Morphodynamics of Borssele Wind Farm Zone

Meeting "*Tender Borssele*"

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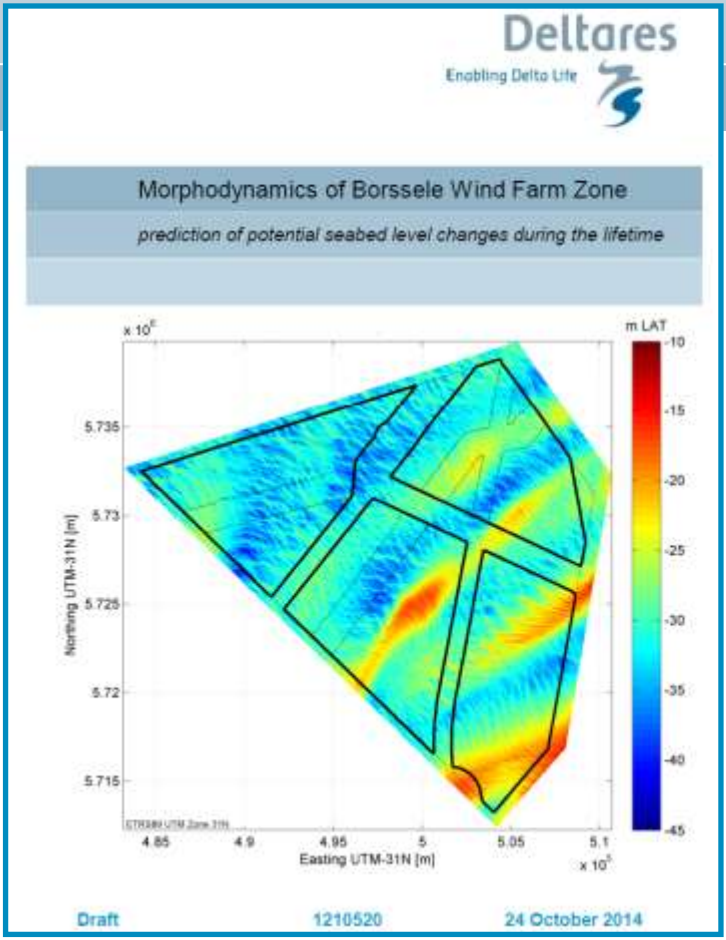
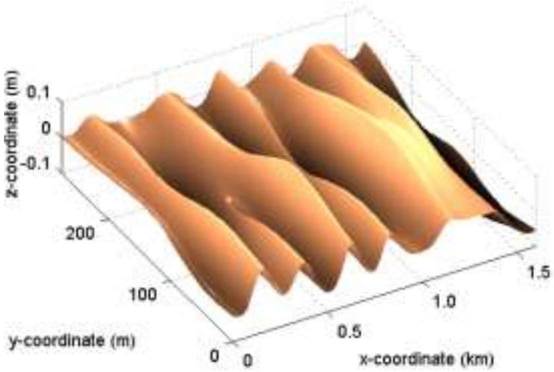


Contents of presentation



- ➢ Introduction Deltares
- ➢ Introduction Morphodynamics
- ➢ Methodology
- ➢ Results
- ➢ Conclusions and recommendations (for 2nd phase)
- ➢ Ideas for future developments





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Introduction to Deltares

Deltares is an **independent** institute for **applied research** in the field of **water, subsurface and infrastructure**.

- merger since 2008 of WL | Delft Hydraulics, GeoDelft and parts of TNO and Rijkswaterstaat
- applied research & specialist consultancy
- independent: serving companies and governments
- focus on safety against flooding, availability of resources (energy, raw materials and water) and ecology
- extensive hydraulic/geotechnical laboratories and computer modeling facilities
- open-source policy: “dare to share”

- > 800 staff (mostly MSc/PhD), > 28 nationalities
- main offices in Delft and Utrecht, The Netherlands
- branch offices in Singapore, USA, Jakarta, Abu Dhabi/Dubai, Rio de Janeiro

Deltares’ campus in Delft

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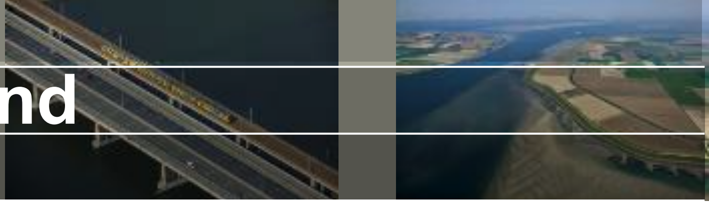
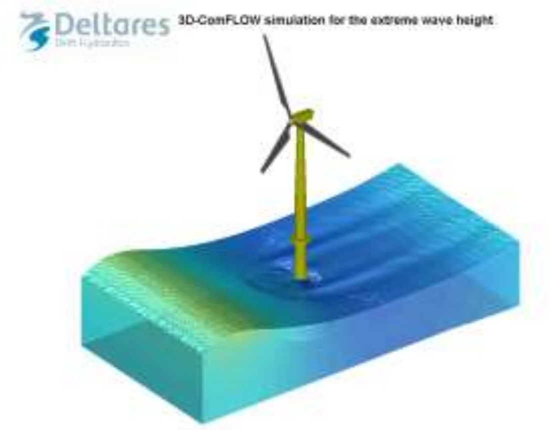


Deltares' activities in offshore wind

Hydrodynamics
- ✓ Metocean/environmental conditions (waves, currents, water levels)
- ✓ Operational forecasting systems (for installation and O&M)
- ✓ Wave loads / impacts on foundations



Geotechnics
- ✓ Geotechnical design of foundations (e.g. cyclic liquefaction)
- ✓ Pile installation techniques (impact-driving, vibrating)
- ✓ Cable burial techniques (jetting, ploughing, trenching, self-burial)
- ✓ External threats to electricity cables (anchors, fishnets, objects)

Morphology & morphodynamics
- ✓ Offshore geology, seabed characteristics
- ✓ Scour and scour protection of all kinds of foundations
- ✓ Bed level changes due to morphodynamics (e.g. sand waves)
- ✓ Cable routing and site selection in morphodynamic areas

Offshore surveying
- ✓ One-sweep-survey

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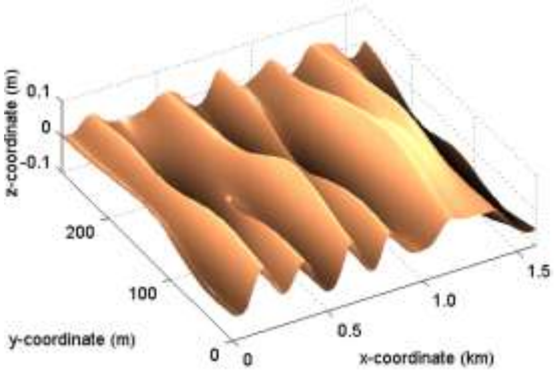

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Overview of offshore morphodynamic seabed features

	Length	Height	Mobility	Threat to Cables
Ripples:	Centimeters	Centimeters	Mobile and Transient	Minimal
Mega-Ripples:	10s of meters	Decimeters	Mobile and Transient	Minimal
Sand Waves:	100s of meters	Meters	Mobile and Persistent	Large
Sand Banks:	Kilometers	10s of meters	Stationary	Minimal

Overview of offshore morphodynamic seabed features

	Length	Height	Mobility	Threat to Cables
Ripples:	Centimeters	Centimeters	Mobile and Transient	Minimal
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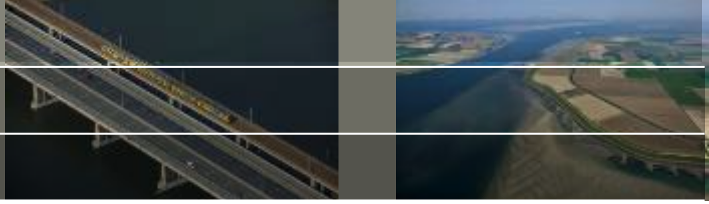
Sand Waves:				
Sand Banks:	Kilometers	10s of meters	Stationary	Minimal

Ripples and Mega-Ripples too low

&

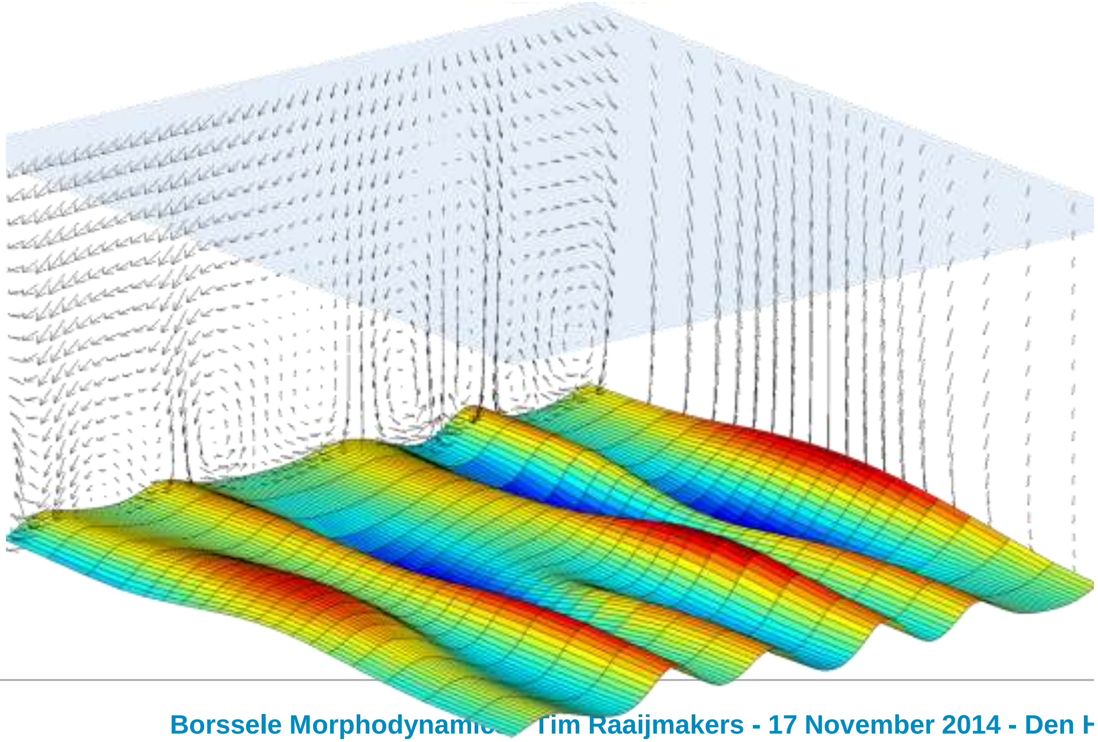
Sand Banks too slow

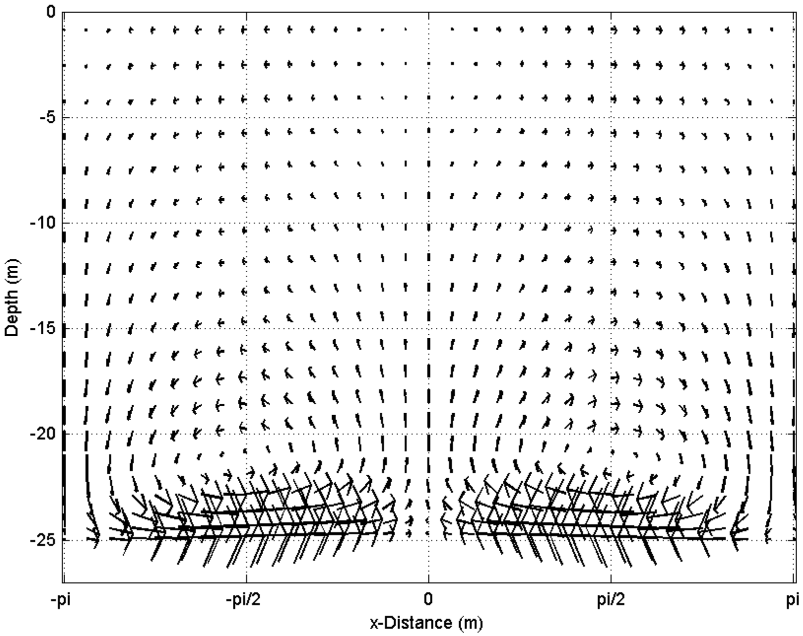


Sand Wave Morphodynamics

- Inherent property of sandy seabeds
- Development due to tidally averaged recirculation cells
- Global phenomenon!

