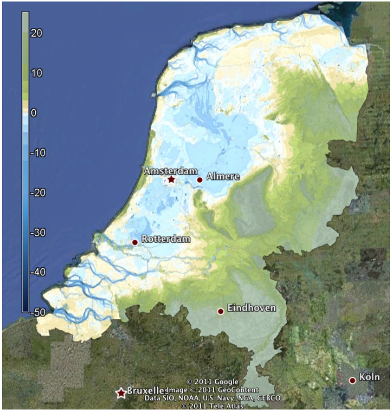
1. the Dutch coast
2. the $^1/_{10000}$ storm
3. sea level rise
4. Alternative approach: respond

# Outline

# The Netherlands below sea level

**Elevation**

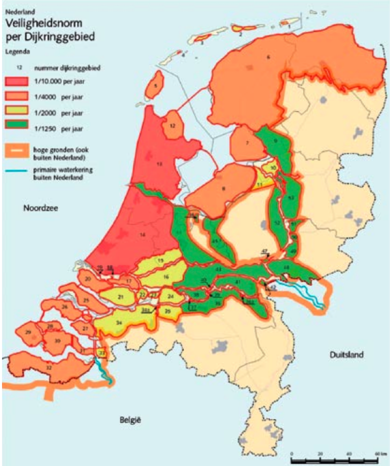
40% Of the Netherlands is below sea level.



# How safe should it be?

**Norm**

Dutch safety standard of 1/10000 (exceedance probability for the Holland Coast per year) is based on economic evaluation of the hinterland.



# How was the $1/10000$ calculated?

## Insurance problem, see Van Dantzig (1956)

$$L = p(h > H) V \sum_{t=0}^{\infty} (1+\delta)^{-t} \qquad (1)$$

$L$ reservation needed to deal with costs of a flood, $p(h > H)$ probability of a flood, $V$ value of the goods, $\delta$ interest rate, $t$ time (years).

## Minimize loss

$$\frac{dI}{dX} + \frac{dL}{dX} = 0 \qquad (2)$$

$I$ cost of heightening the dikes (per meter). $X$ change in dike height.

# What else is important for determining the heights of the dikes

## Other aspects taken into account

1. Increase of wealth
2. Sinking of the land

## Not taken into account

1. Quality/Cost of life
2. Recovery speed/cost
3. Deflation
4. Consequential losses
5. Risk perception

Figure: Sir William Petty

How much confidence do we have in our estimates relevant to our coastal defence?

# Outline

# How big is the 1/10000 storm?

**The size of the 1/10000 storm.**

Over 3m.

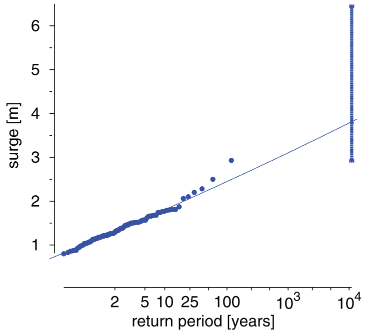



Figure: Confidence interval of storm surge for Hoek van Holland (van den Brink 2004)

# How to reduce the size of the confidence interval?

**The size of the confidence interval**

$$\frac{1}{\sqrt{n}}$$

# How to reduce the size of the confidence interval?

**The size of the confidence interval**

$$\frac{1}{\sqrt{n}}$$

**How to get a bigger $n$?**

- Pre-historic storms
- Historic storms
- Measured storms
- Modelled storms

# Statistical methods

## Peak over threshold

$$F_{(\xi,\mu,\sigma)}(x) = \begin{cases} 1 - \left(1 + \frac{\xi(x-\mu)}{\sigma}\right)^{-1/\xi} & \text{for } \xi \neq 0, \\ 1 - \exp\left(-\frac{x-\mu}{\sigma}\right) & \text{for } \xi = 0. \end{cases} \quad (3)$$

Needs high resolution (multiple measurements per day) time series.

## Block maxima

$$F_{(\xi,\mu,\sigma)}(x) = \exp\left(-\left[1 + \xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right) \quad (4)$$

$$F_{(\mu,\sigma)}(x) = e^{-e^{-(x-\mu)/\sigma}}. \quad (5)$$

Needs information about maximum per year (ordering).

