Sediment mobility modelling and maerl habitat dynamics in Galway Bay

Dr Siddhi Joshi and Dr Eugene Farrell
Discipline of Geography and Ryan Institute
National University of Ireland Galway

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Geological Survey
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NDP
National Development Plan

NUI Galway
OÉ Gaillimh

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Department of Communications, Climate Action & Environment

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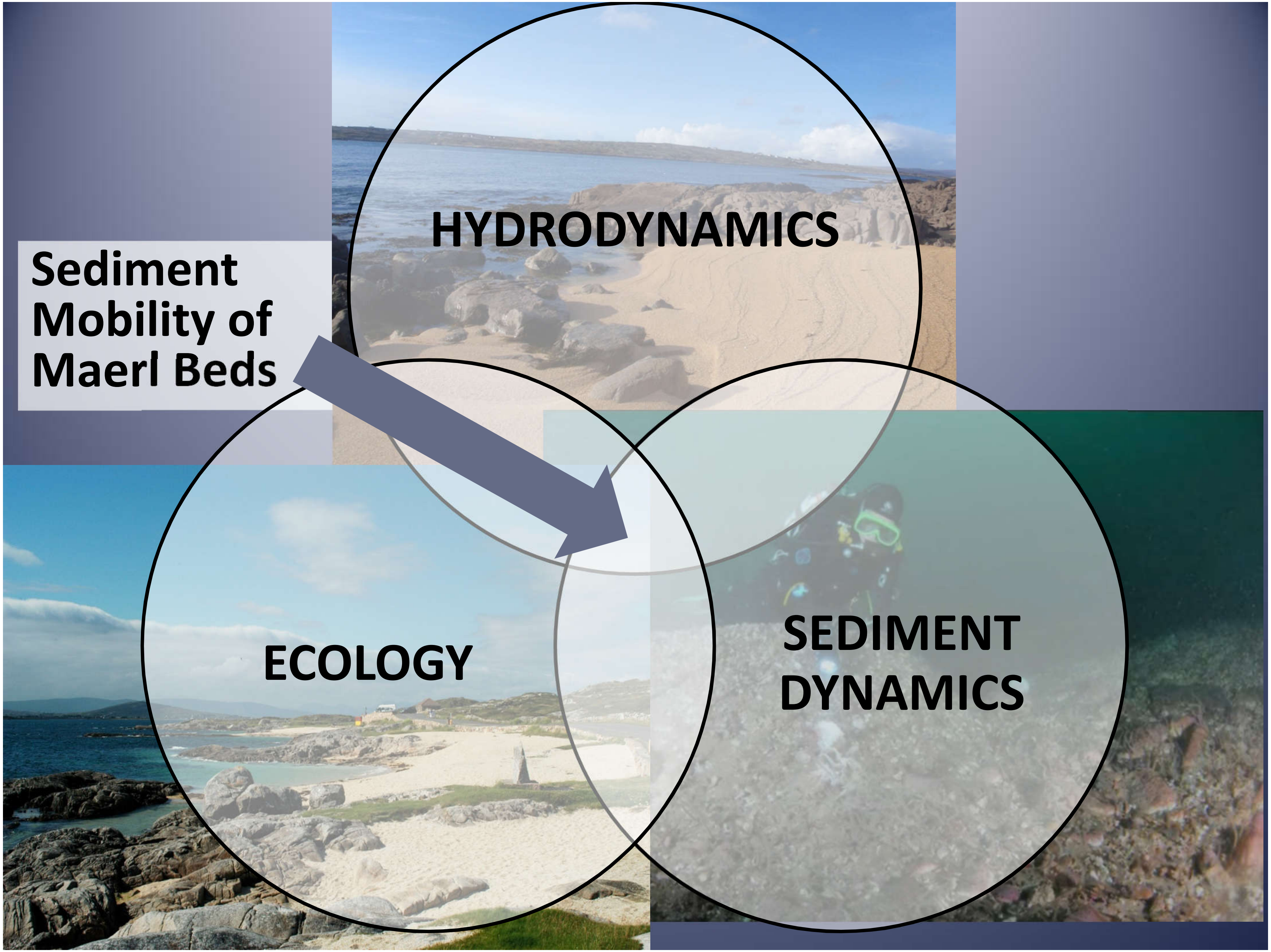
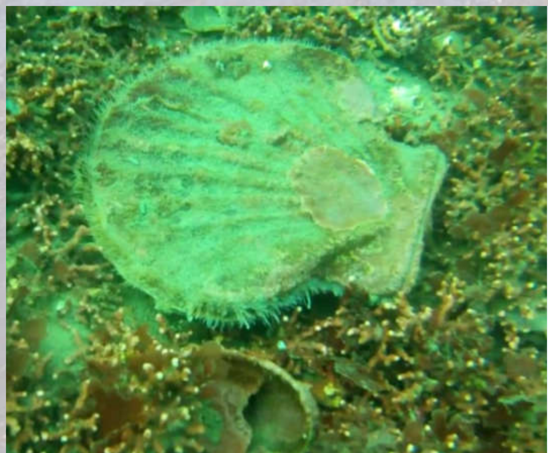
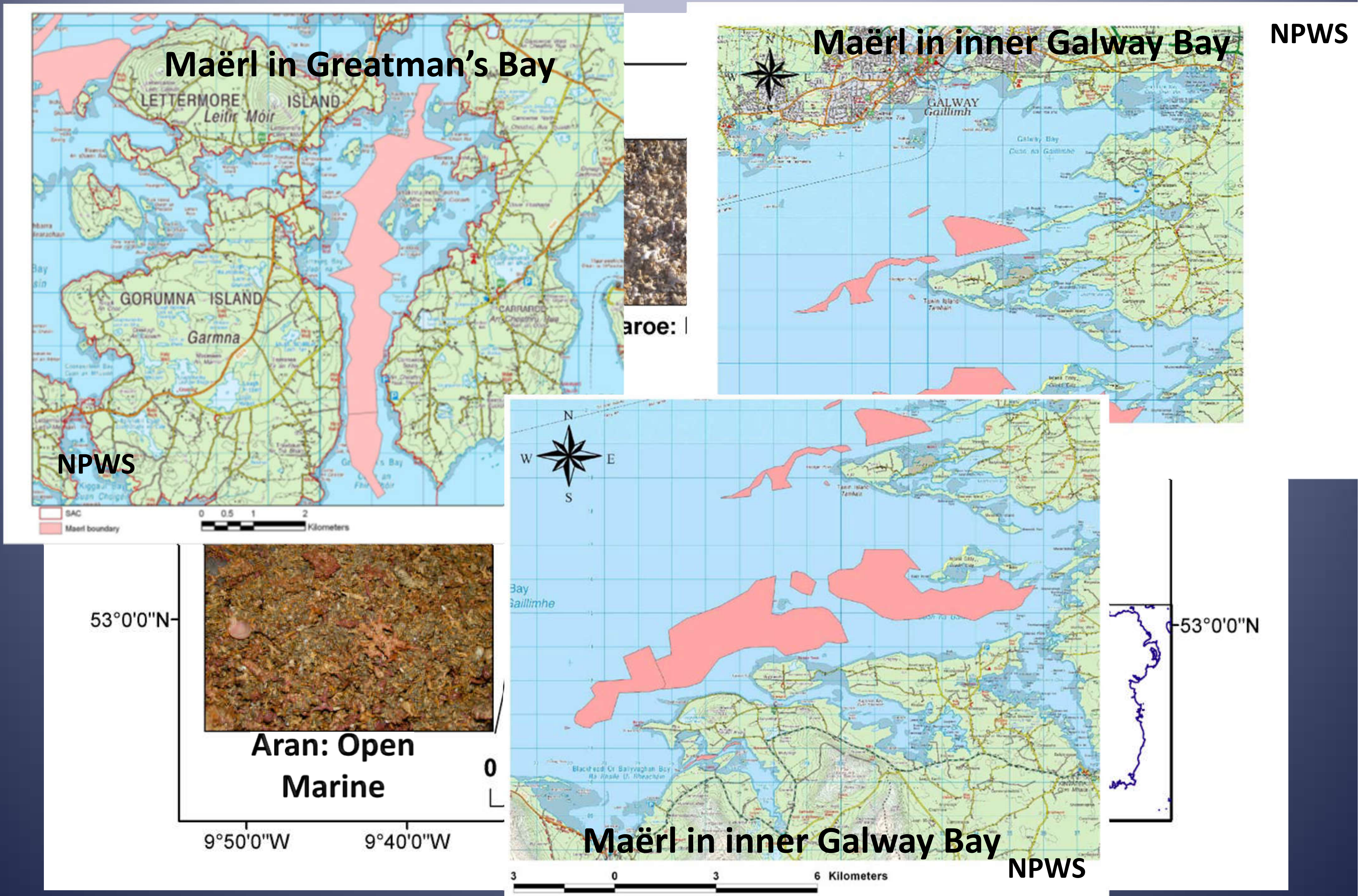