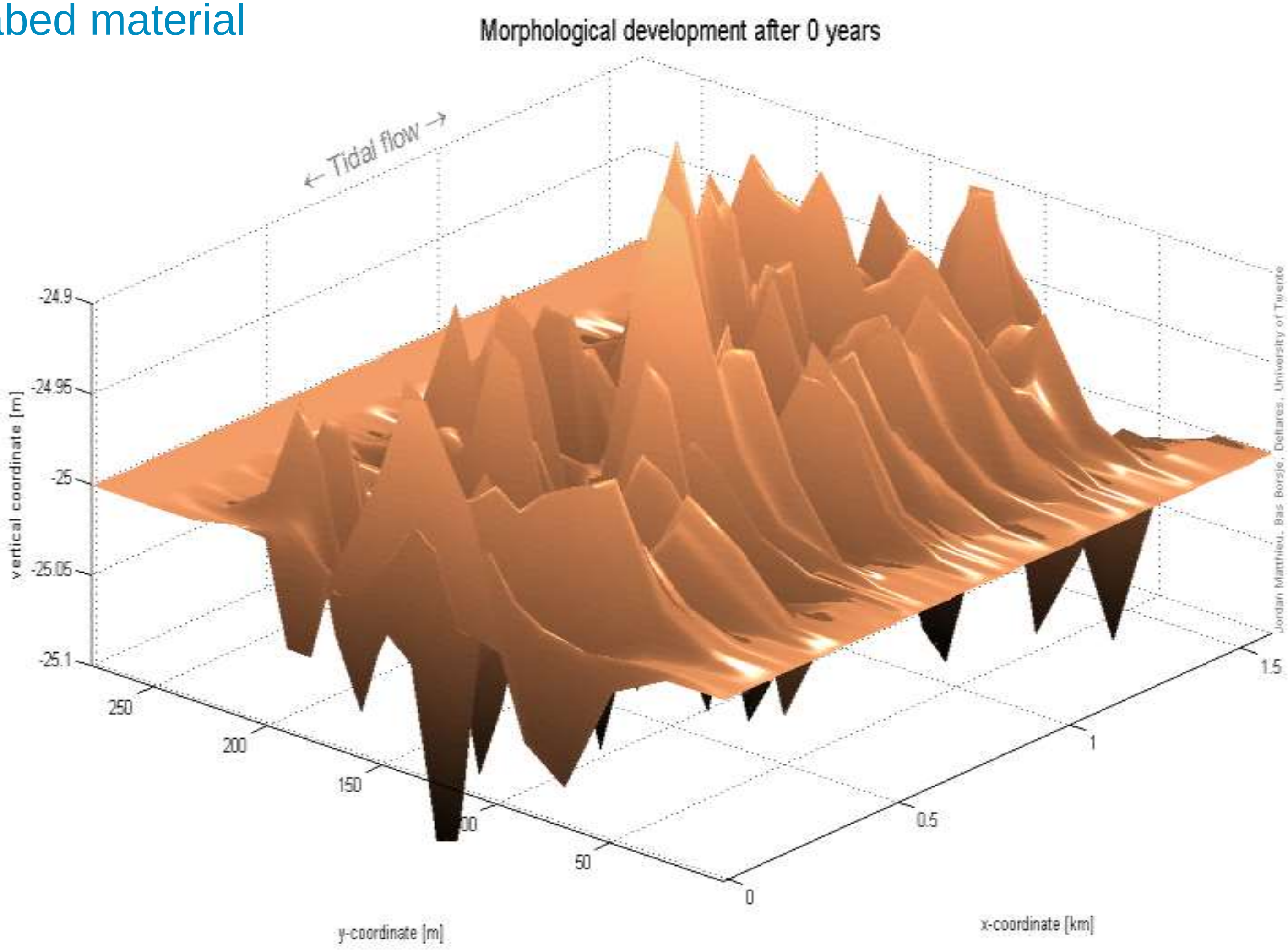
- Sand wave length: typically 200-600 meters
- Sand wave height: 10-30% of the water depth
- Migration Rate: up to 10s of meters per year





Example of Sand Wave Model in Delft-3D

Self-organizing of random bed perturbations into natural sand wave fields that belong to the local hydrodynamic forcing, water depth and seabed material



Sand waves and their environmental dependencies

Migration Rate:

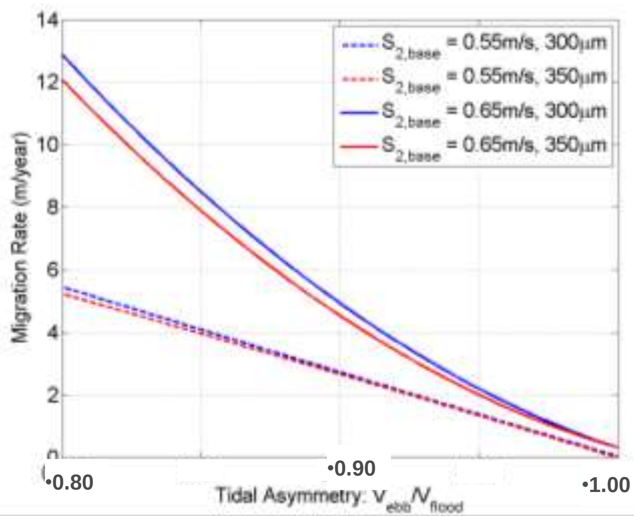
- Grain size
- Tidal asymmetry
- Wave length

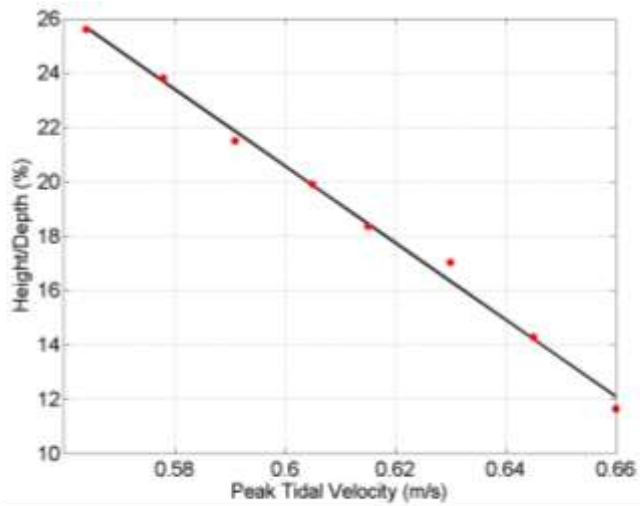
Amplitude:

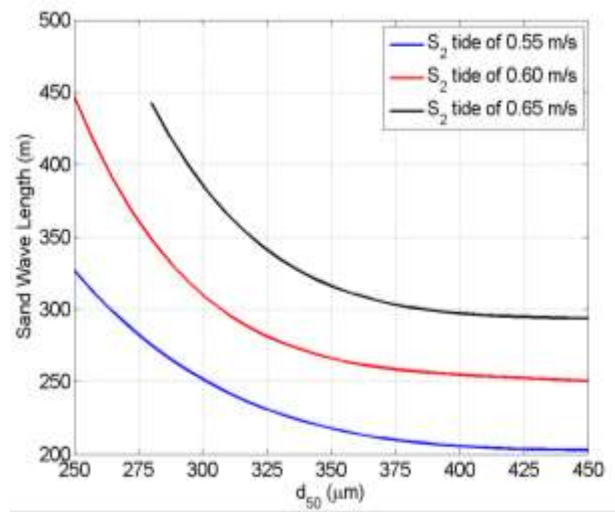
- Grain size
- Tidal asymmetry
- Peak tidal velocity
- Water depth

Wavelength:

- Grain size
- Peak tidal velocity







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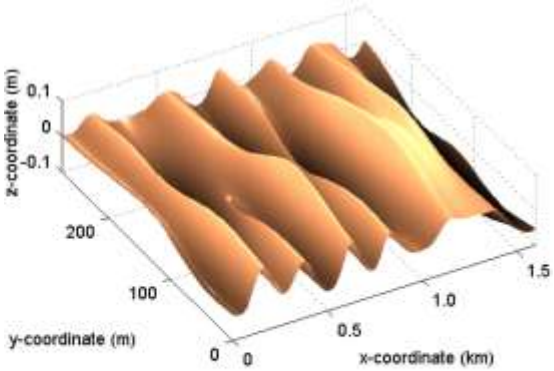

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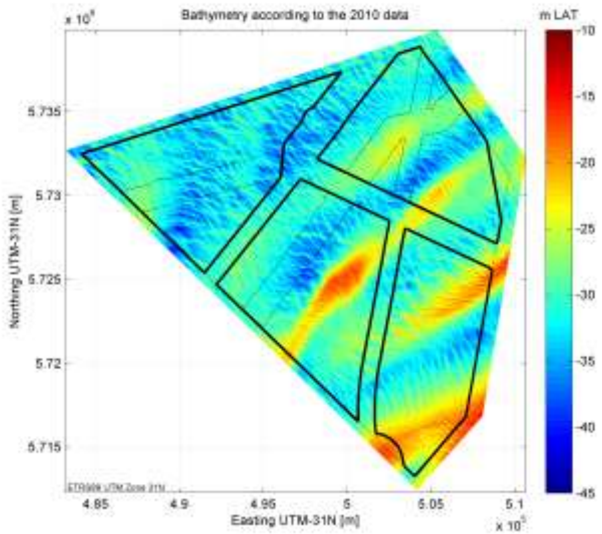
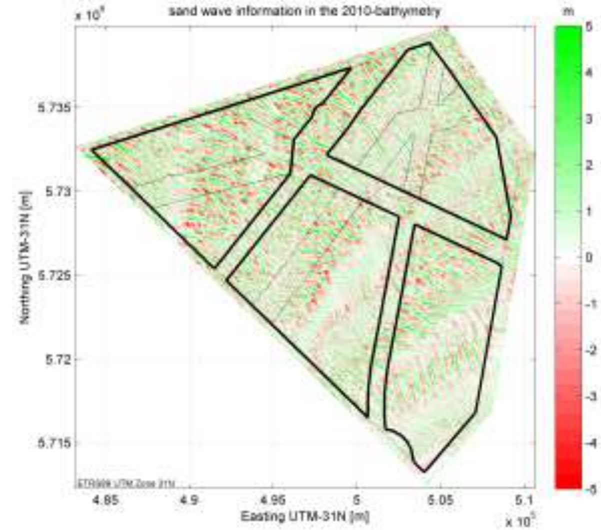
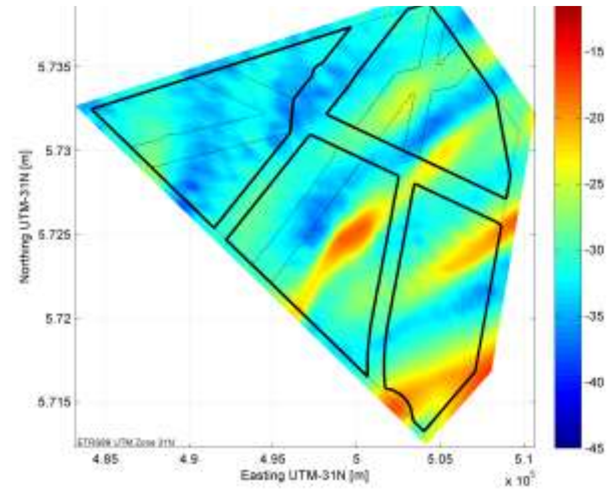
Methodology – Bathymetric filtering

- Large scale filtering (700m)
- Obtain “static” bathymetry
- Obtain sand wave field