# Available data

| | |
|---|---|
| Pre-historic | information from geological records (–1500) |
| Historic | information from letters, reports, paintings, flood stones (1500–1800) |
| Measured | information from measurements (1800–) |
| Modelled | based on assumptions (–) |

# Goal

### The 3 biggest storms of the 18th century

Use historical records and give an estimate of the size of the biggest storms of the 18th century.

# Ordering

Table: Storms of the 18th century

| Year | Classification [a] | Order [b,*] |
| --- | --- | --- |
| 1715 | D | 5 [c] |
| 1717 | D | 3 |
| 1741 | / | 4 [d] |
| 1775 | D | 1 [e] |
| 1776 | C | 2 [f] |

# The area of interest


Figure: Northern part of the Holland coast. Locations mentioned in presentation

# The Christmas Flood of 1717


Source gallica.bnf.fr / Bibliothèque nationale de France

Figure: Flood map of the 1717 Christmas Flood

# Data for the 1717 storm: paintings

Figure: Paintings from Egmond aan Zee between 1600–1750

- Water levels from Amsterdam
- 1 floodstone
- Letters, poems, reports
- Maps
- Paintings

# Using paintings as a data source

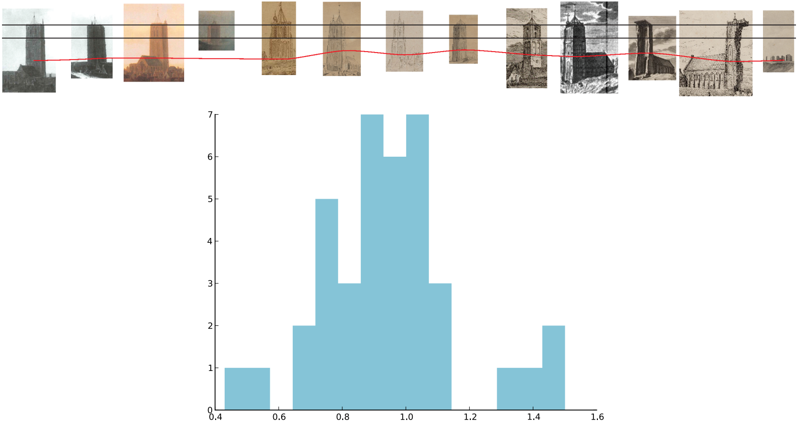



Figure: Estimating painter reliability

# 3D model of Egmond at 1717

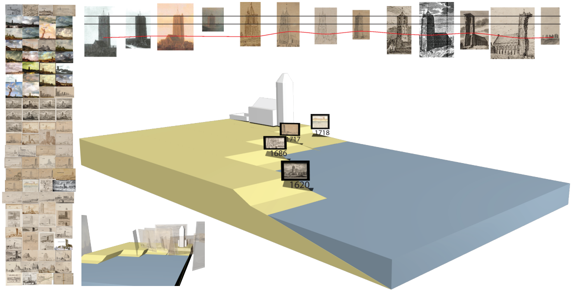



Figure: Reconstruction of erosion in the period 1600–1717

# Post storm profile

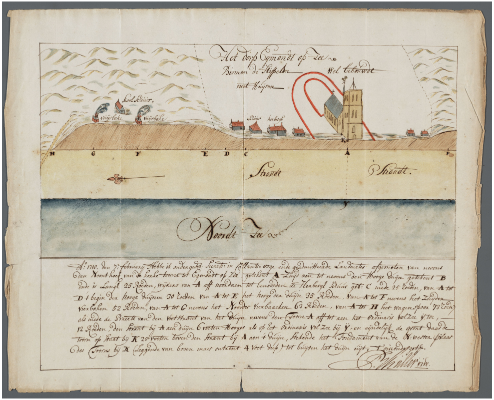



Figure: Post storm measurements (1718).

# Pre and post storm profile

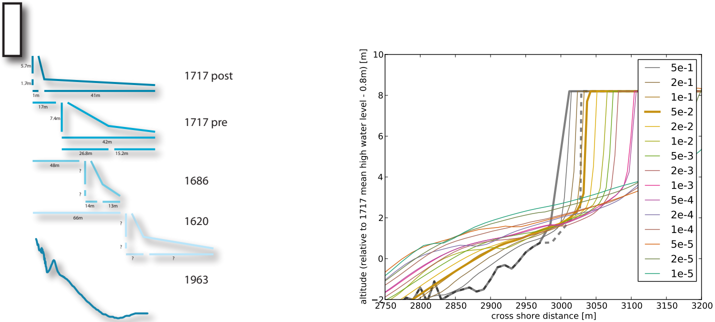



Figure: Estimating the pre and post storm profile. Inverse model the magnitude of the storm.