Sediment Mobility of Maerl Beds
HYDRODYNAMICS
ECOLOGY
SEDIMENT DYNAMICS

Maerl/Rhodolith Research Objectives

- **Utilise oceanographic models for conservation of maerl in Galway Bay**
  - Free living coralline red algae found in shallow marine environments
  - Forms dense biogenic gravel beaches composed of maerl debris
- **Two main maerl forming species in Ireland:**
  - *Phymatolithon calcareum* and *Lithothamnion corallioides*
- **Determine fundamental sediment dynamics properties of maerl**
- **Model sediment mobility of maerl beds: Integrate maerl in coupled hydrodynamic-wave-sediment transport models**
- **Beach Morphodynamics experimental field work**



Galway Bay Study Sites

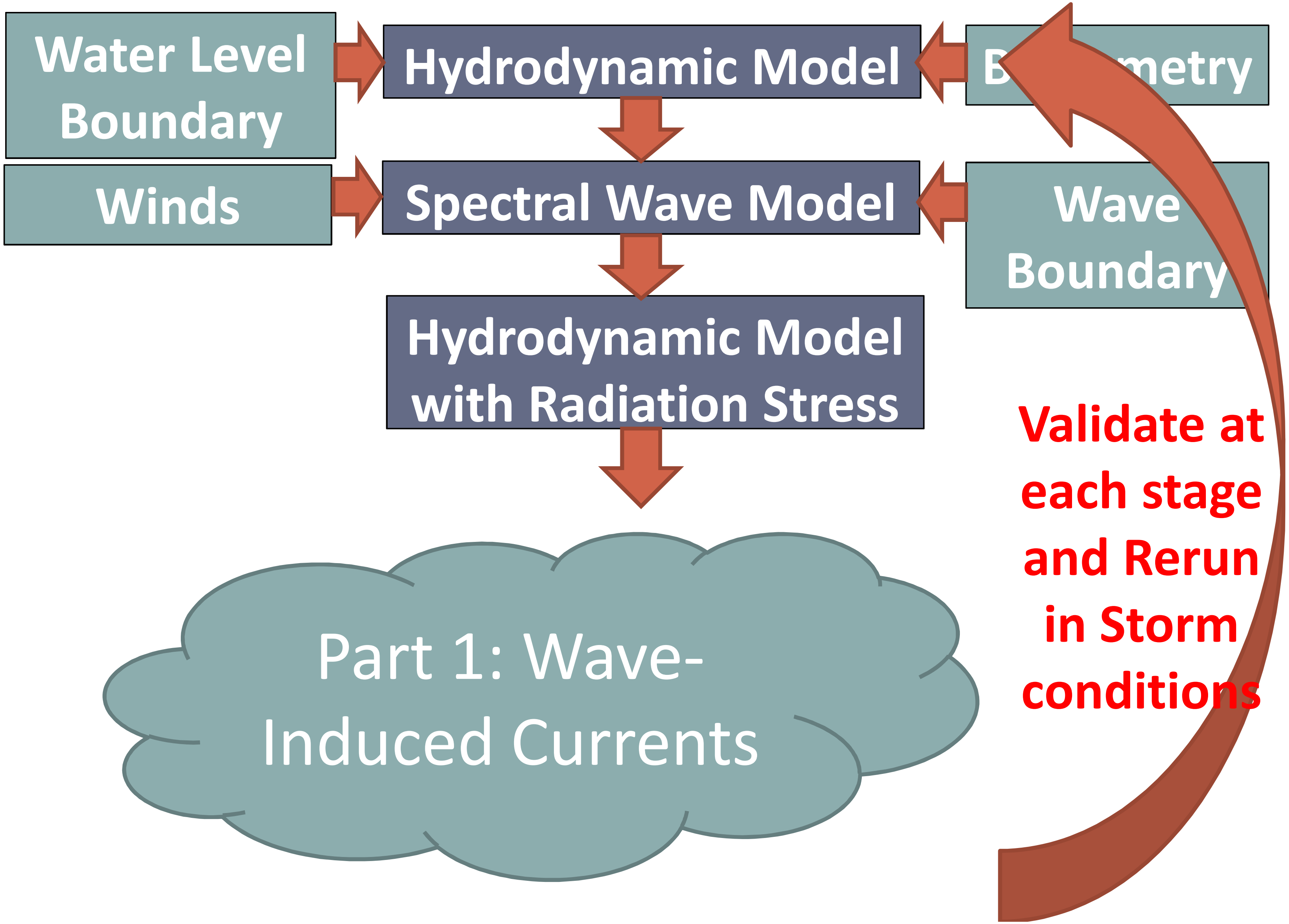


Hydrodynamics at Maerl Beds

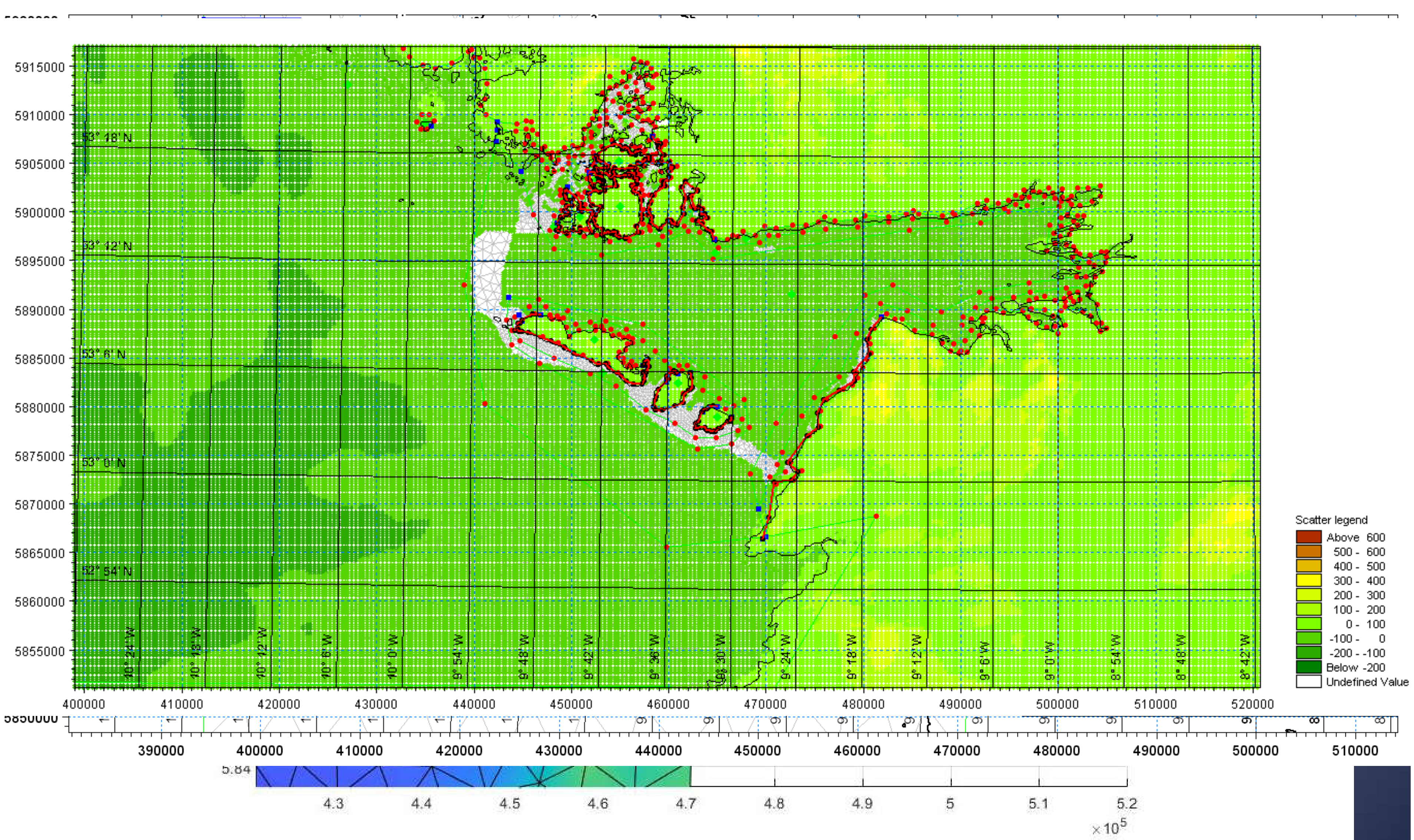
1. What is the relative importance of the different physical processes operating in Galway Bay for the mobility of maerl-siliciclastic sediment?
2. Which hydrodynamic parameters are the most influential on sediment mobility?
3. How does their relative importance change from calm to storm conditions?
4. Does sediment mobility modelling provide a more useful approach for understanding seafloor dynamics than sediment transport models?
5. Can sediment mobility act as a physical surrogate for maerl siliciclastic sediment?
6. How can sediment mobility maps be used in marine spatial planning to minimise the disturbance of maerl?