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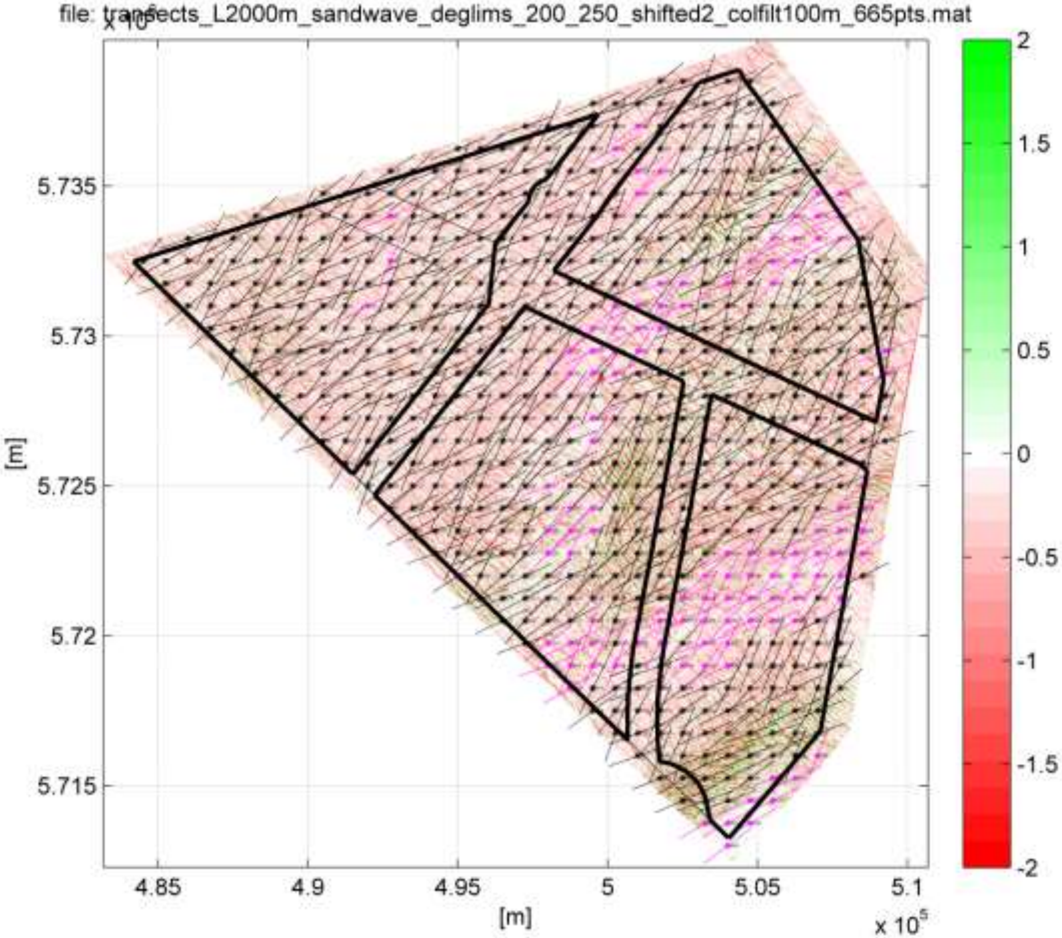
Methodology – Determination of bed form migration

- Analyze sand wave fields at many different transects
- Determine migration directions by finding the best fit (optimizing cost function)



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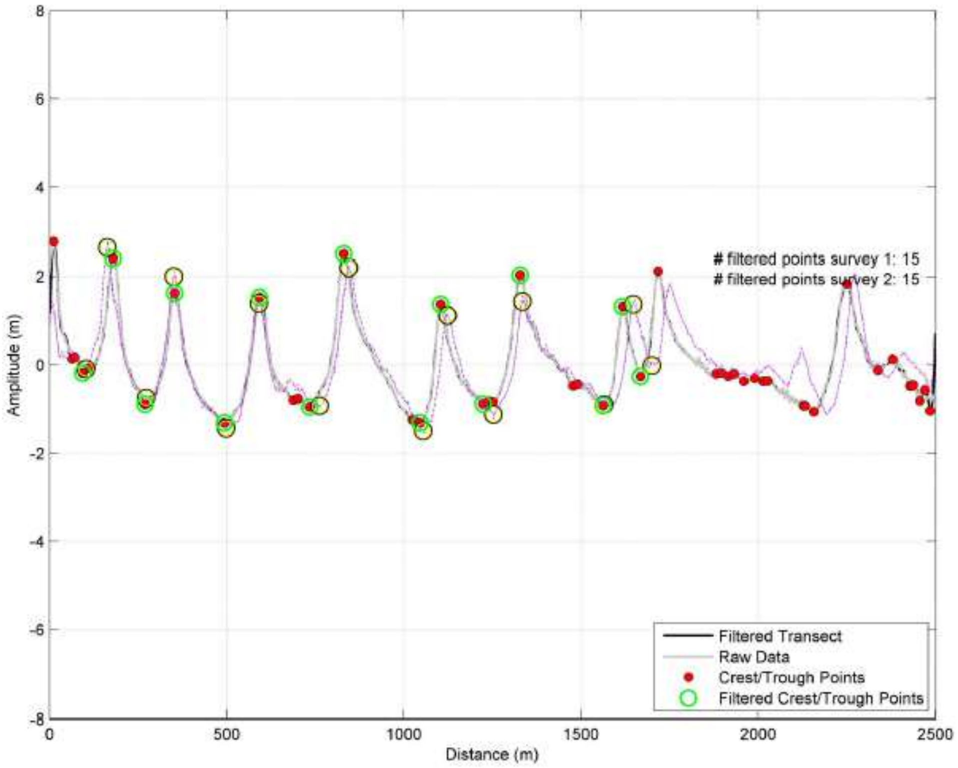
Methodology - Fourier analysis on transects

- Identify crests and troughs
- Track identified points
- Obtain statistics per transect

- Some manual steps:
  - Check each transect
  - Generation / extinction of waves

- Results in sand wave statistics



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Design Seabed Levels

Reference SeaBed Level (RSBL)

The lowest possible seabed level during the lifetime of the wind parks

RSBL = Static Seabed Level - Max. Negative Surrounding Sand Wave Amplitude

Maximum SeaBed Level (MSBL)

The highest possible seabed level during the lifetime of the wind parks

MSBL = Static Seabed Level + Max. Positive Surrounding Sand Wave Amplitude

- Both are dependent on chosen lifetime of OWPs and accuracy of 1) migration direction, 2) migration rate and 3) sand wave height.
- The first two are quite uncertain and variable in Borssele and are expected to be determined more accurately in the 2^{nd} phase
- Therefore, for now (1^{st} Phase) the RSBL and MSBL are conservatively determined by surrounding sand wave height only
- To cover for shape changes and survey inaccuracies the 99% lowest and highest seabed levels in an surrounding area of 2000m are used

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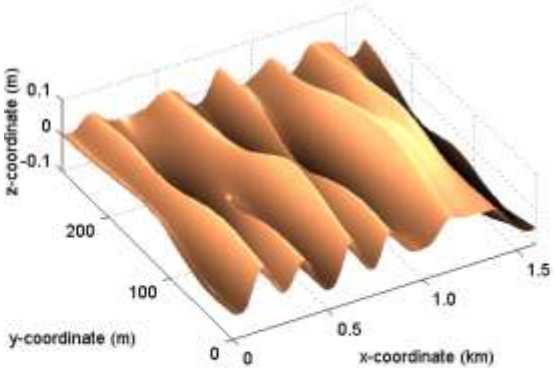

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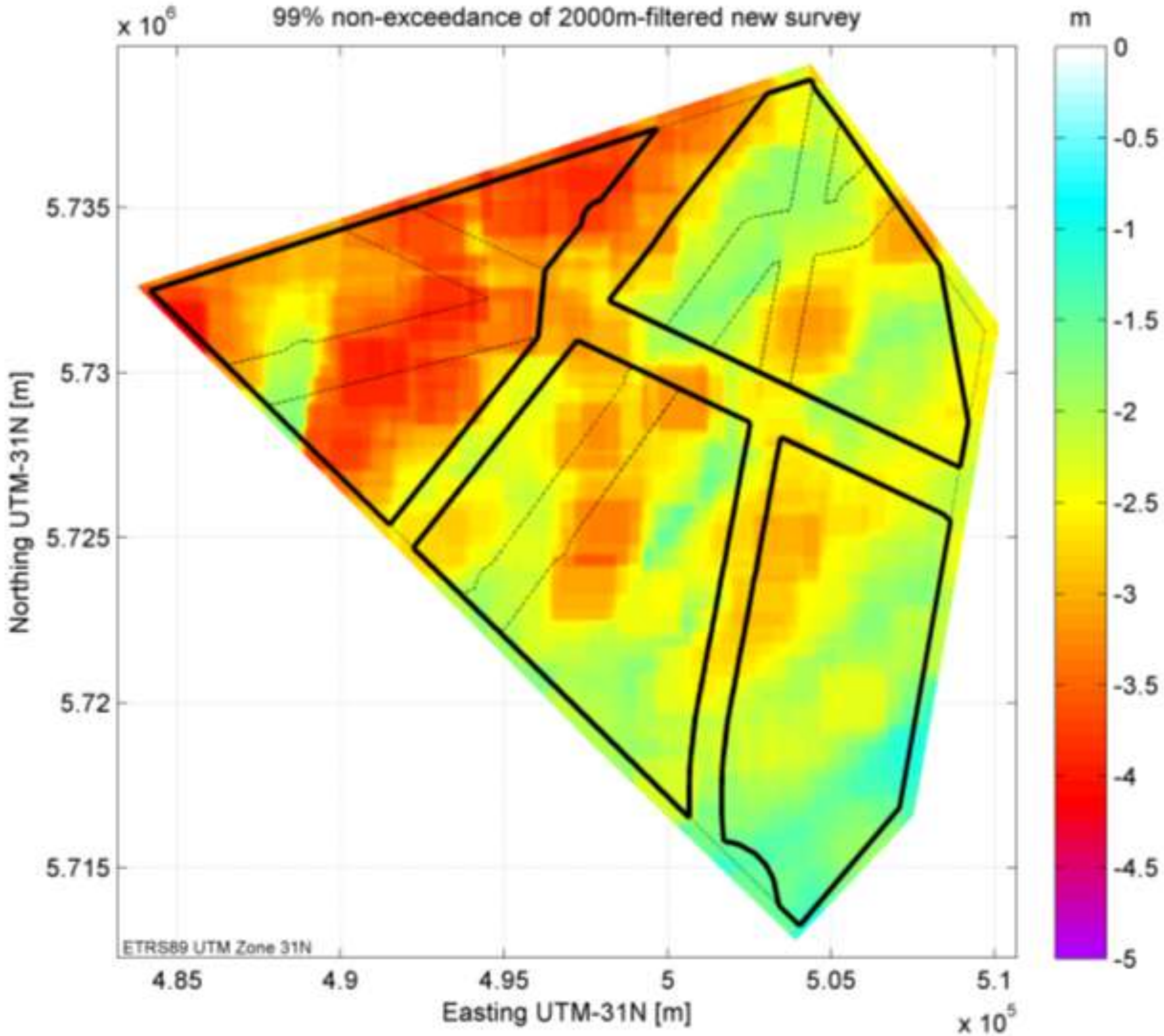
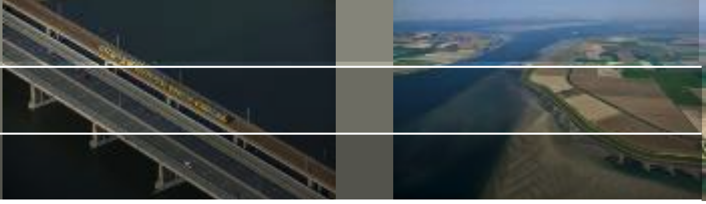
Results – determining sand wave troughs

- Conservative estimate for nearby sand wave troughs
- Determined by 99% non-exceedance values of trough levels
- Sand wave troughs are clear deeper in the NW (deeper area)



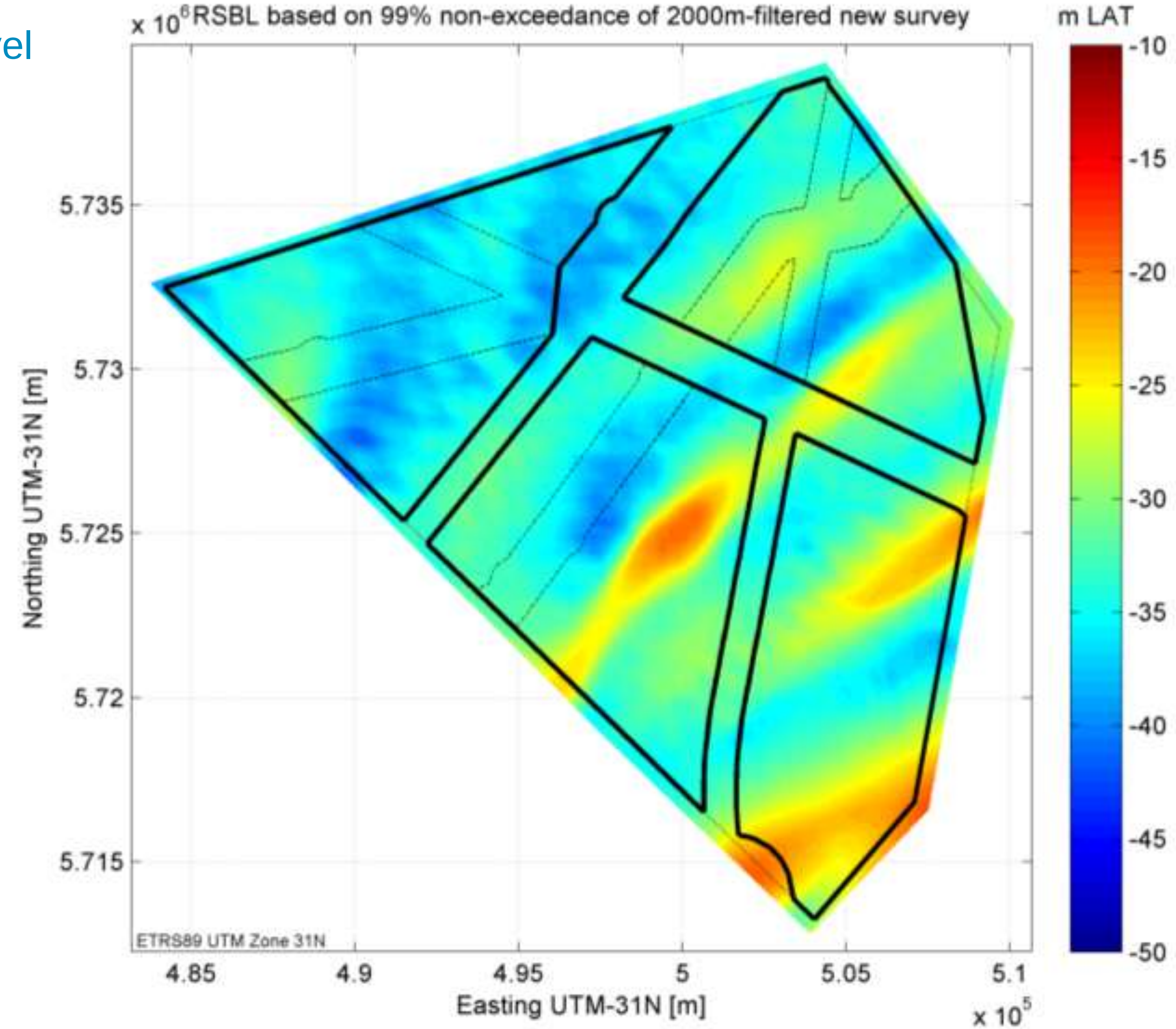


Results – determining RSBL

RSBL: Reference SeaBed Level (in areas of 2000m)