# The storm of November 1775

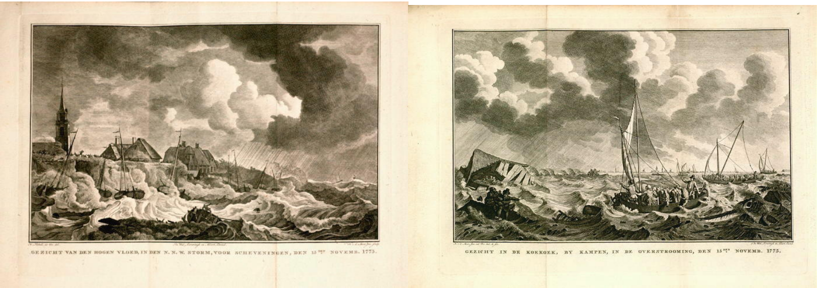



Figure: Paintings of the 14–15 November storm at Scheveningen

# Data for the 1775 storm: shell deposits

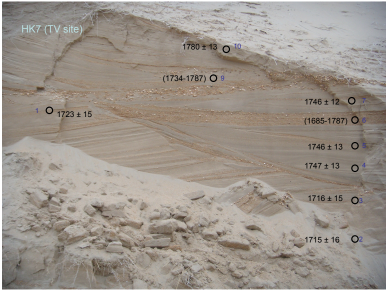



Figure: Shell deposits found after the storm of November 2007, OSL dating by Cunningham, pictures: M. Bakker

# Modelling the 1775 storm

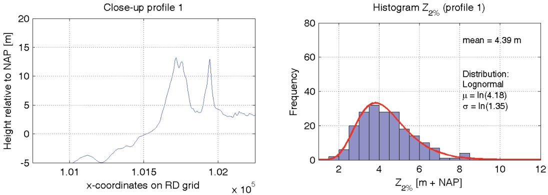



Figure: Modelling the storm run up, source A. Pool

# Modelling the 1775 storm

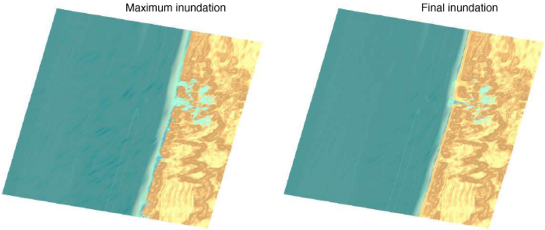



Figure: Modelling the storm run up, source A. Pool

# The storms of the 18th century

Table: Estimated magnitude of the three largest storms of the 18$^{th}$ century

| Year | Water level | Wave height | Wave period | Return period |
|---|---|---|---|---|
| 1717 | 3.1 m | 6.8 m | 10.4 s | 20 years |
| 1775 | 4.6 m | 8.8 m | 13.9 s | 3300 years |
| 1776 | 4.3 m | 8.5 m | 13.4 s | 1300 years |

# The updated confidence interval

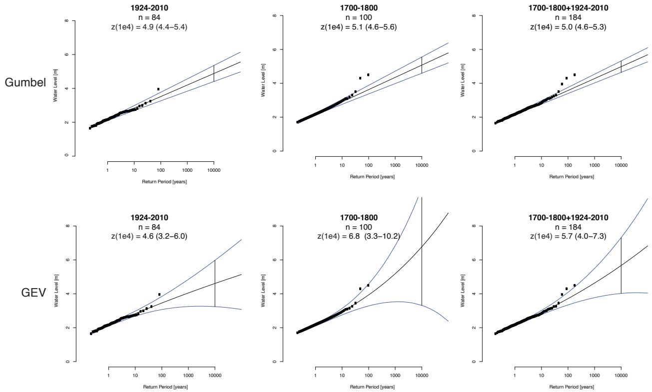



Figure: 30% smaller confidence interval using the Gumbel method. Higher estimate 1.4 with bigger confidence interval using the GEV method.