→ **Coupled Modelling**

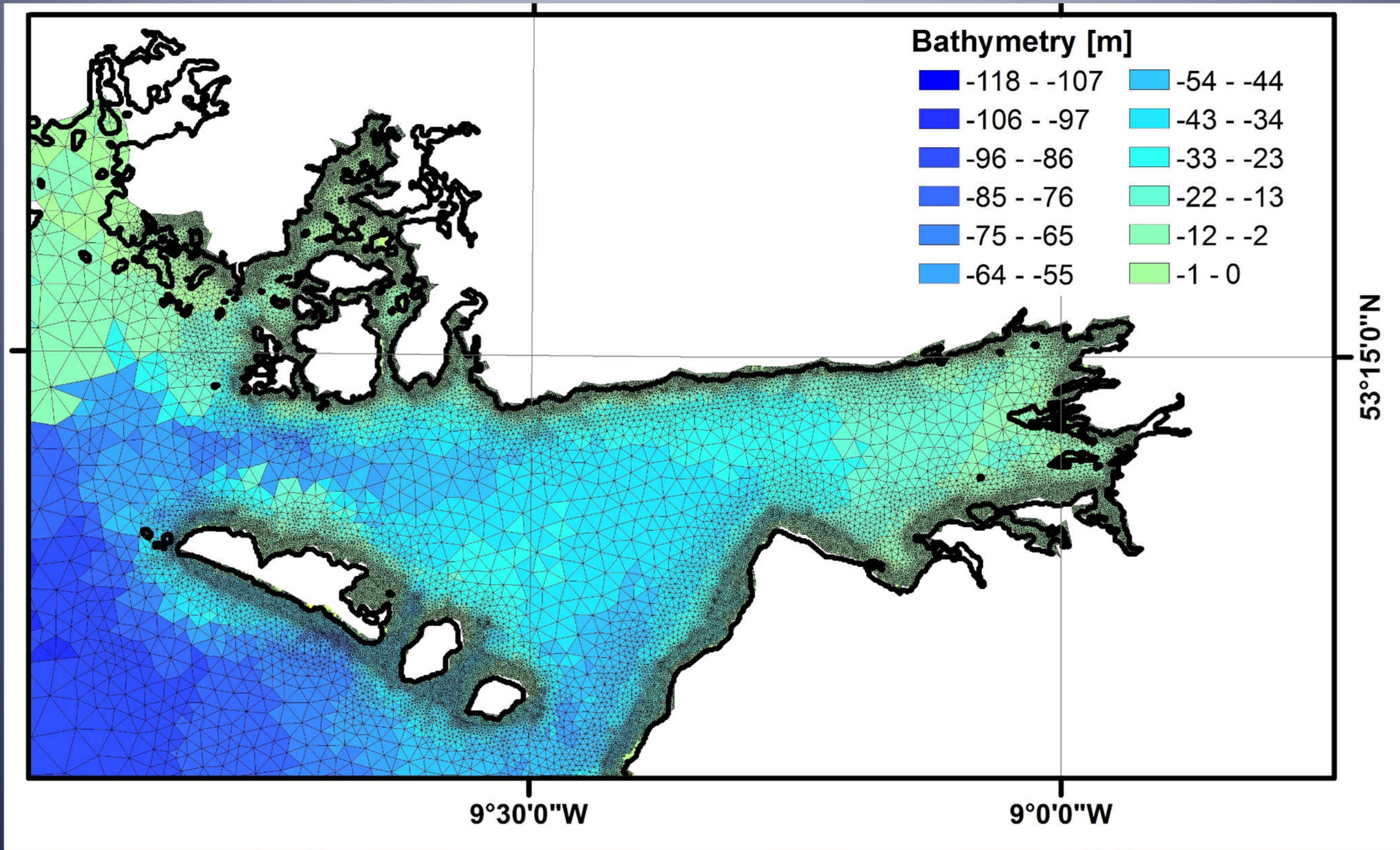
Coupled Modelling Methodology



MESH Generation



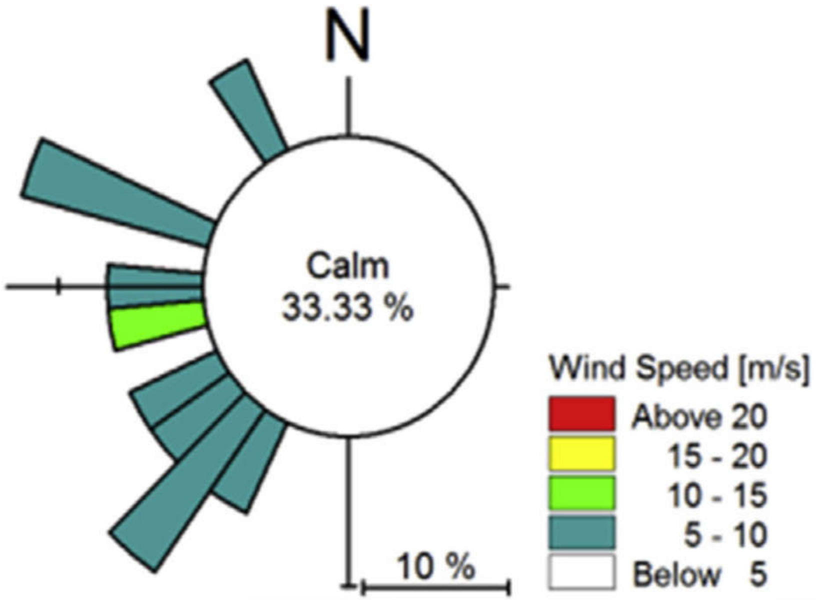
Flexible Mesh with High Resolution

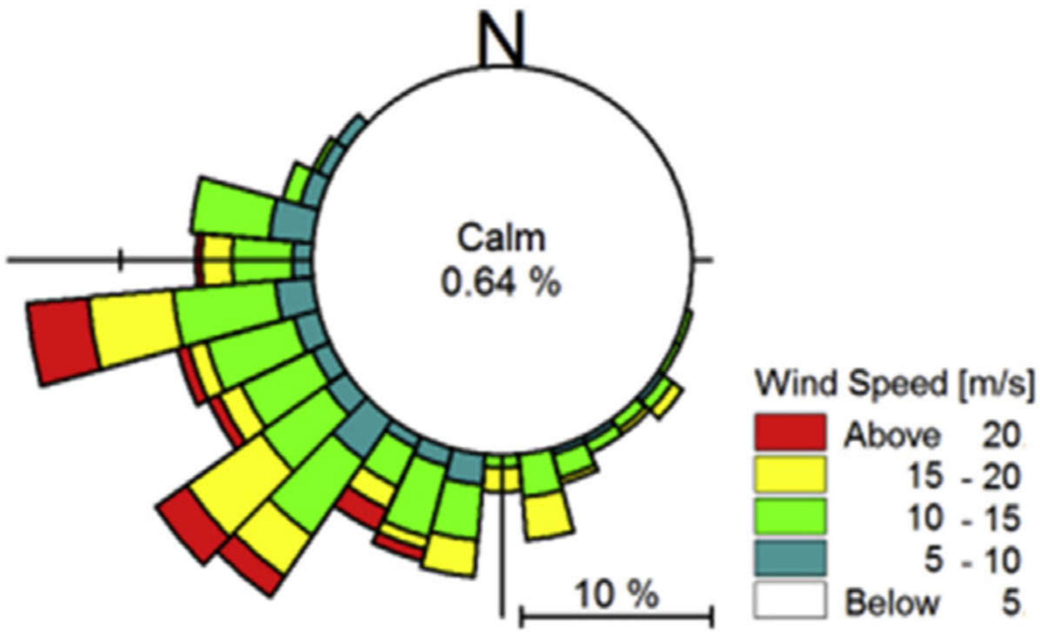


Storminess in Galway Bay

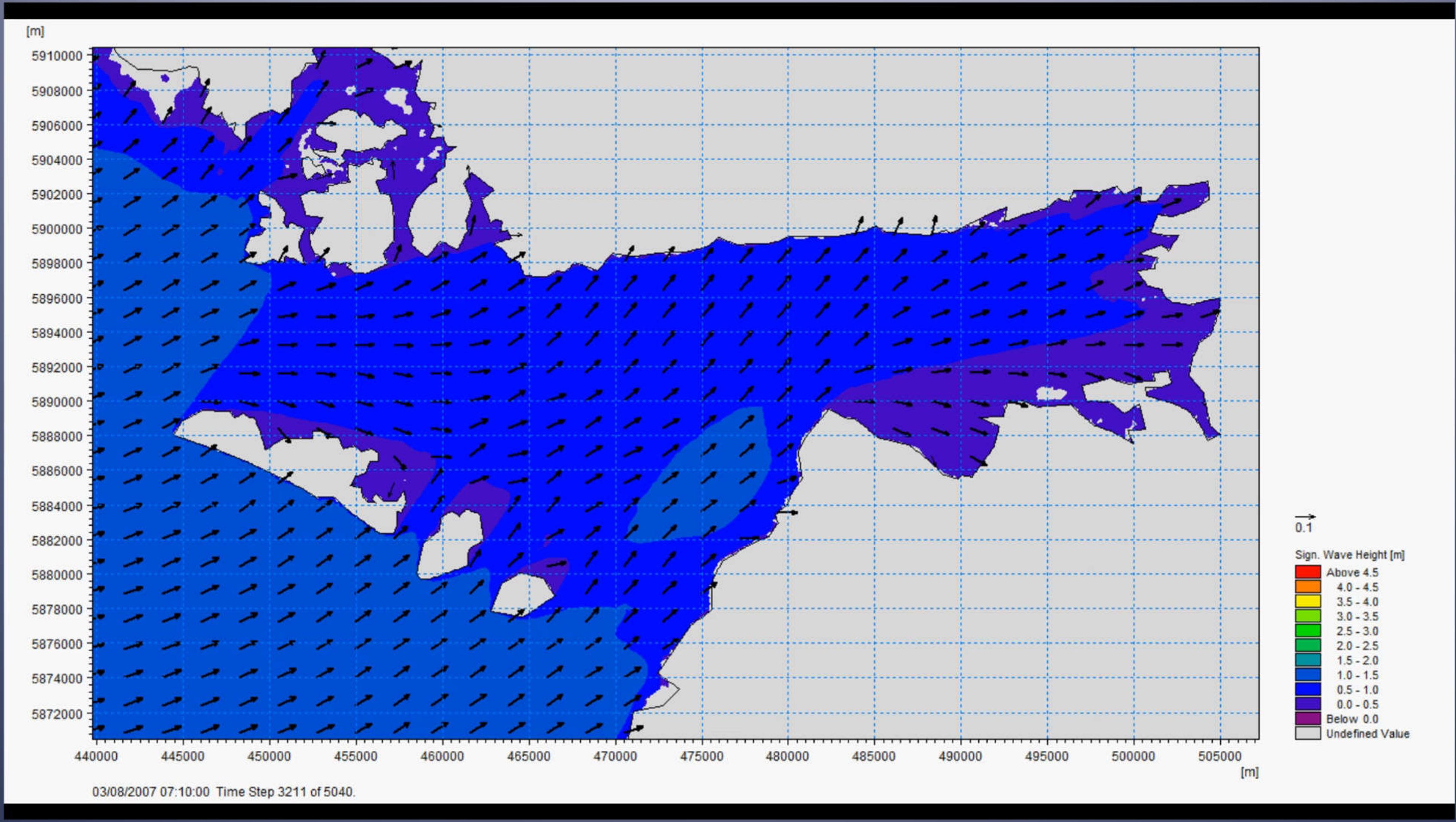
Summer Conditions
- Spring-neap cycle modelled
- Summer storm
- Anti-clockwise gyre
- Partially enclosed bay by three Aran Islands