The lowest possible seabed level during the lifetime of the wind parks

RSBL = Static Seabed Level - Max. Negative Surrounding Sand Wave Amplitude



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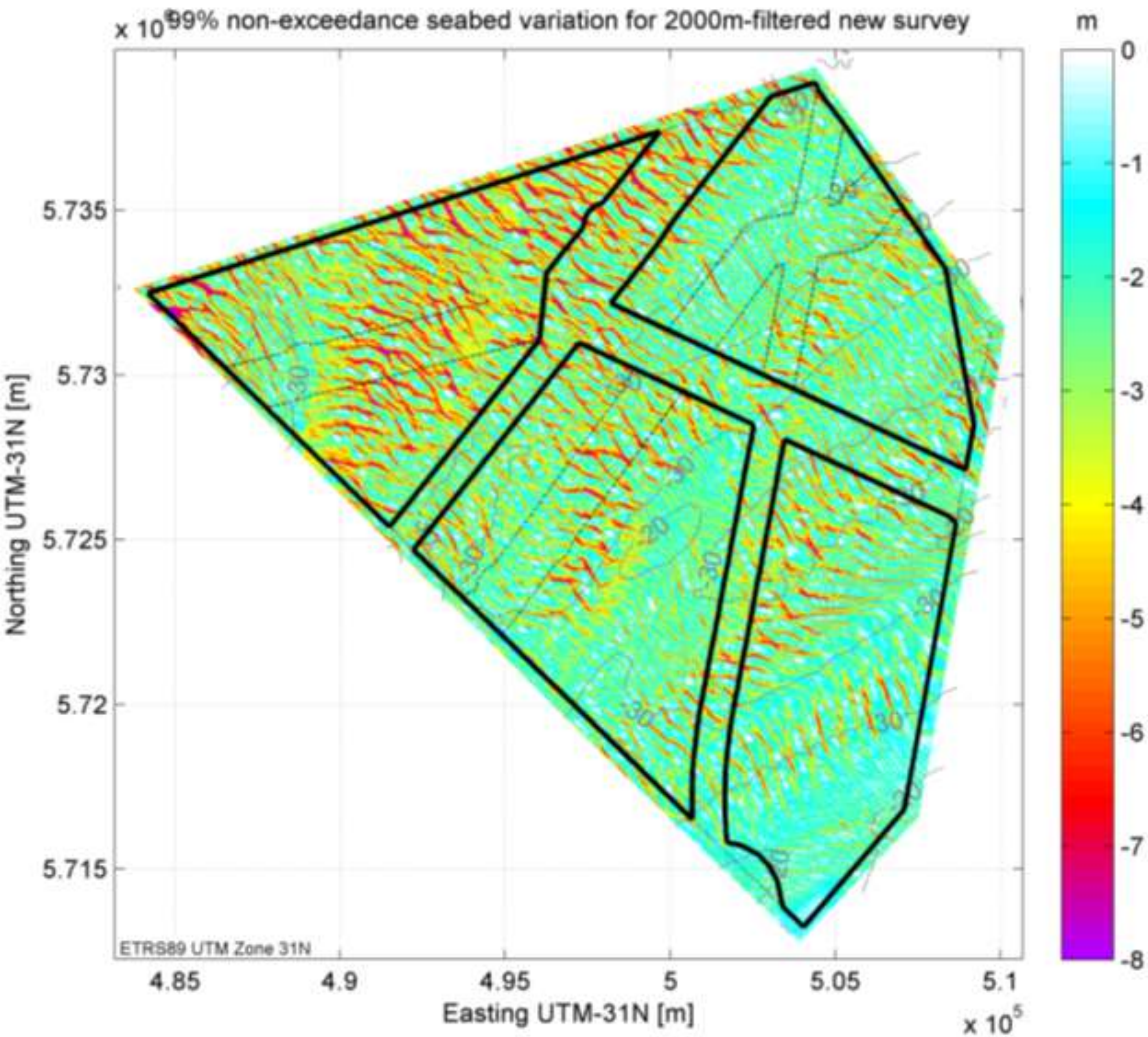
Results – determining RSBL

99% non-exceedance downward seabed variation



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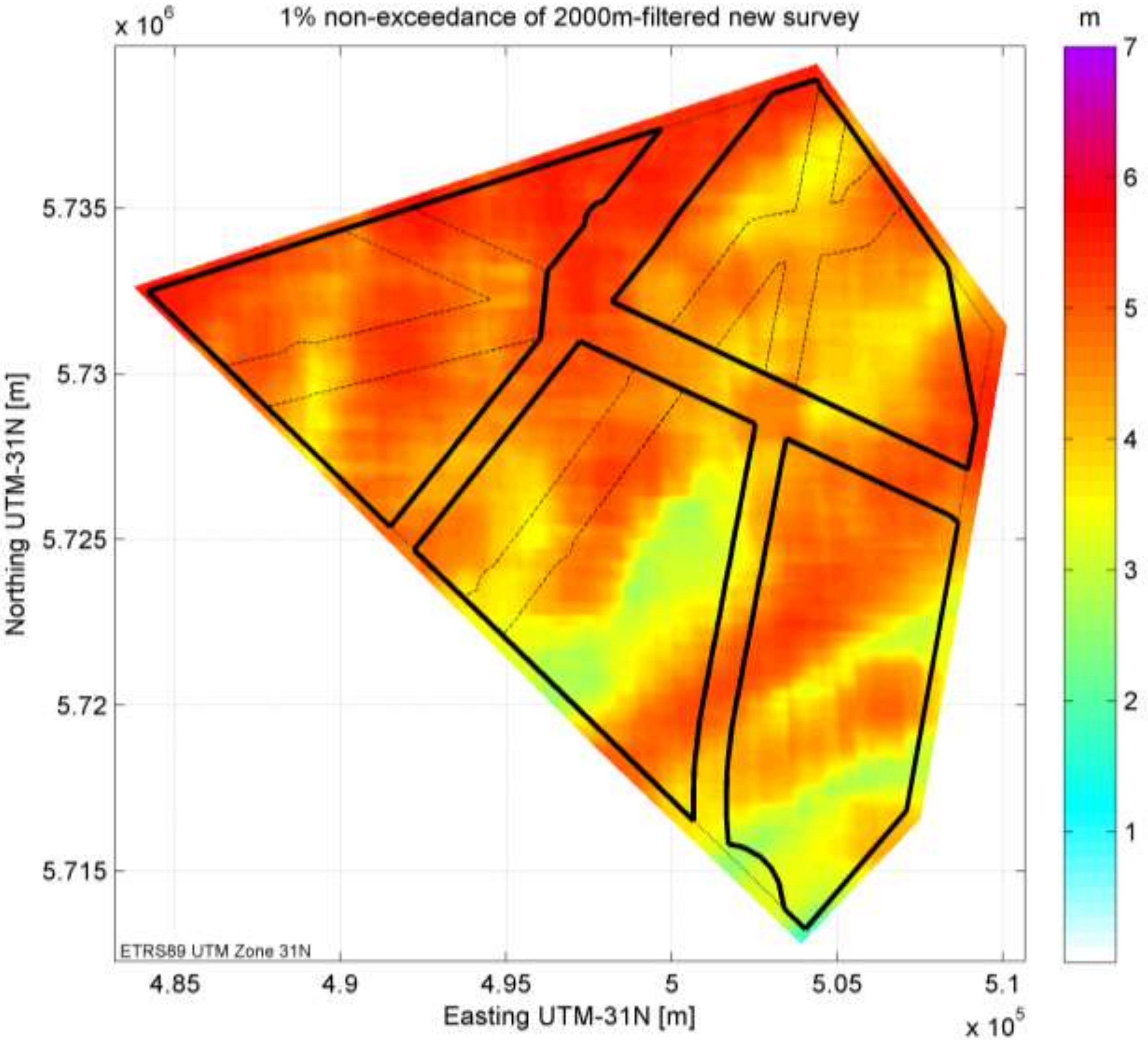
Results – determining sand wave crests

Maximum Sand Wave Crest Level (in areas of 2000m)



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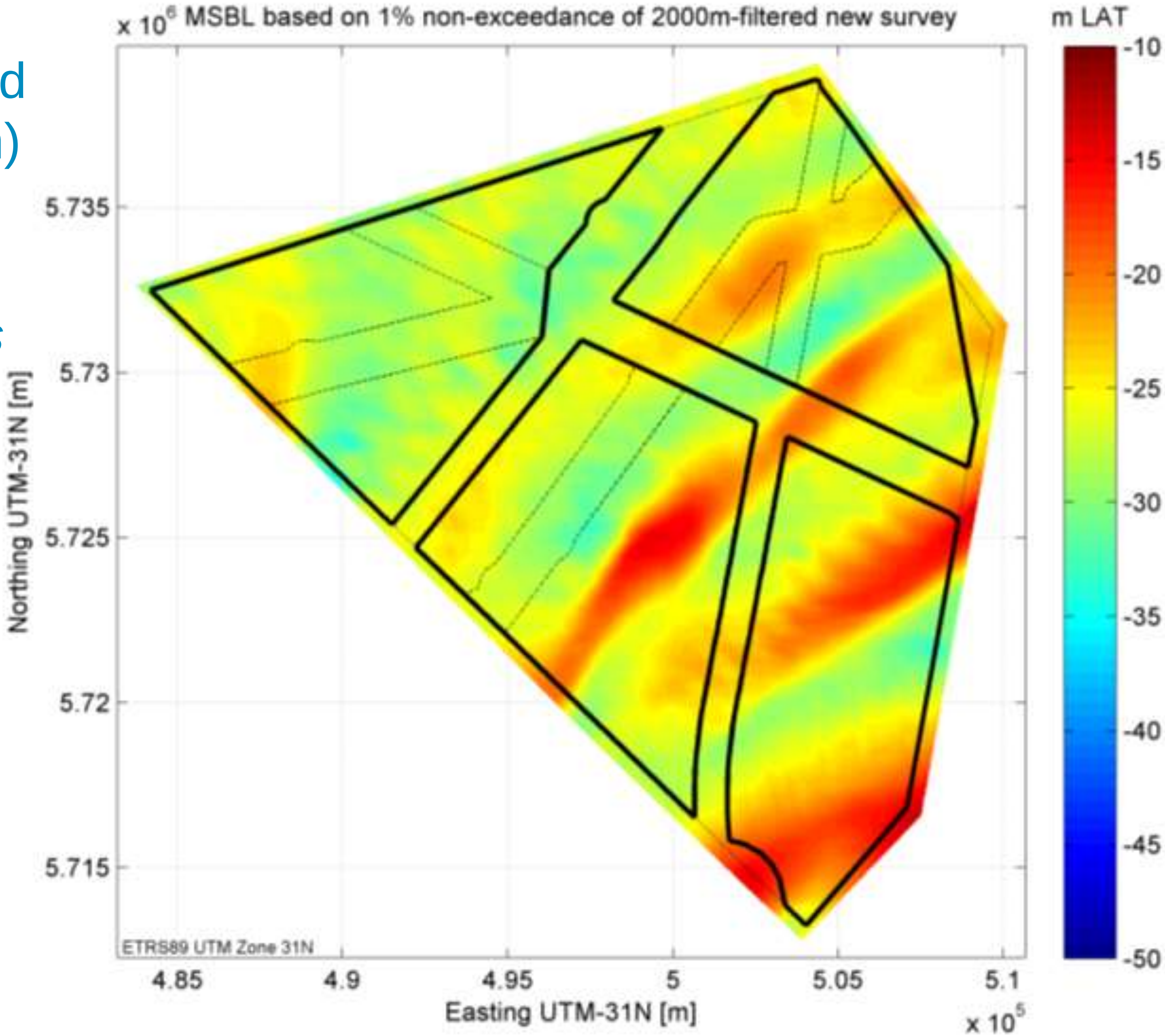
Results – determining MSBL