# Conclusions

**Can we reduce the size of the confidence interval of the $^1/_{10000}$ surge?**

Only if we assume a constant shape.

**Are paintings useful as a data source?**

Yes but multiple paintings should be used because they have a low precision.

# Outline

How much confidence do we have in our sea level rise estimates?

Erosion -

Tide +=

Surge =

Waves =

Sea level +

Subsidence -

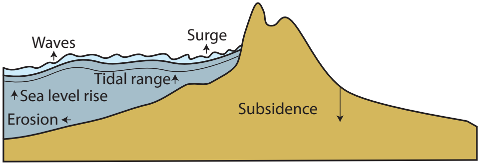



Figure: Possible changes affecting coastal safety

# Erosion

## Erosion

Coast is extending due to extensive nourishments.

Figure: Sand engine, source: Rijkswaterstaat/Joop van Houdt

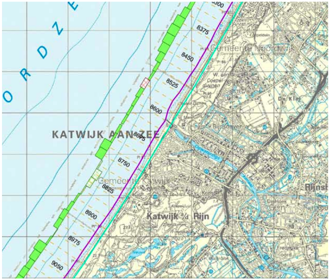
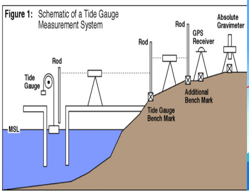
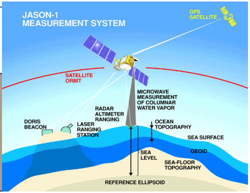



Figure: Growth of coast at Katwijk, source: Kustlijnkaartboek 2011

# Sea level measurements




(a) Tide gauge




(b) Altimetry

(c) Tide gauge

(d) Altimetry

# Sea level rise

## Relative sea level rise

Constant trend of 19cm/century

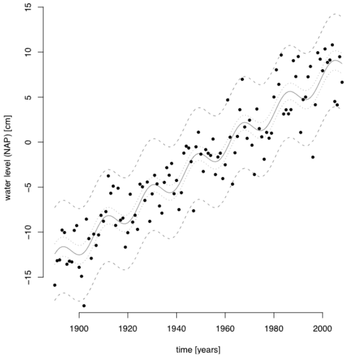



Figure: Sea level rise since 1890

# Spectral analysis

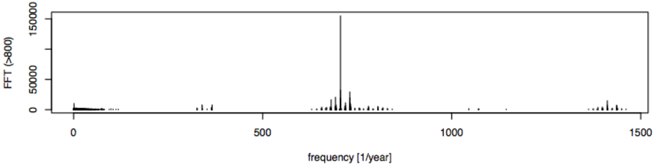



Figure: Spectral analysis of sea level measurements

# Spectral analysis

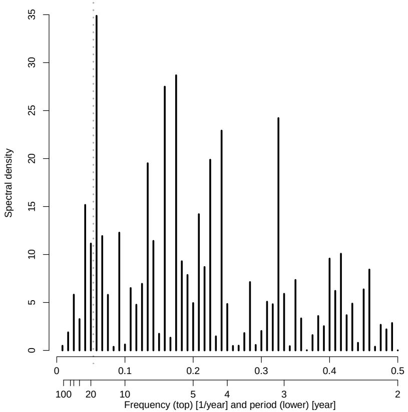



Figure: Spectral analysis of sea level measurements

## Multiple linear regression

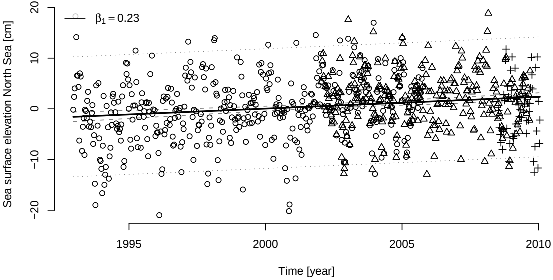
Equation fitted for all stations and satellite grid.