Winter Storm Conditions
- Severe storm conditions
- North Atlantic Oscillation Anomaly of +3.54
- Wintertime temperatures, intensity
- Frequency of storms

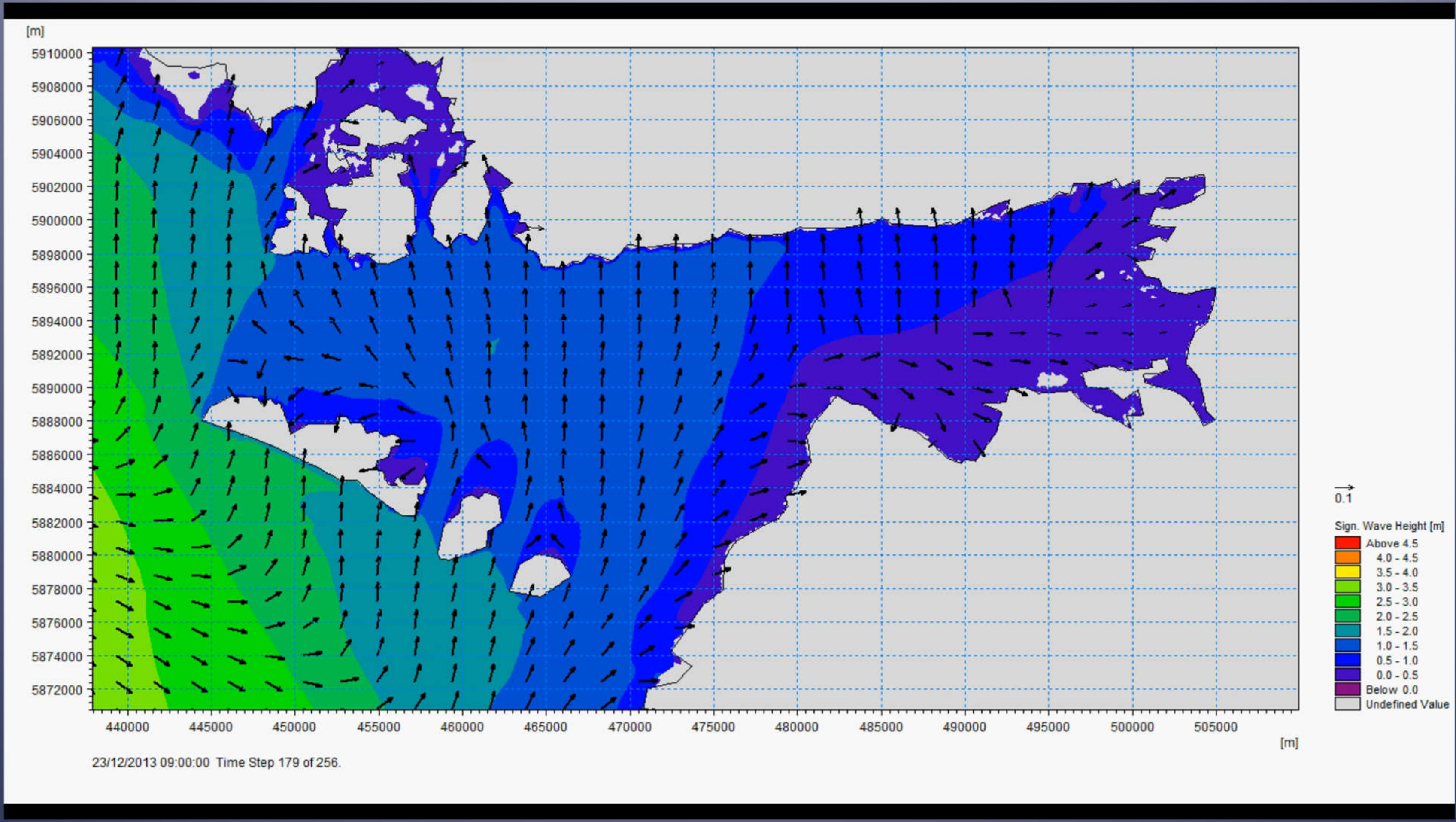




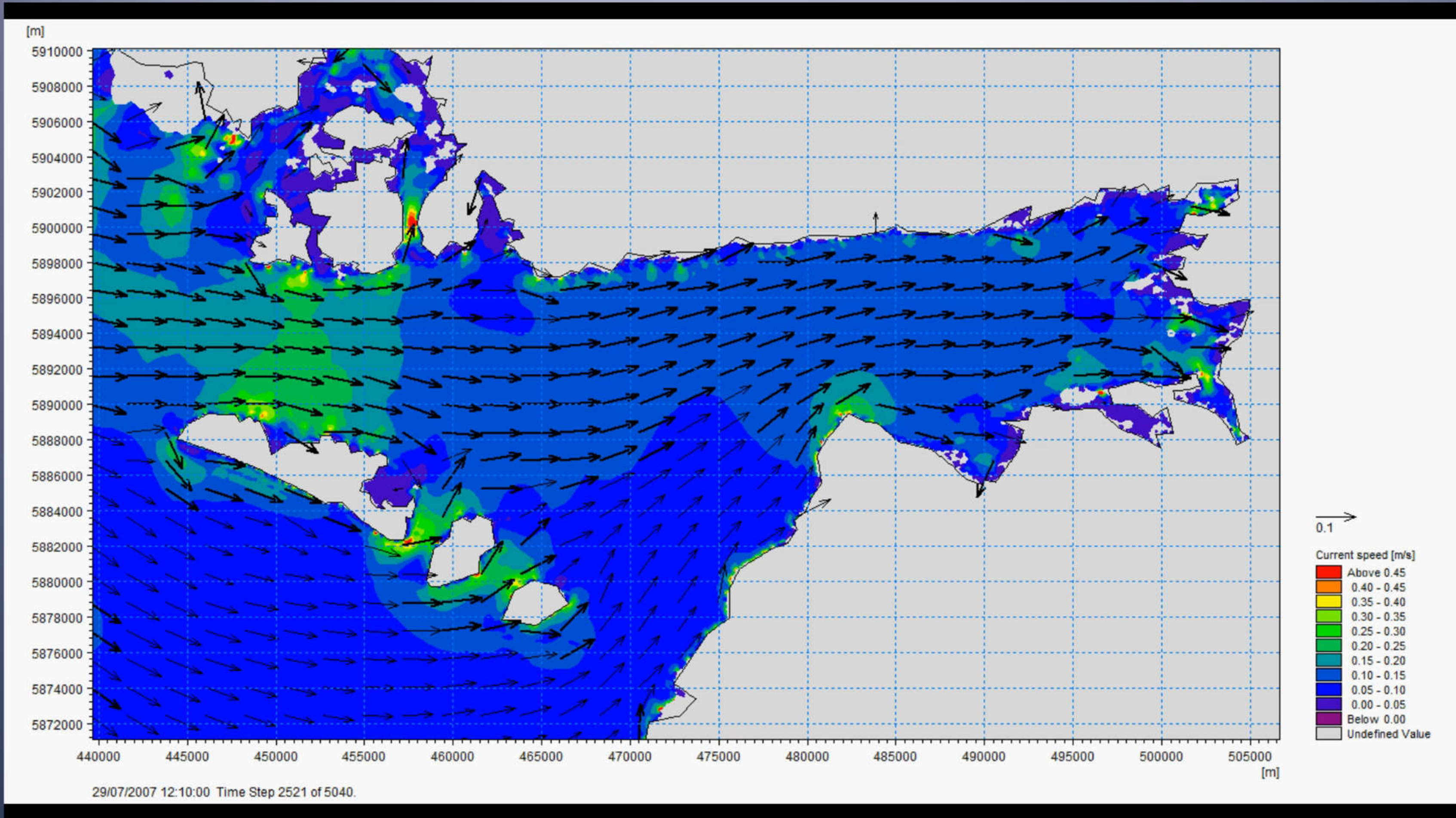
Significant Wave Height - Summer



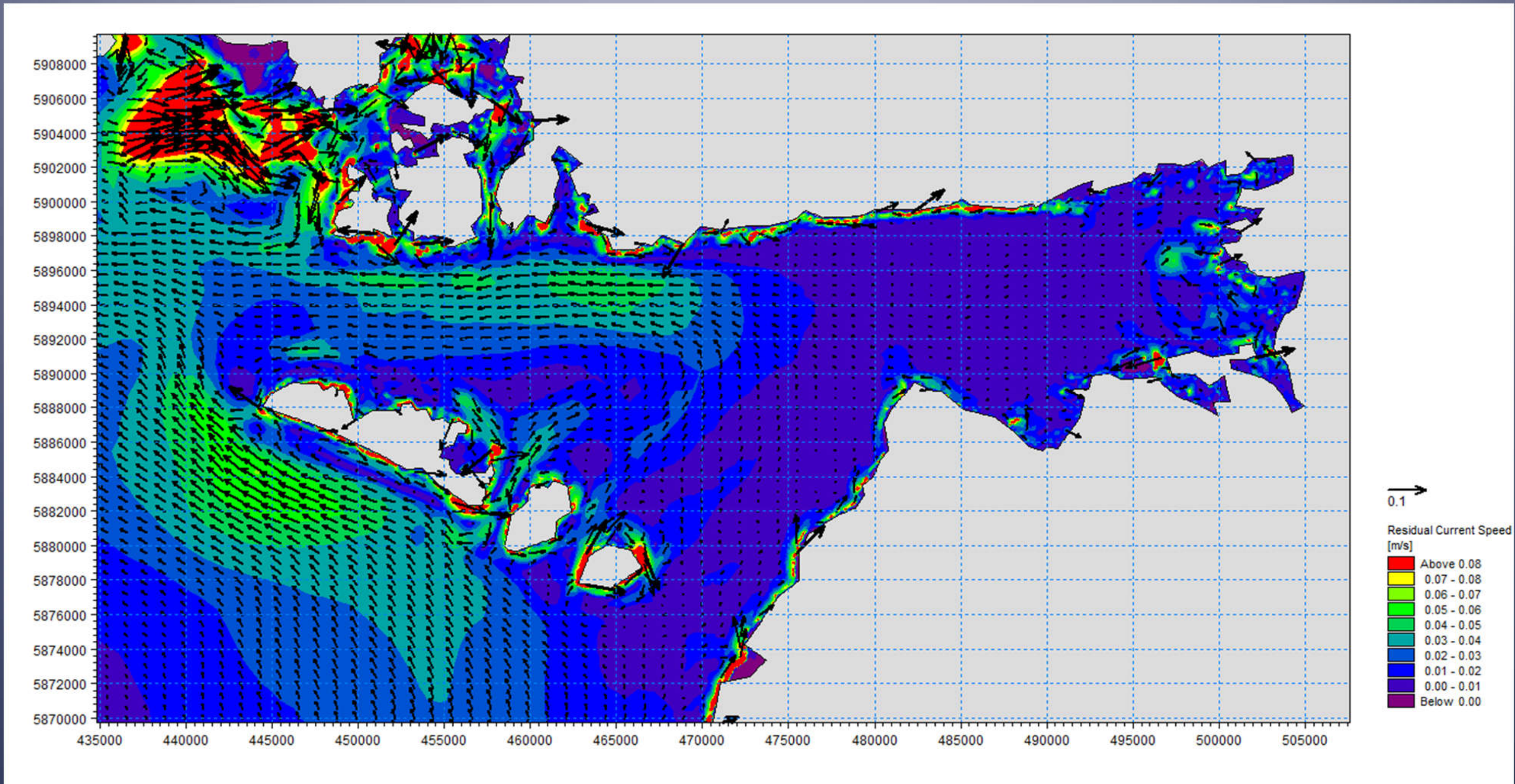
Significant Wave Height- Winter



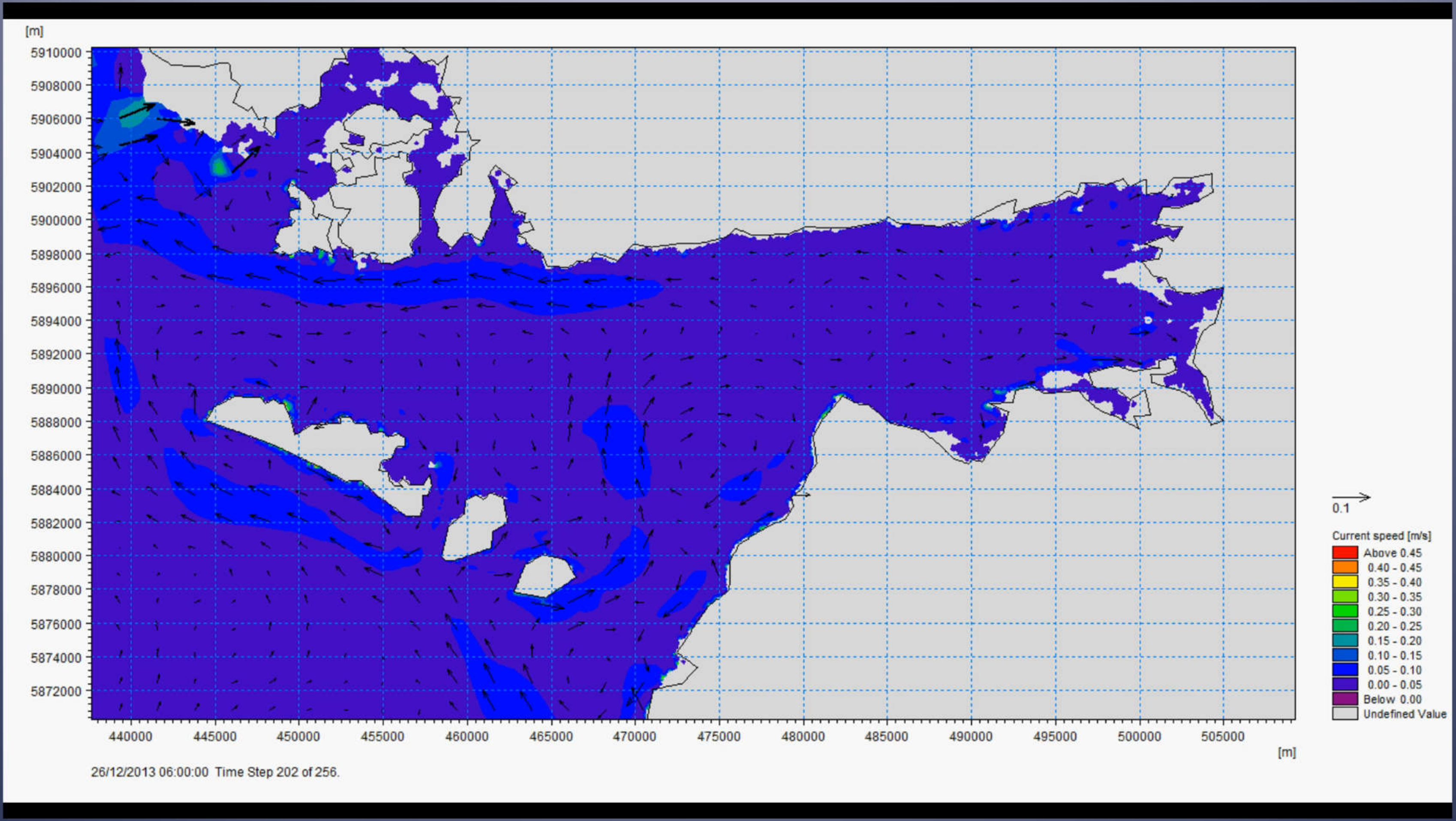
Wave Induced Currents – Summer