MSBL: Maximum SeaBed Level (in areas of 2000m)

The highest possible seabed level during the lifetime of the wind parks

MSBL = Static Seabed Level + Max. Positive Surrounding Sand Wave Amplitude



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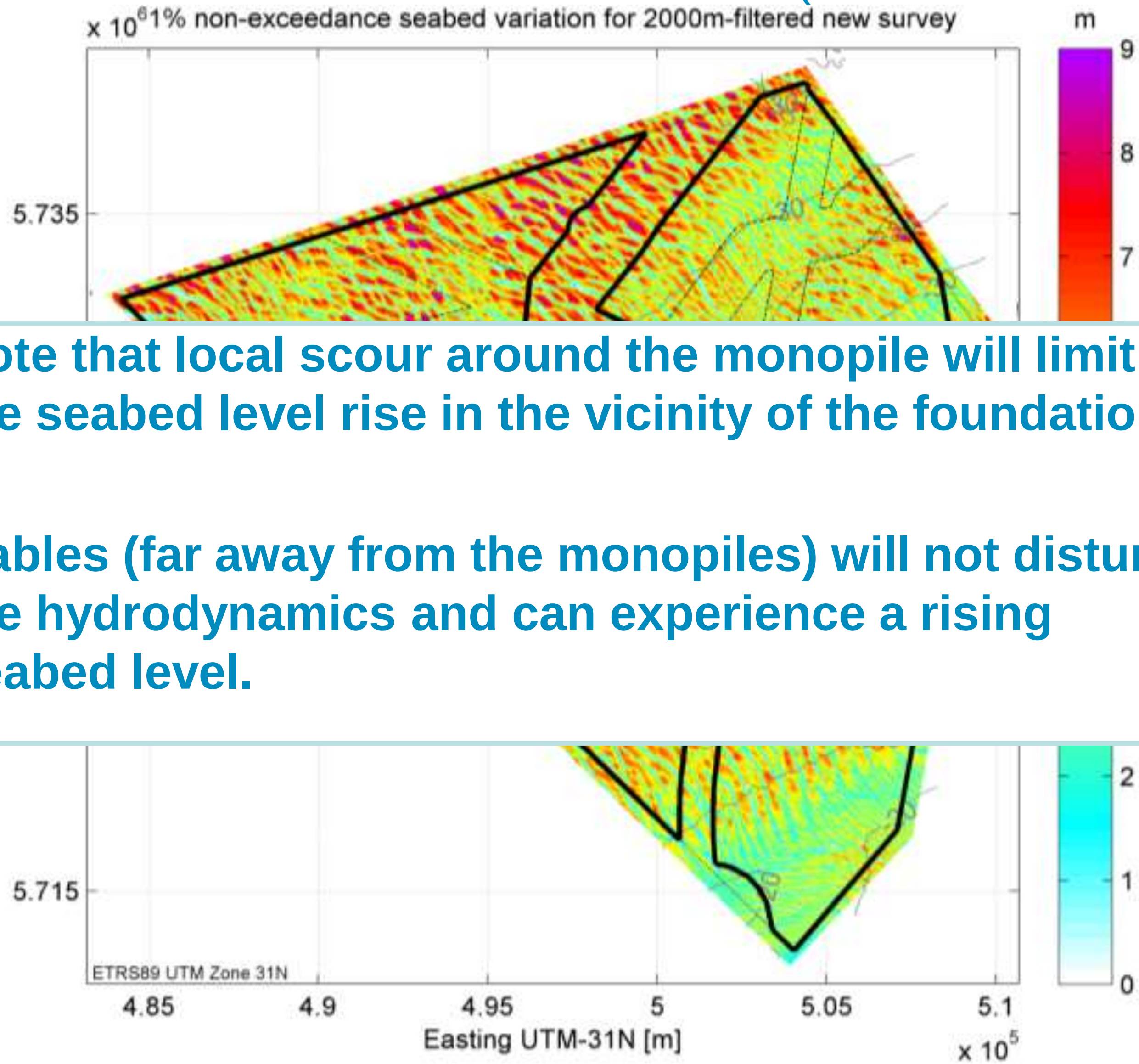
Results – Maximum Potential Seabed Level Rise

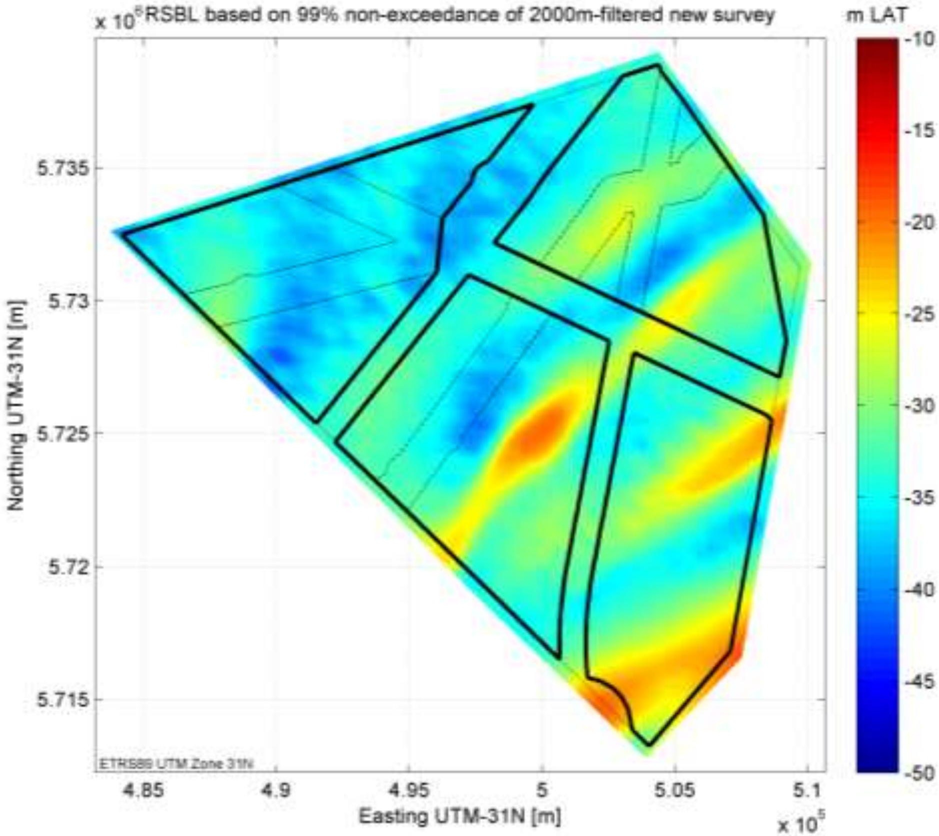
Maximum Potential Seabed Rise (in areas of 2000m)

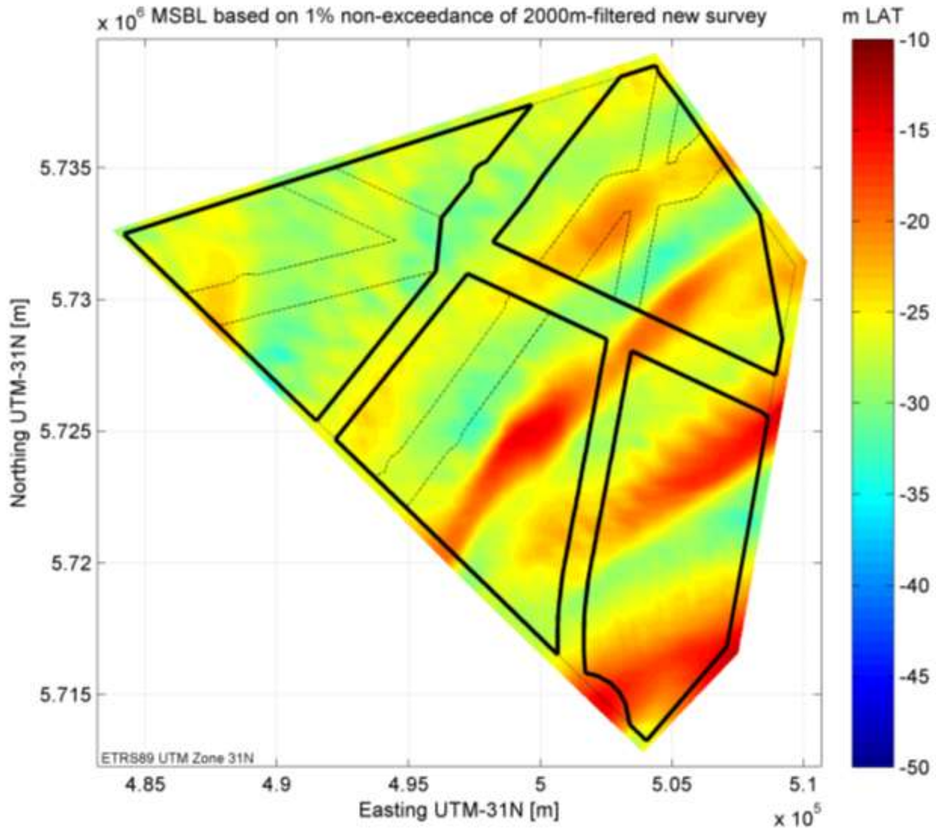


Note that local scour around the monopile will limit the seabed level rise in the vicinity of the foundation!

Cables (far away from the monopiles) will not disturb the hydrodynamics and can experience a rising seabed level.

Results – comparing RSBL with MSBL





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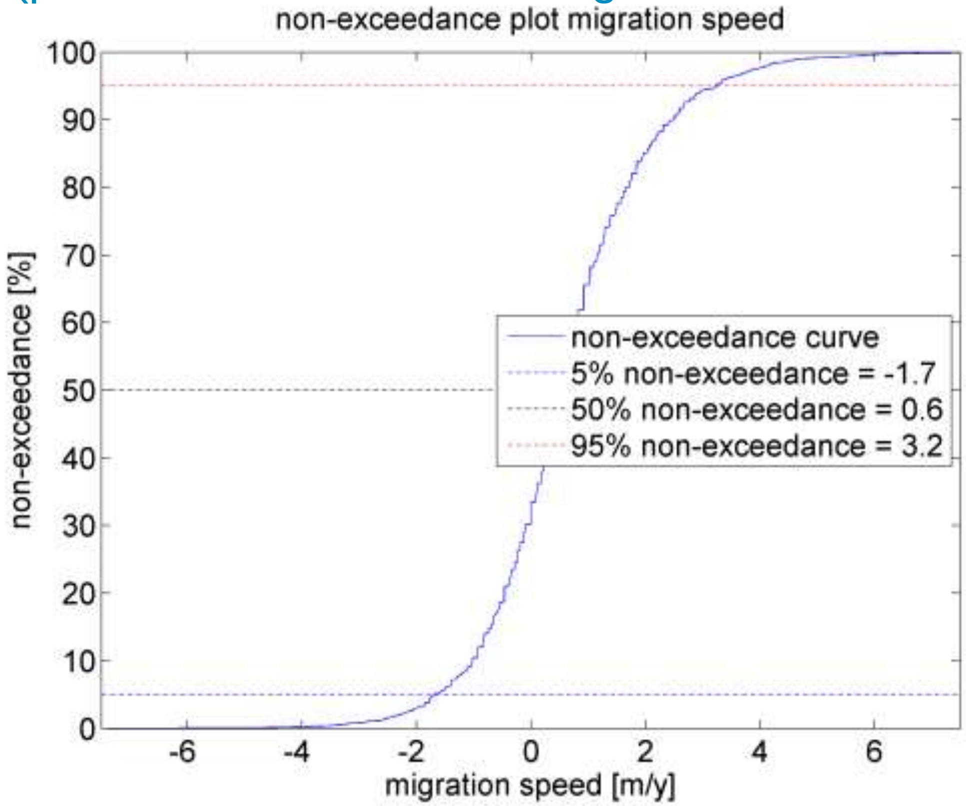
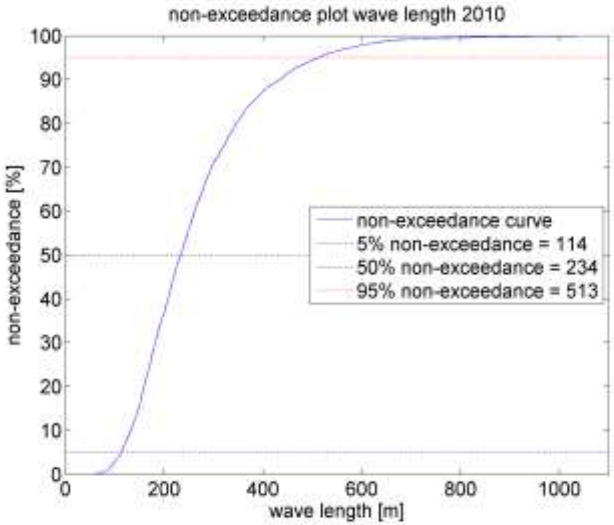
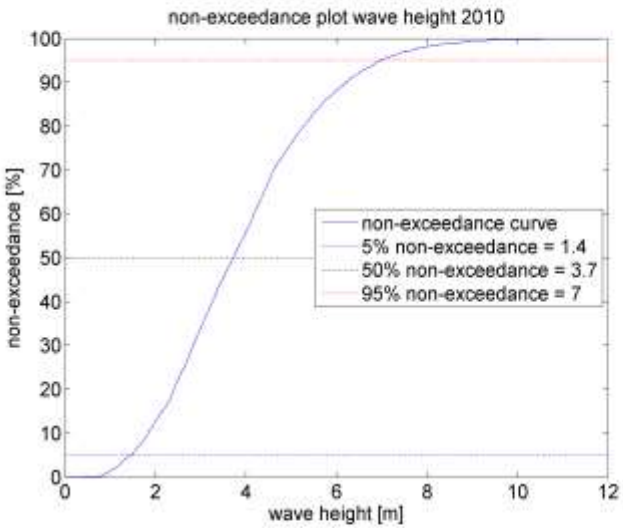
Results – sand wave statistics