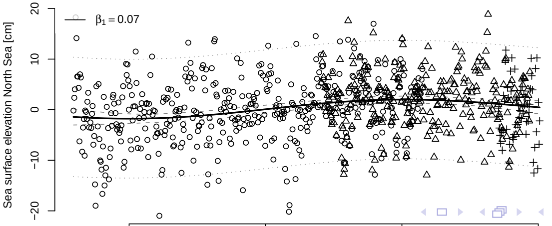
$$h(t) = \underbrace{\beta_0}_{\text{mean level}} + \underbrace{\beta_1 t}_{\text{trend}} \underbrace{(+\beta_2 t^2)}_{\text{acceleration}} + \underbrace{a \sin(\frac{2\pi t}{18.6}) + b \cos(\frac{2\pi t}{18.6})}_{\text{nodal cycle}} \quad (6)$$

$$A = \sqrt{a^2 + b^2} \quad (7)$$

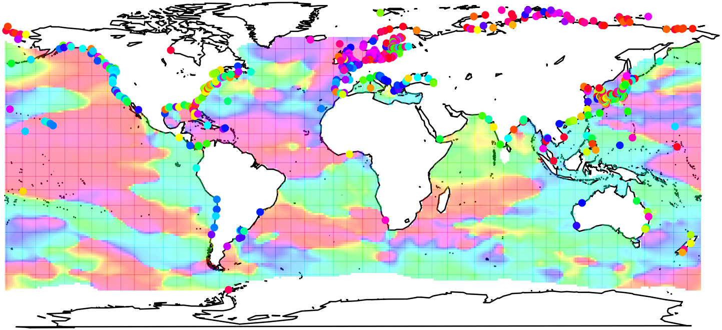
$$\phi = \arctan \frac{a}{b} \quad (8)$$

# Dutch coast


$\beta_1 = 0.23$
Sea surface elevation North Sea [cm]
Time [year]
1995
2000
2005
2010
-20
-10
0
10
20


$\beta_1 = 0.07$
Sea surface elevation North Sea [cm]
-20
-10
0
10
20

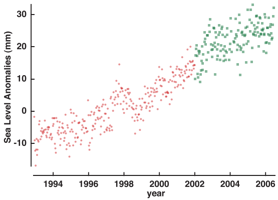
# Global effect



# Trends

## Global trends

Based on global tide gauges and recently on satellites.




| | |
|---|---|
| 1900 - 1979 | 0.175 cm/year [?] |
| 1993 - 2001 | 0.25 cm/year [?] |
| 1993 - 2003 | 0.28 cm/year [?] |
| 1993 - 2003 | 0.31 cm/year [?] (based on [?]) |

# Estimates and scenarios

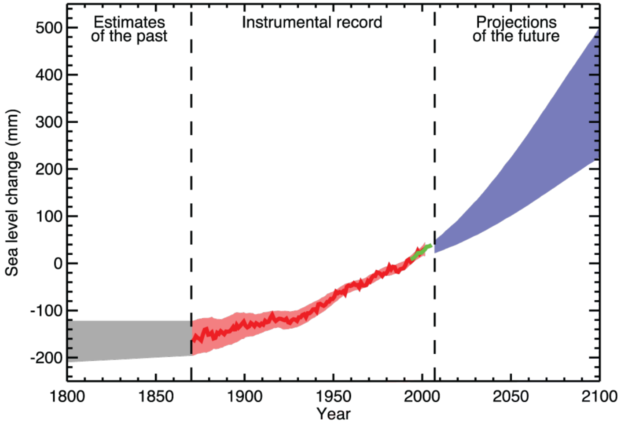
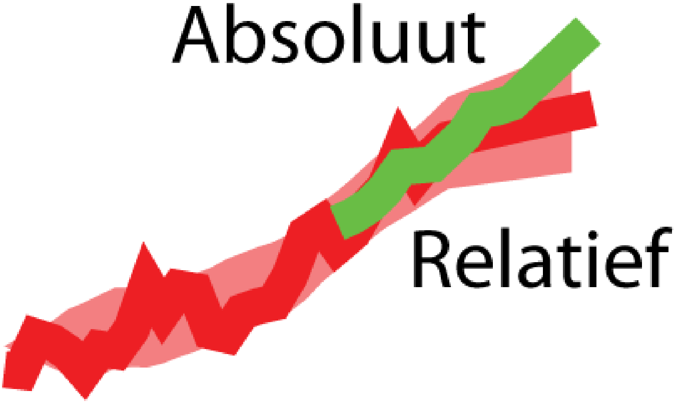