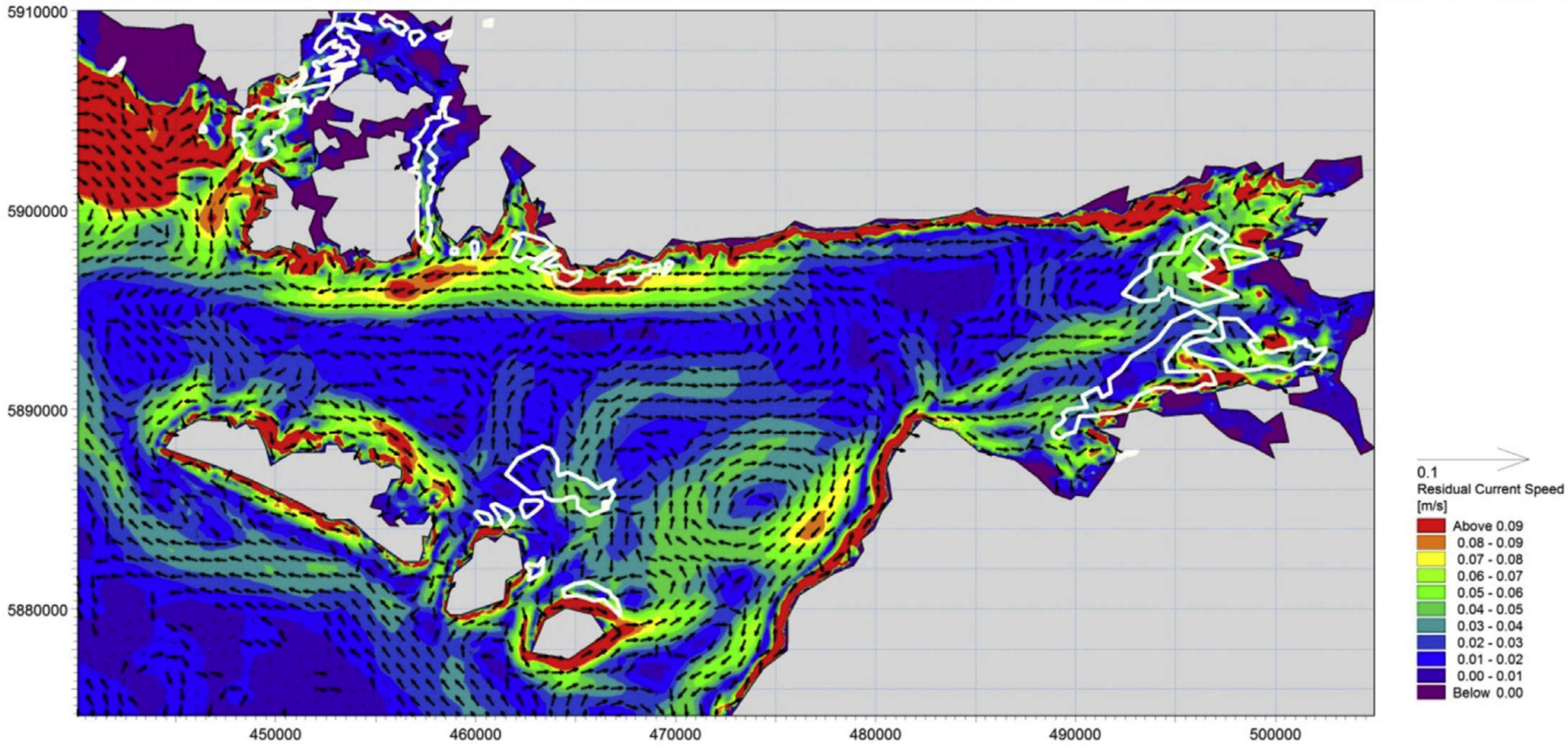
Wave-Induced Residual Currents-Summer



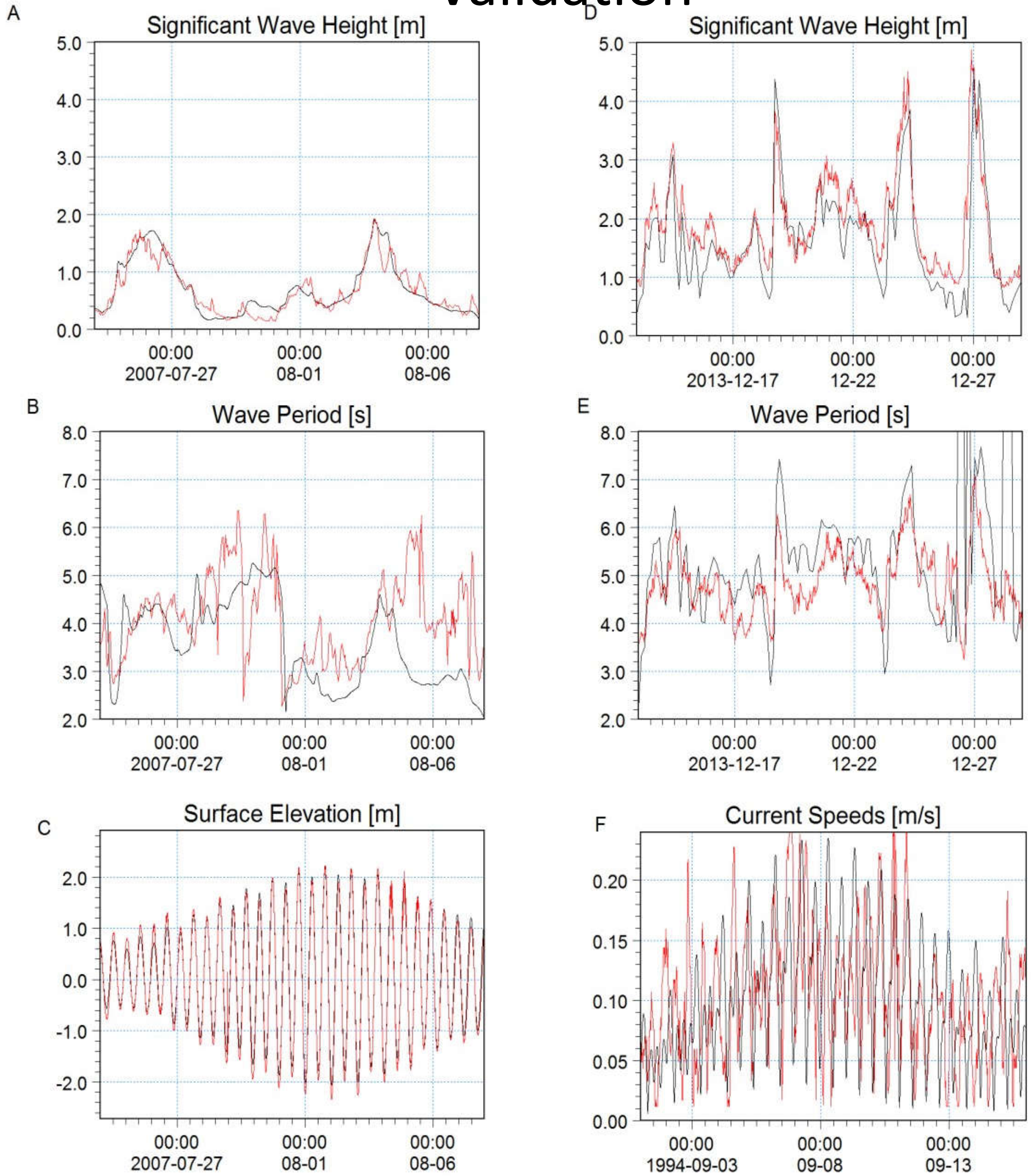
Wave-Induced Currents- Winter



Maerl found at periphery of residual current gyres during storm conditions

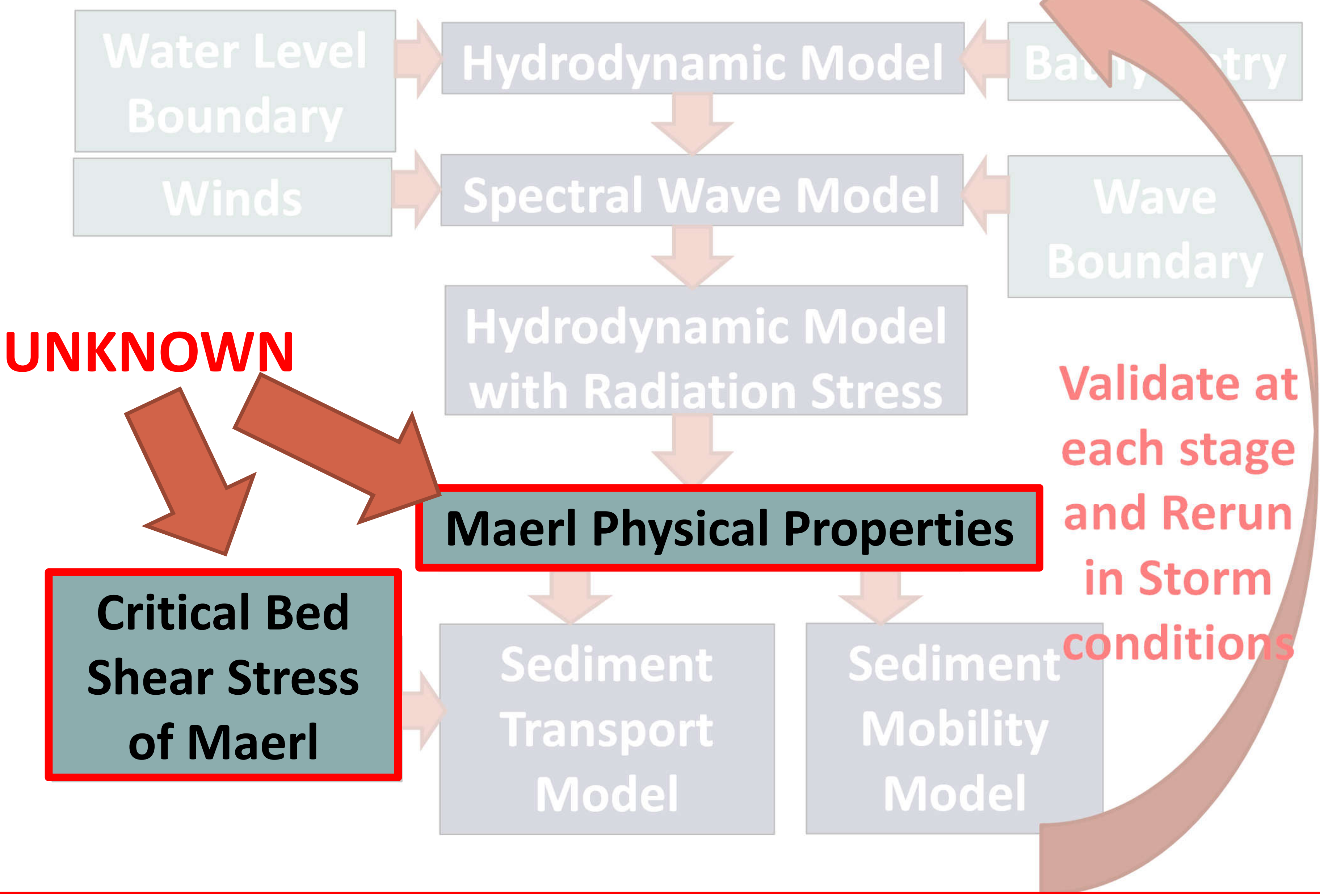


Validation



A
Significant Wave Height [m]
5.0
4.0
3.0
2.0
1.0
0.0
00:00
2007-07-27
00:00
08-01
00:00
08-06
B
Wave Period [s]
8.0
7.0
6.0
5.0
4.0
3.0
2.0
00:00
2007-07-27
00:00
08-01
00:00
08-06
C
Surface Elevation [m]
2.0
1.0
0.0
-1.0
-2.0
00:00
2007-07-27
00:00
08-01
00:00
08-06
D
Significant Wave Height [m]
5.0
4.0
3.0
2.0
1.0
0.0
00:00
2013-12-17
00:00
12-22
00:00
12-27
E
Wave Period [s]
8.0
7.0
6.0
5.0
4.0
3.0
2.0
00:00
2013-12-17
00:00
12-22
00:00
12-27
F
Current Speeds [m/s]
0.20
0.15
0.10
0.05
0.00
00:00
1994-09-03
00:00
09-08
00:00
09-13