Migration rates for entire BWFZ
Exceedance curve
(positive is towards SW; negative towards NW)



Wave lengths and wave heights





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Results

Envisaged in 2nd Phase

- Re-do the entire analysis with additional MBES survey
- Improve (or confirm?) the migration directions and rates
- Check assumptions on static sand banks (for the OWP's lifetimes)
- Check conservation of sand wave shapes and if necessary include uncertainty range
- Narrow uncertainty ranges by taking actual migration rates into account
- RSBL will be located higher where possible
- MSBL will be located lower where possible
- Vertical range that foundations need to be able to deal with reduces

.... Movie example of seabed predictions (300yr!) based on migration rates and directions

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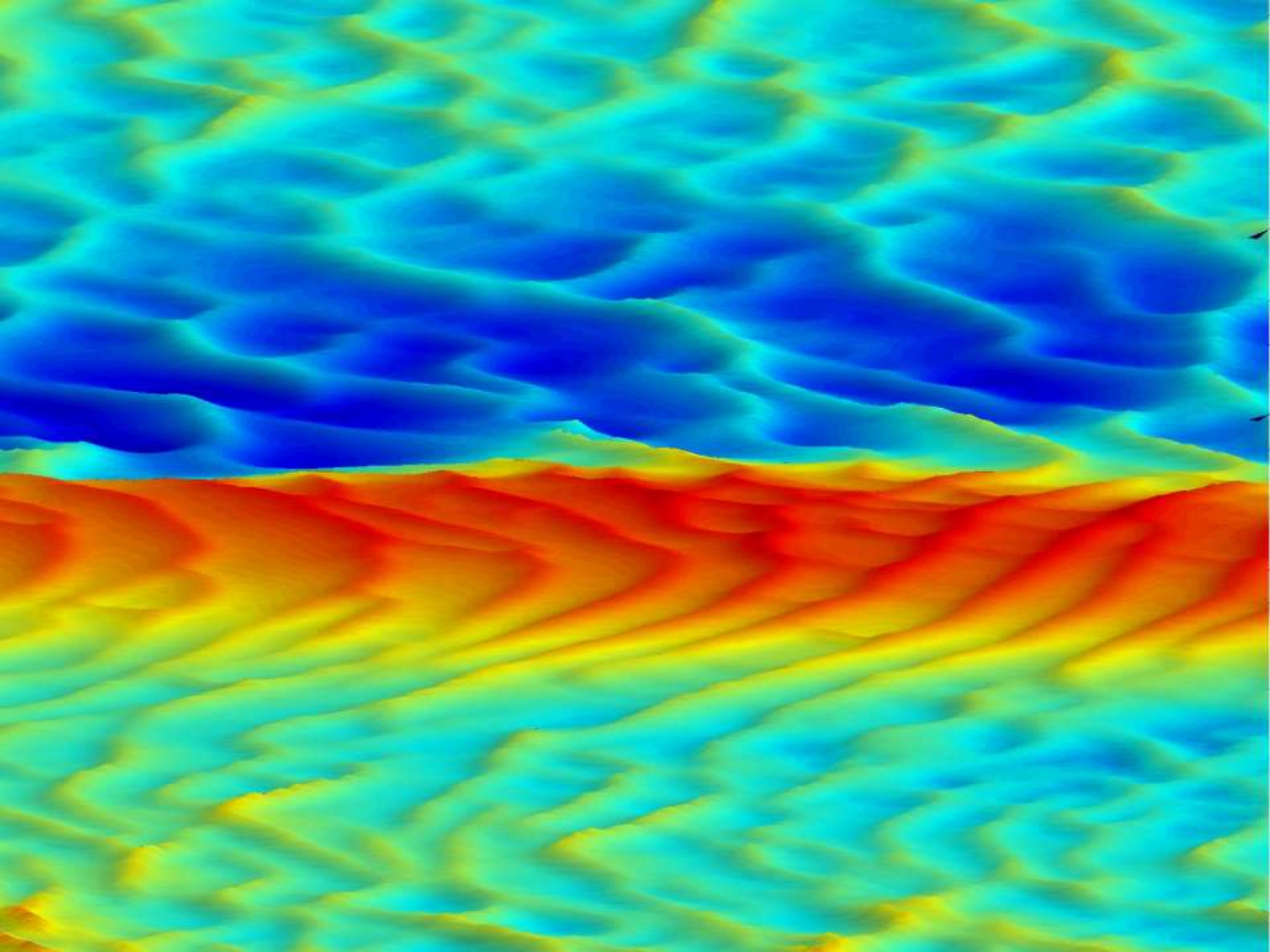
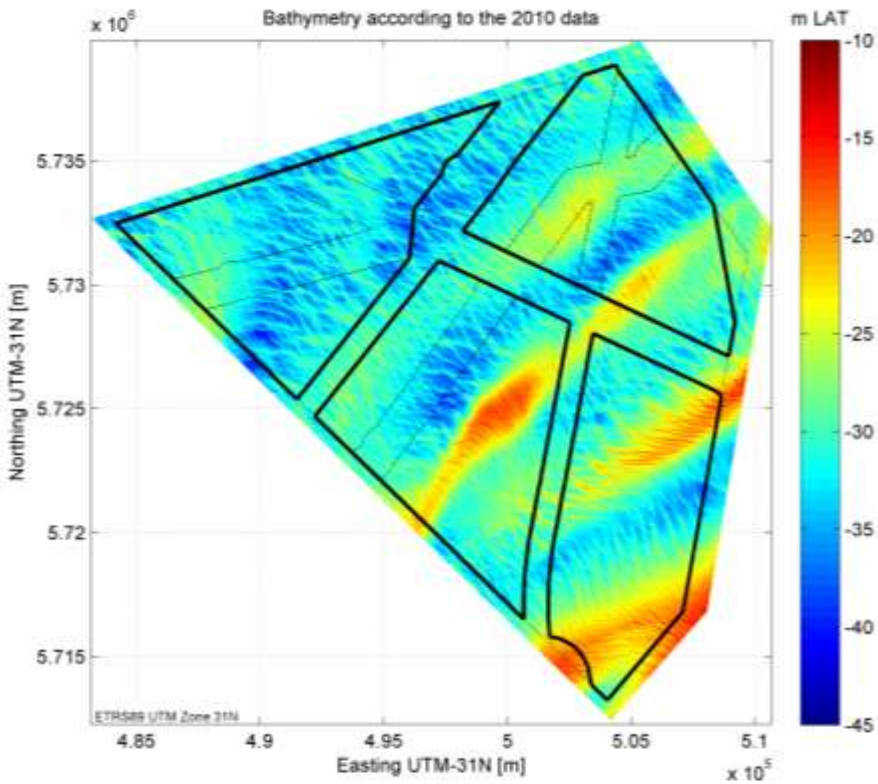
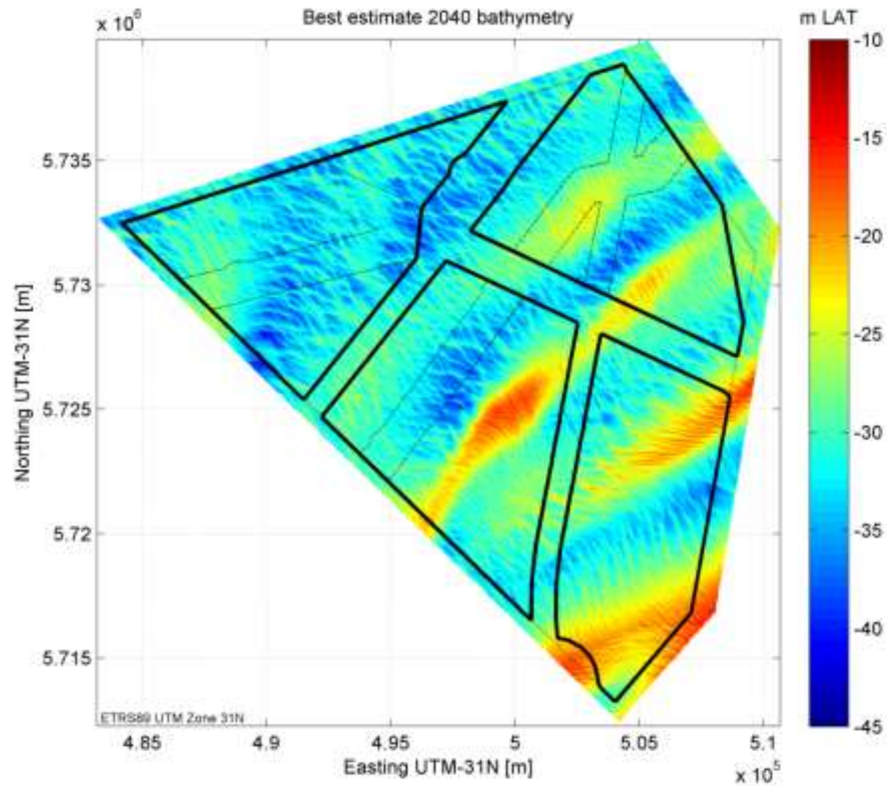


Results

Best estimate bathymetry, based on migration rates and directions

2010 **2040**





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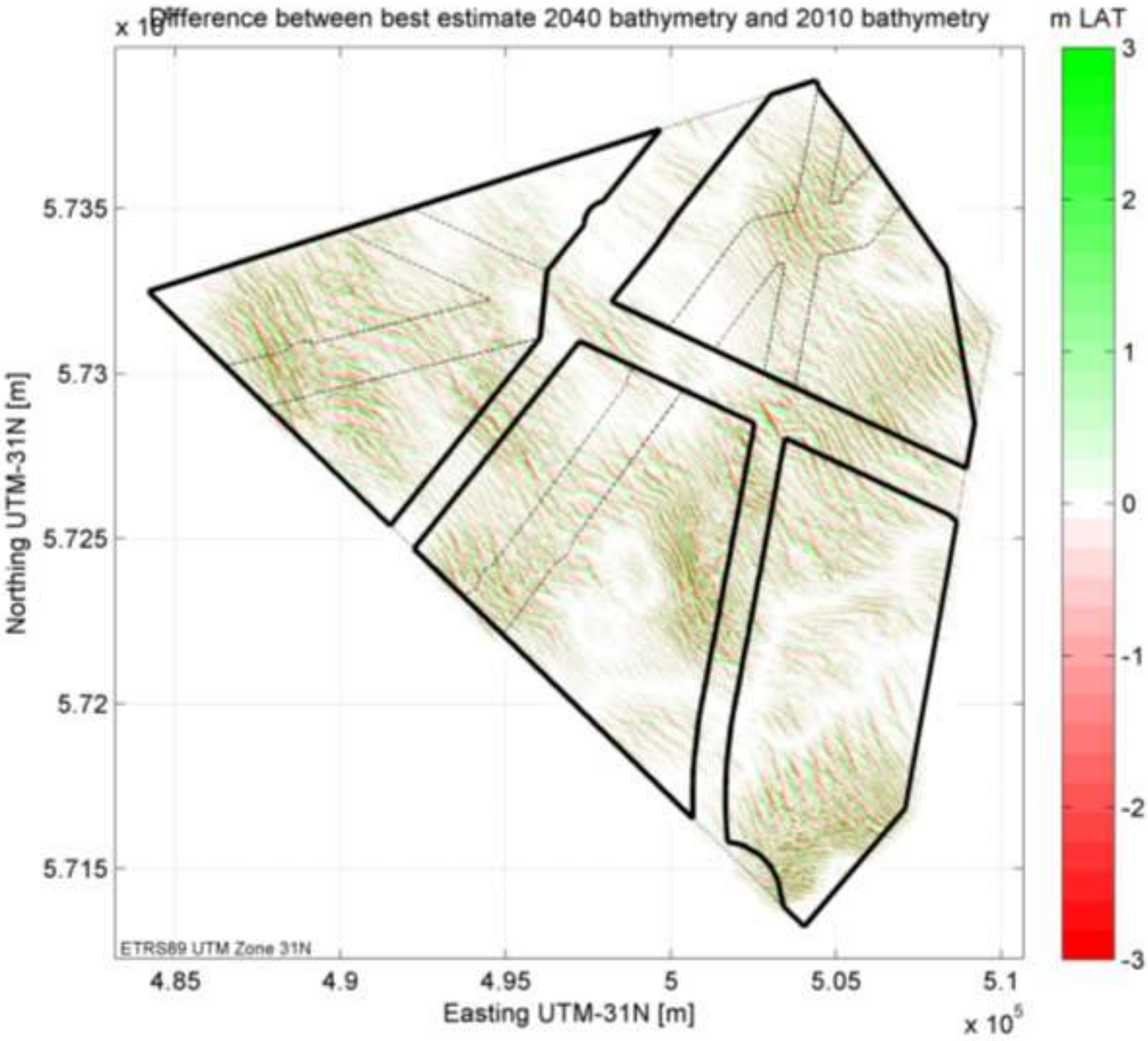
Results