Figure: Sea level rise, source IPCC

# Estimates and scenarios



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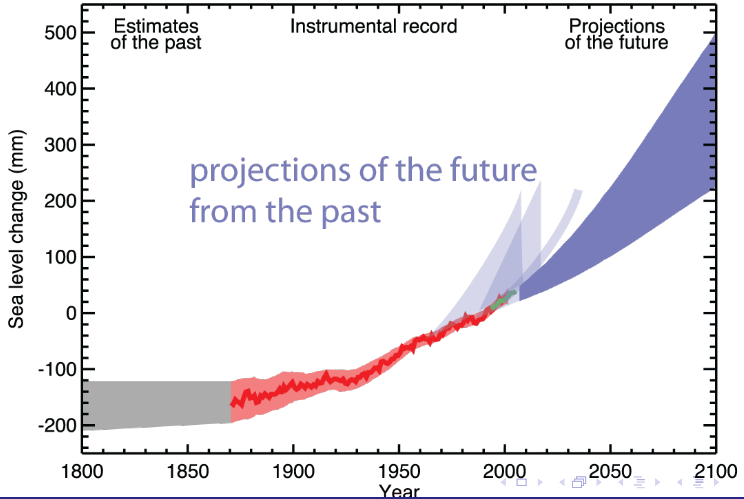
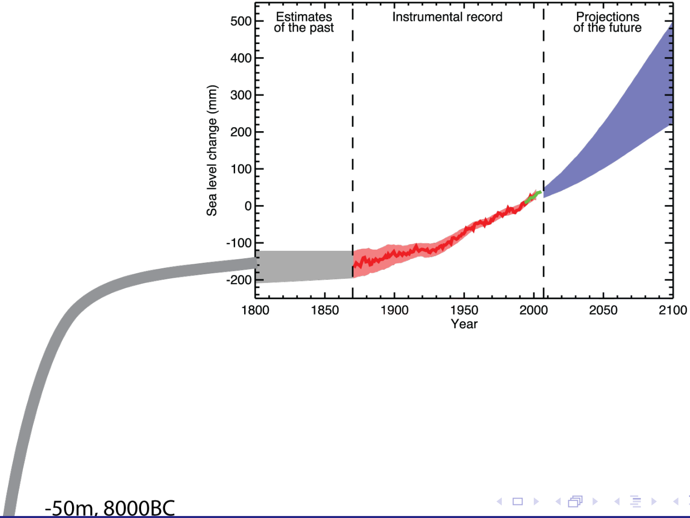


# Estimates and scenarios



# Paintings

## Sea level trends in Venice.

Using paintings as a source for sea level rise estimates.

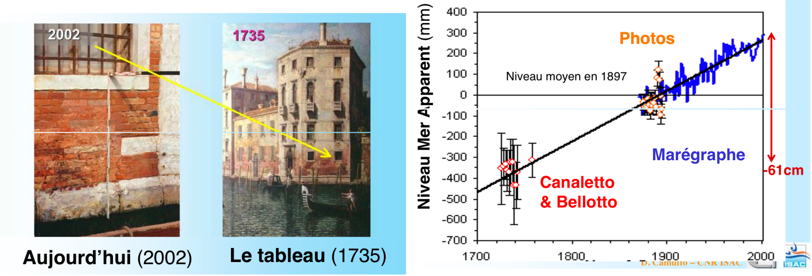



Figure: Sea level rise (source: D. Camuffo 2010)

# Outline

# Operational modelling

## Forecasts

Predicting coastal changes 3 days ahead.

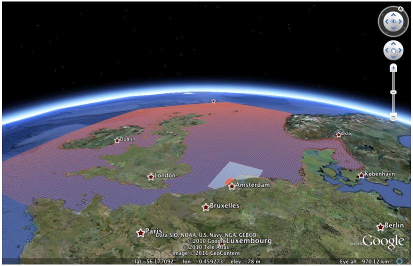



Figure: Operational model for coastal morphology (Baart et al 2009)

# Operational modelling

## Forecasts

Improvements to several aspects of the operational coastal morphological model.

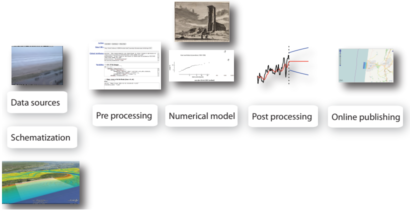



Figure: Improvements to several aspects of the operational coastal morphological model.