Best estimate bathymetry differences between 2010-2040 based on migration rates and directions



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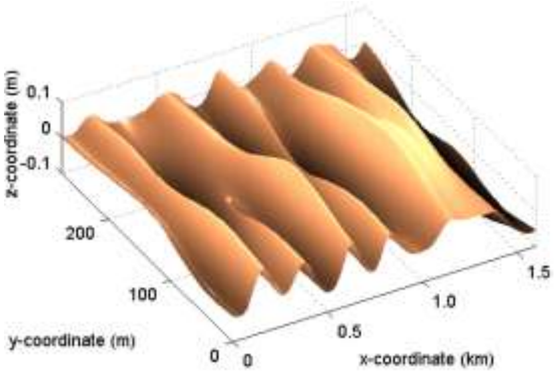

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Conclusions

- The bathymetry in BWFZ consists of a complex system of shore-parallel sand banks covered with shore-perpendicular sand waves.
- The sand banks are considered to be static over the lifetime of the wind parks to be developed in the area (to be checked in 2nd phase).
- The sand waves are (mostly) mobile, have an average length of 230m, average height of 4m and typical migration speeds are in the order of -1.7m/yr (governing NE-direction) to 3.2 m/yr (governing SW-direction).

Area	Median wave height (50% non-exceedance) [m]	Median wave length (50% non-exceedance) [m]	Migration speed 5% non-exceedance [m/yr]	Migration speed 95% non-exceedance [m/yr]
BWFZ	3.7	234	-1.7	3.2
Site I	3.5	245	-1.9	4.2
Site II	3.2	221	-1.7	3.2
Site III	4.2	231	-1.3	2.8
Site IV	3.7	235	-1.8	3.1

- Maximum possible bed lowering up to 8m (outer bound)
- Migration is not (yet) included in calculation of RSBL and MSBL

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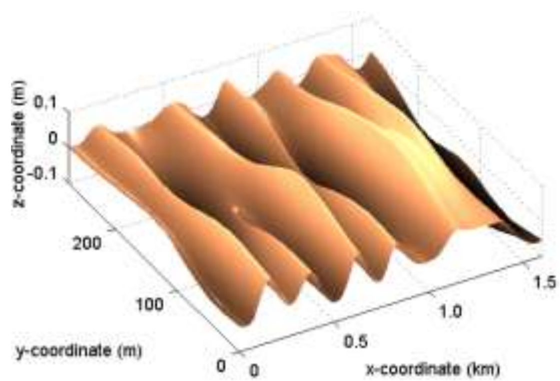

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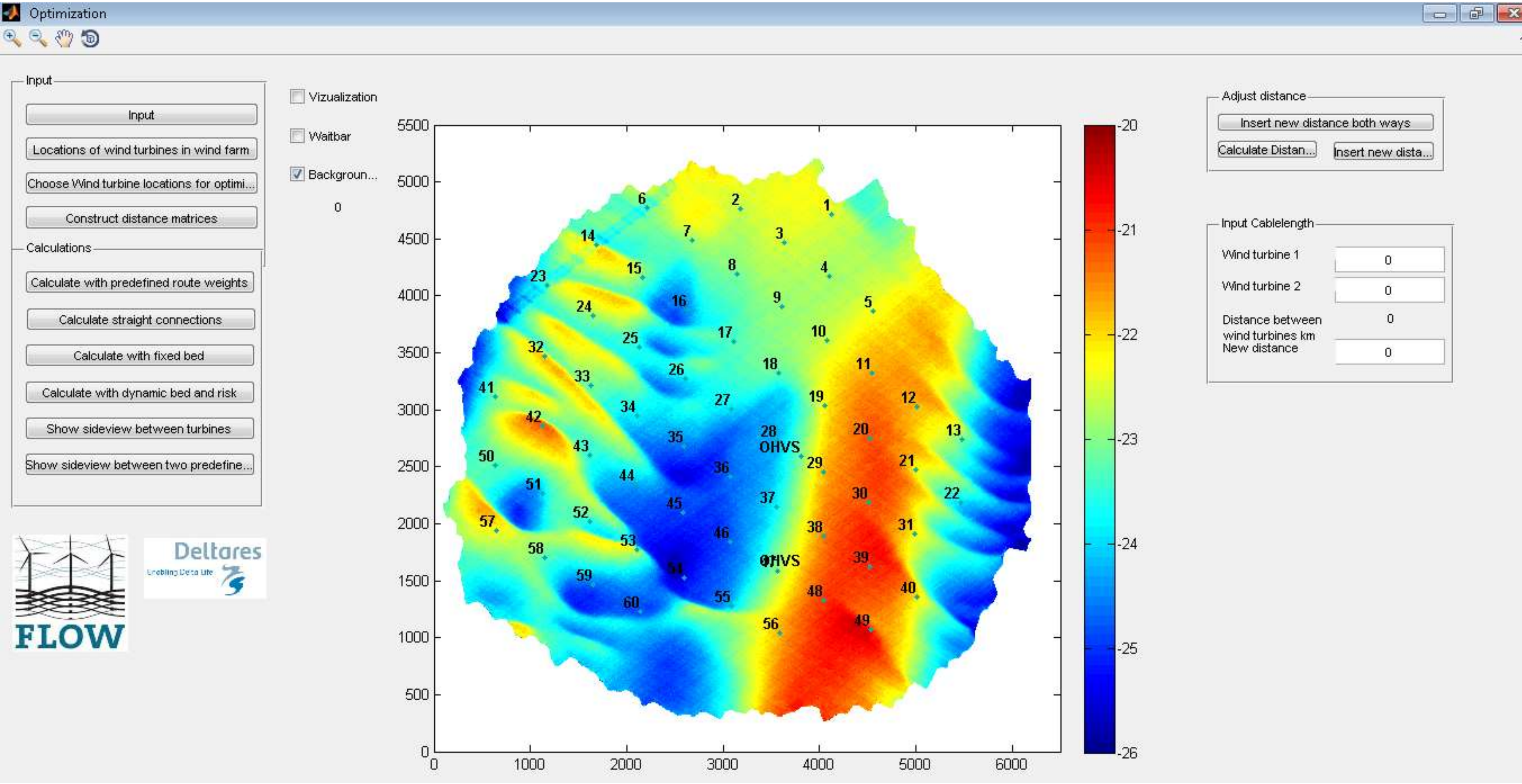
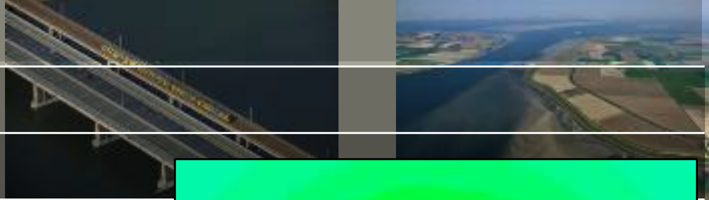
Cable route optimization



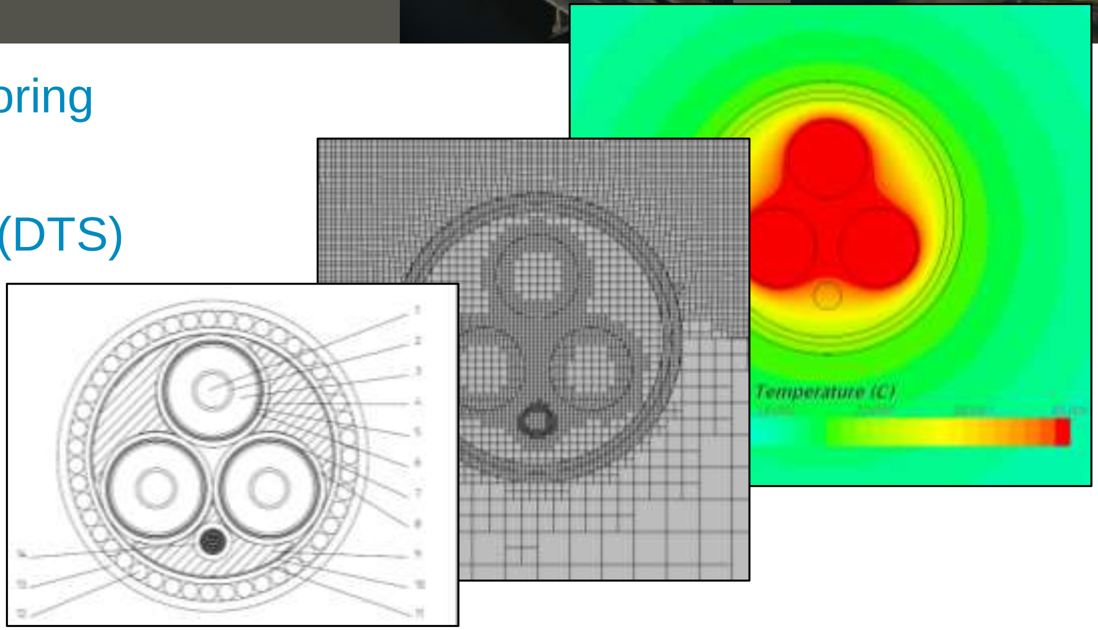
FLOW cables research project



1) Real time cable burial depth monitoring

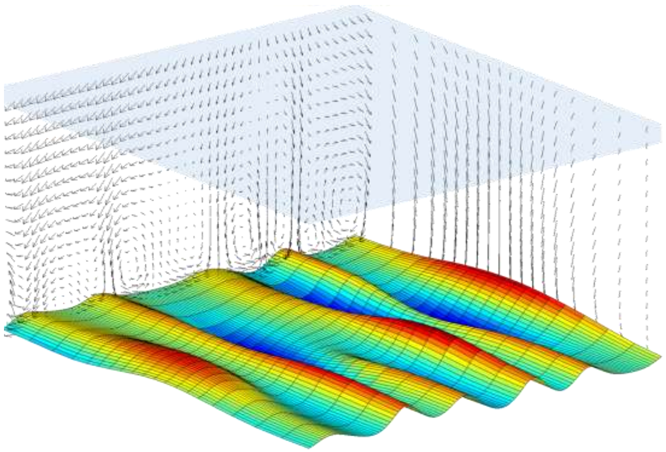
Coupling between:

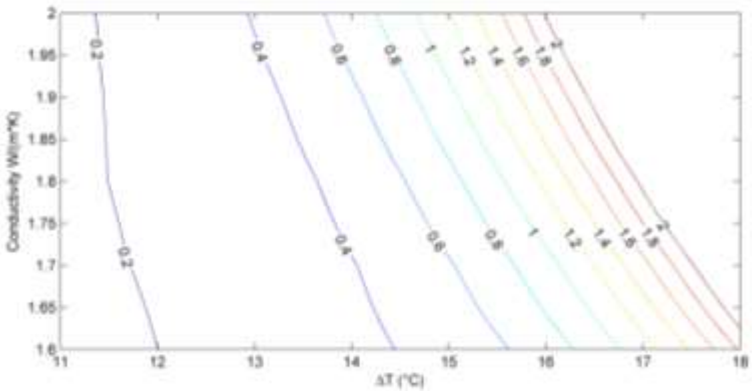
- Distributed Temperature Sensing (DTS)
- Morphology overlying cable