# Improving the coverage

## From local empirical model (applicable to 60%) to a general numerical model (applicable to 90%)

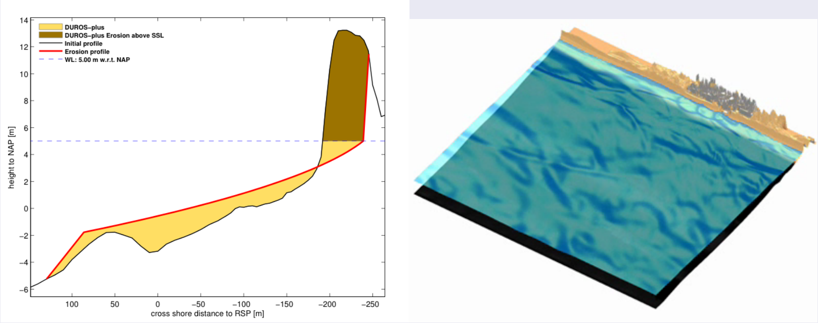



Figure: Duros 1D model versus XBeach 2D model, http://www.xbeach.org

# Open Source models

## Delft3D

Open source modules: FLOW, MOR, WAVE. XBeach

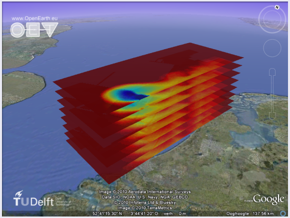



Figure: Delft3D simulation of Rhine rofi, source: De Boer, http://oss.deltares.nl

## OpenEarth

Collaboration to share data model and tools.

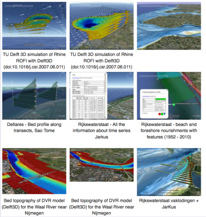



Figure: Visualizations made with OpenEarthTools, http://www.openearth.eu

# Fill your toolbox

## Relevant tools

- **Python** Good for scripting and programming, glue, numerics, plots.
- **R** Preferred language by statisticians.
- **osgeo** Set of open source GIS tools.

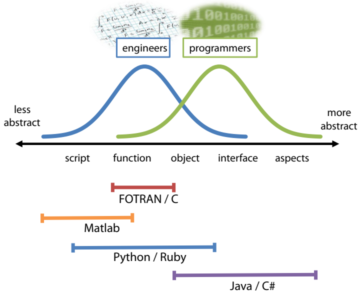



Figure: Application of programming scripting languages

# Operational modelling

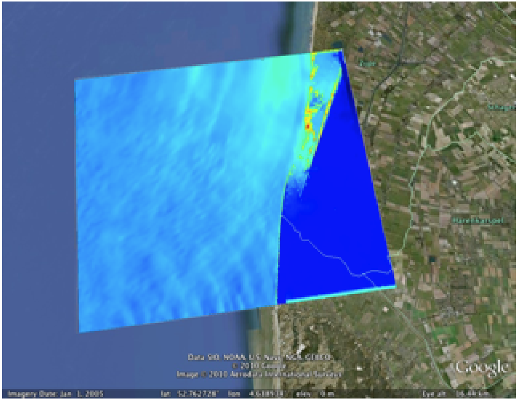


Figure: Forecasting water levels and currents nearshore and erosion

Figure: Swimmer simulator

# Response measures

Figure: Twee gebroeders, 1953

Figure: Research: Emergency measures Delfland, Walstra et al

# Ensemble forecasts

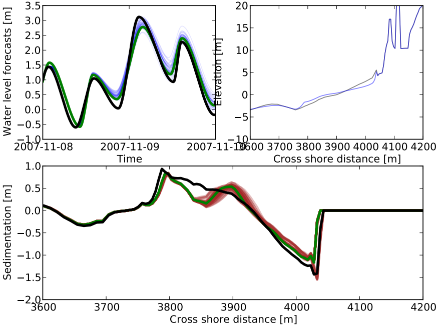



Figure: Ensemble forecasts during the November 2007 storm

Figure: XBeach model of Petten met hyperstorm ($p < 1/10000$).

# References

P H A J M van Gelder.
*Statistical methods for the risk-based design of civil structures.*
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J van Malde.
Historische stormvloedstanden.
Technical Report 2003.08.1, Aqua Systems International, August 2003.