2) Forecasting sand waves

- Calibrating/ Validating Delft3D
- Converting into Flexible Mesh



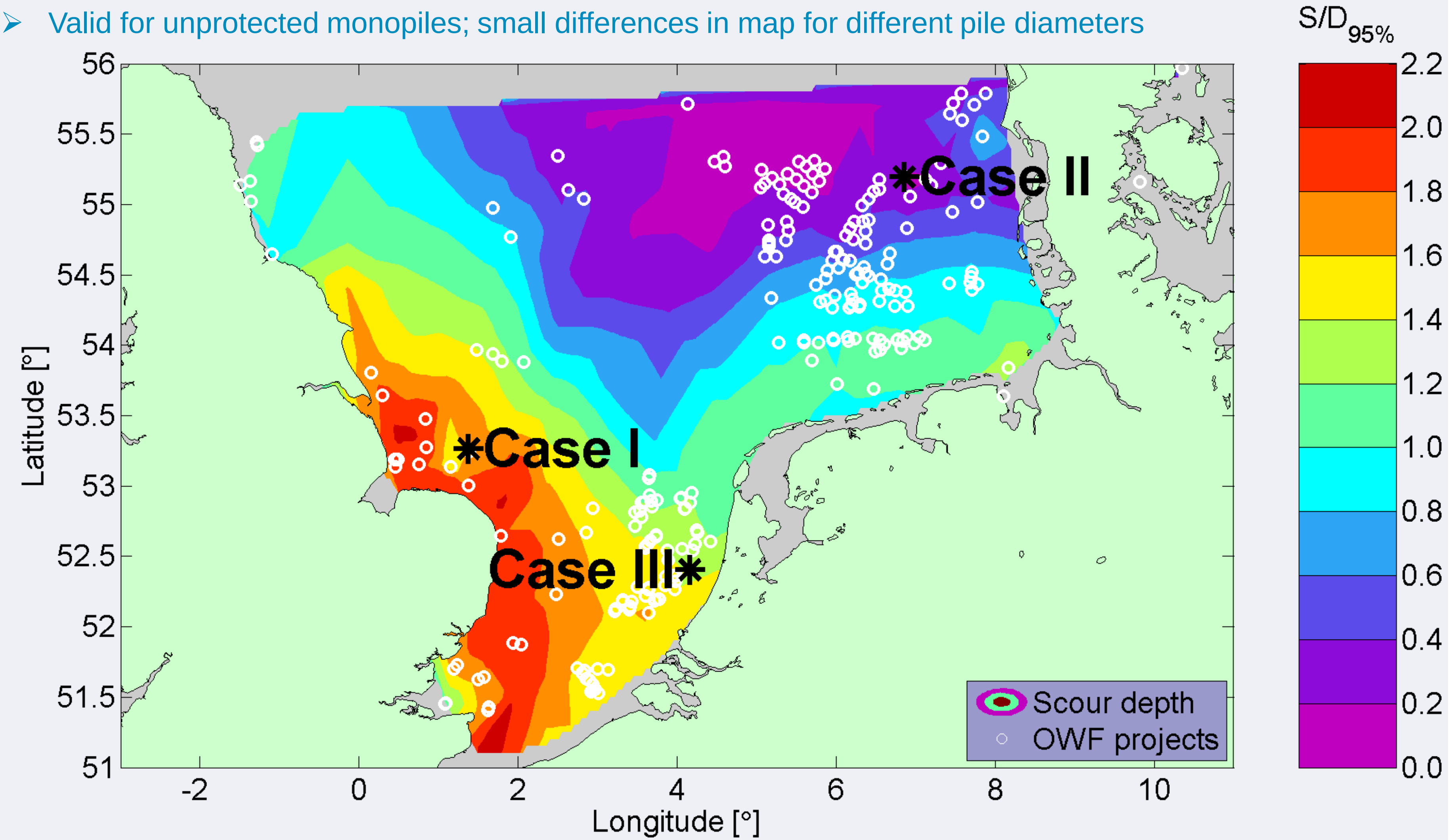


Eneco Van Oord IHC TU Delft Deltares

Safe upperbound for dynamic scour depth: $(S/D)_{95\%}$

Model assumptions:

- Non-cohesive soil (= sandy seabed)
- Based on >100 simulations with different hydrodynamic time series (different starting times)
- Valid for unprotected monopiles; small differences in map for different pile diameters

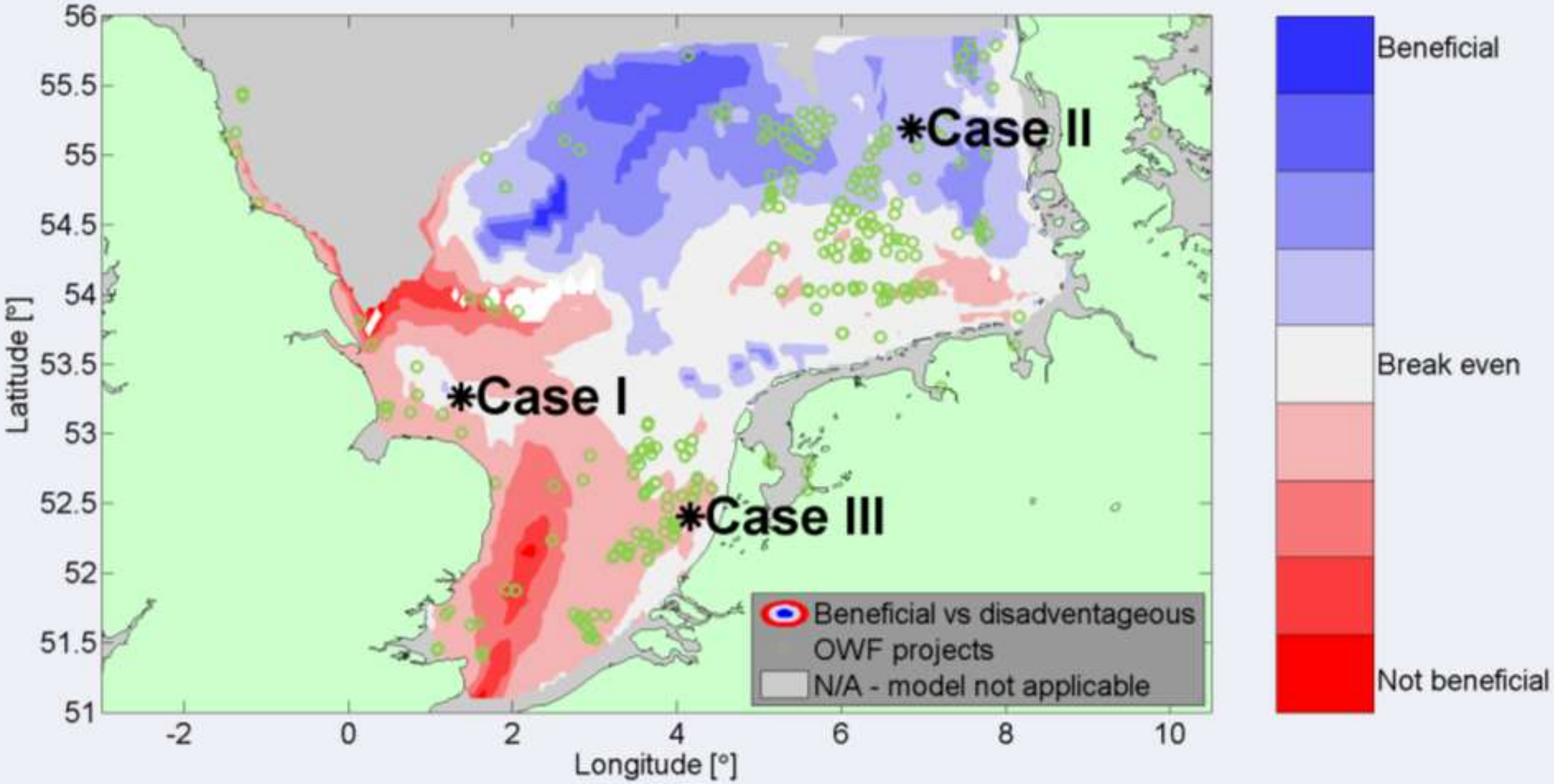


Scour: to protect or not to protect?

Cost of scour protection vs. additional steel

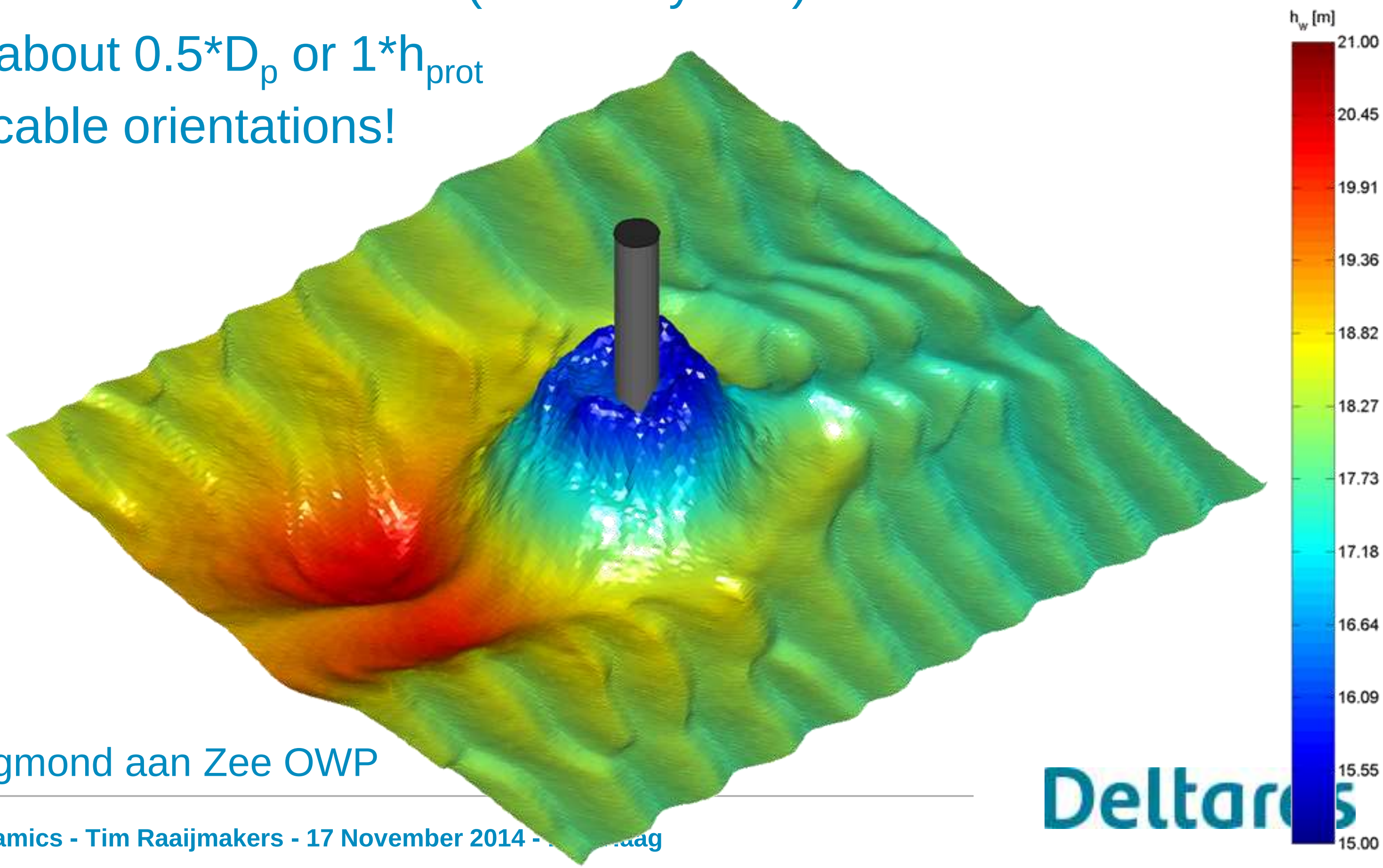
Blue colours mean there is a real potential for leaving out the scour protection

In Borssele installing scour protection is most likely more cost-efficient.



Edge scour development around scour protections

- If a scour protection is installed around the foundations, do not forget about edge scour!
- Location is mainly dependent on tidal current climate
- Development at slow time scales (order of years)
- Depth up to about $0.5*D_p$ or $1*h_{prot}$
- Check your cable orientations!



Edge scour hole at Egmond aan Zee OWP

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Thank you for your attention!

¿Questions?

Scale model in Deltares' Atlantic Basin of Dolwin-2 transformer platform located in German Bight (North Sea)

More information? Email: tim.raaijmakers@deltares.nl