Coupled Modelling Methodology



Maerl Hydrodynamic & Physical Properties

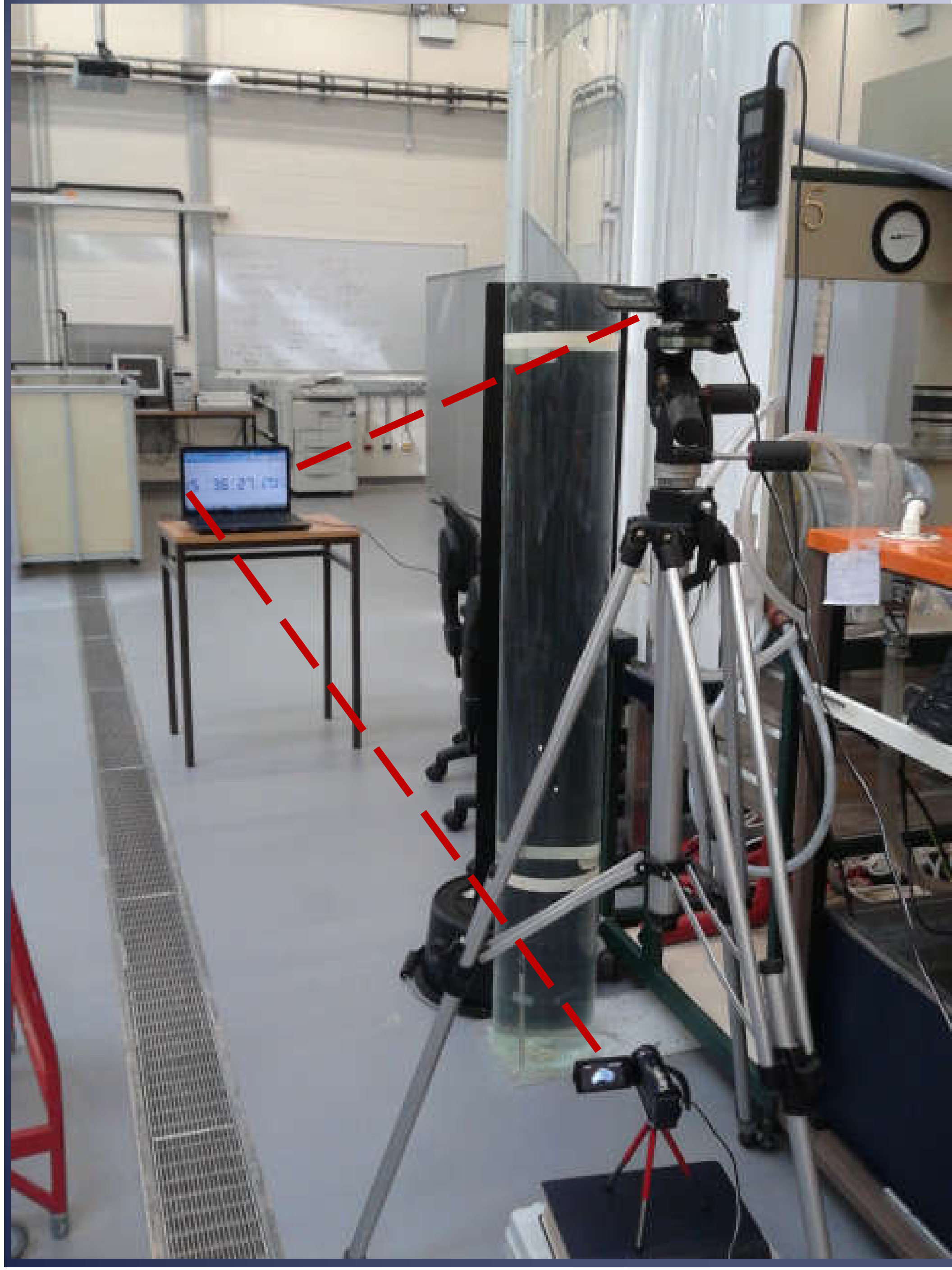
Maerl Properties Measurement

- Grain Size and Shape
- Settling Velocity
- Grain Density

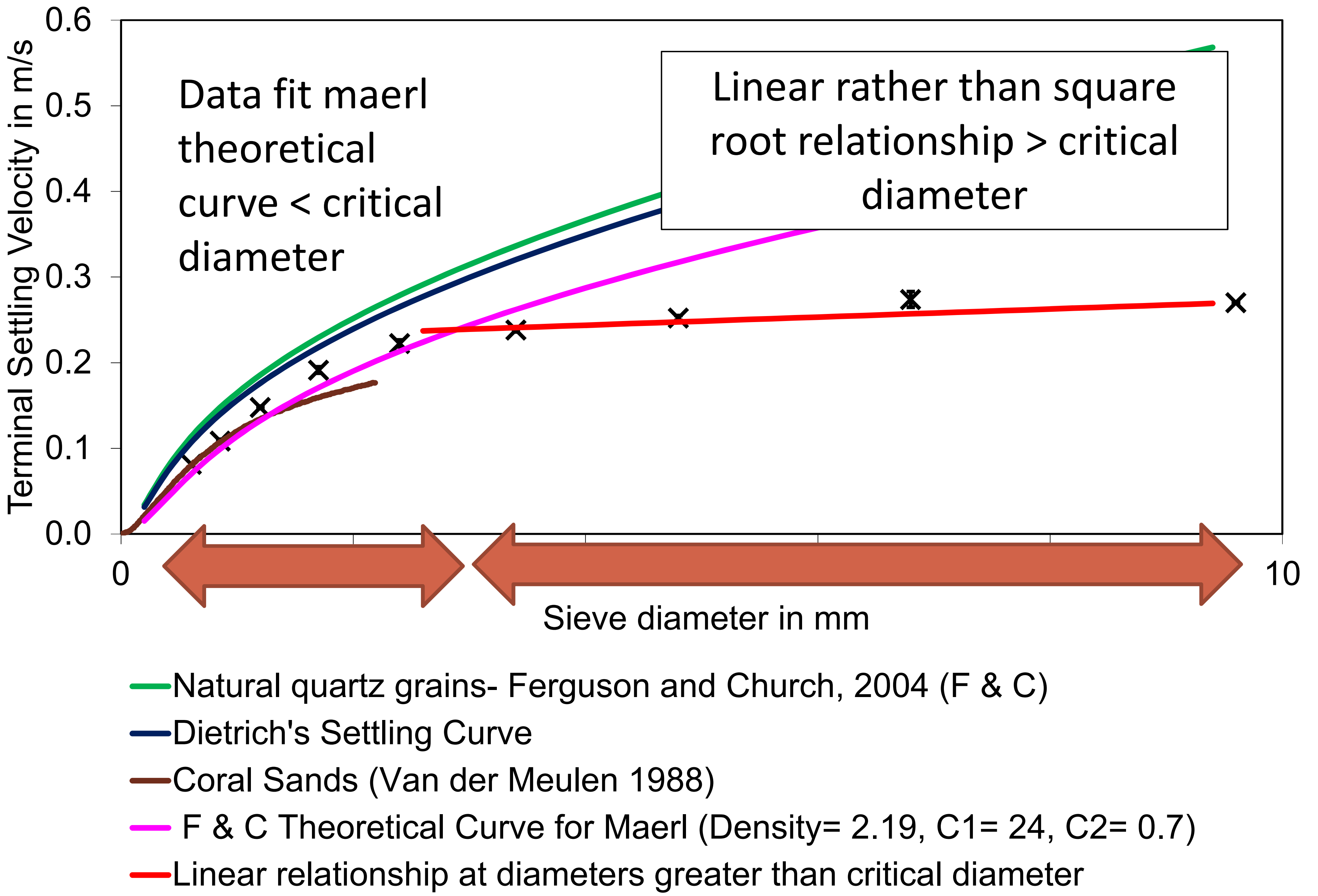
Critical Bed Shear Stress Determination

- Law of the Wall
- Turbulent Kinetic Energy (TKE)
- Critical Shields Parameter

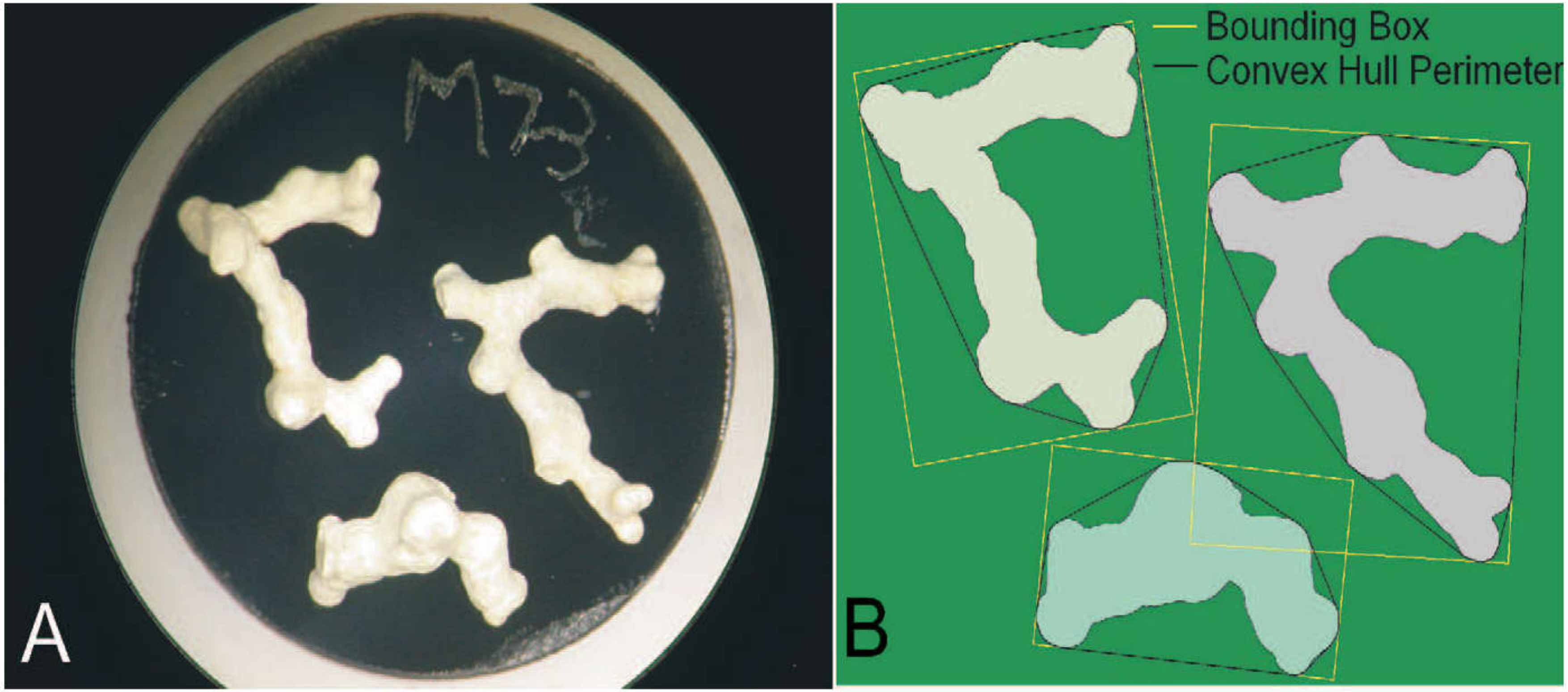
Settling Velocity
2m Settling tube
2 video cameras and water bath



Results: Settling Velocity of maerl



Detailed 2D Microscope image analysis



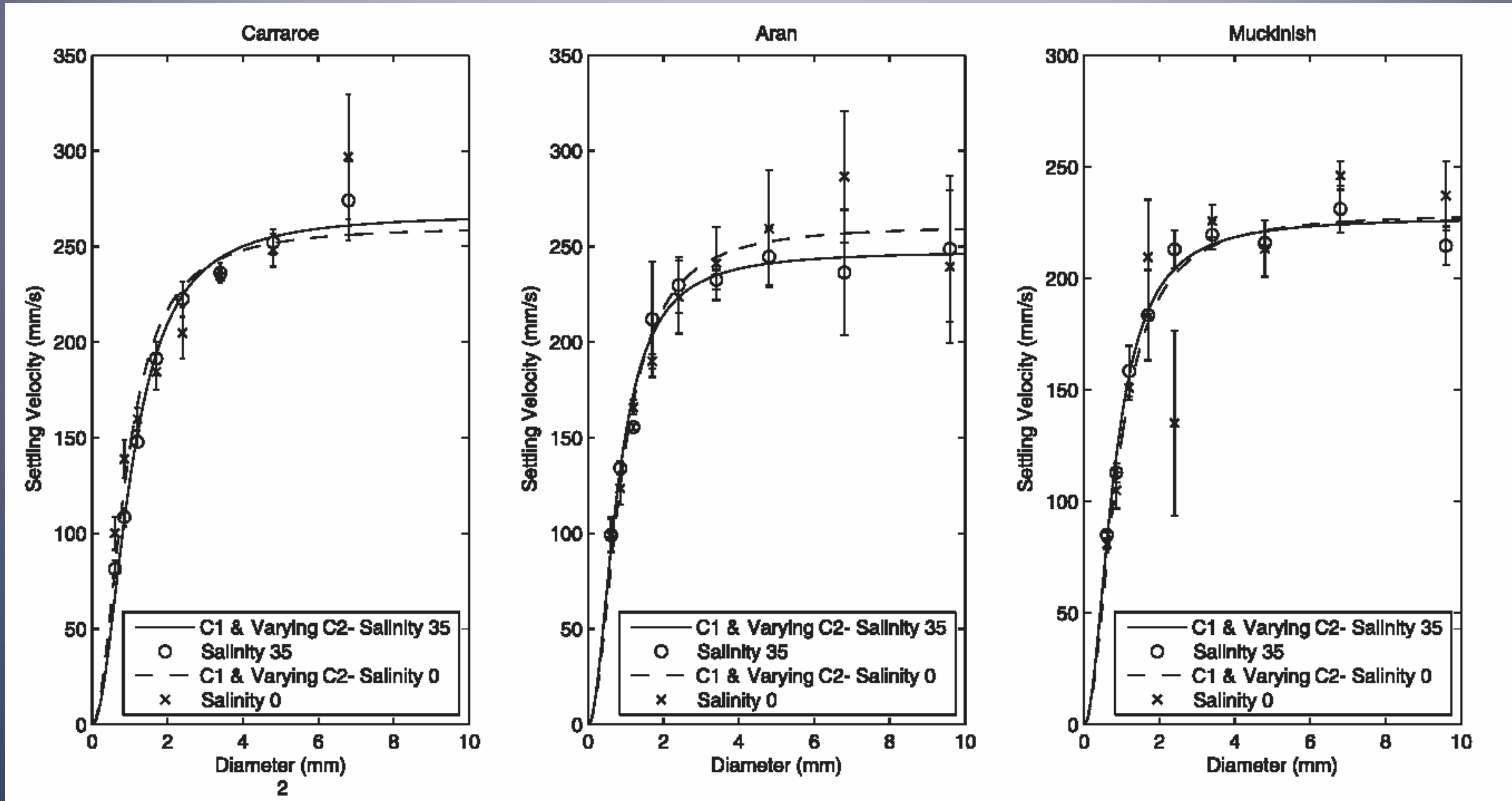
Grain form: Elongation
Grain outline: Convexity
Combination: Circularity
Convexity – proxy for branch density and grain roughness

Ferguson and Church (2004) universal equation for settling velocity

$$w_s = \frac{Rgd^2}{C_1 v + (0.75\, C_2 Rgd^3)^{0.5}}$$

R = Submerged specific gravity
g = Gravitational acceleration
d = Grain diameter
v = Kinematic viscosity coefficient
C_1 = 18 C_2 = 1 for natural grains
C_1 = 24 C_2 = 1.8 for highly angular quartz grains

Our modification to Ferguson and Church



$C_1 = 42 \pm 2$
$C_{21} = 265 \pm 8$

$C_1 = 33 \pm 3$
$C_{21} = 284 \pm 6$

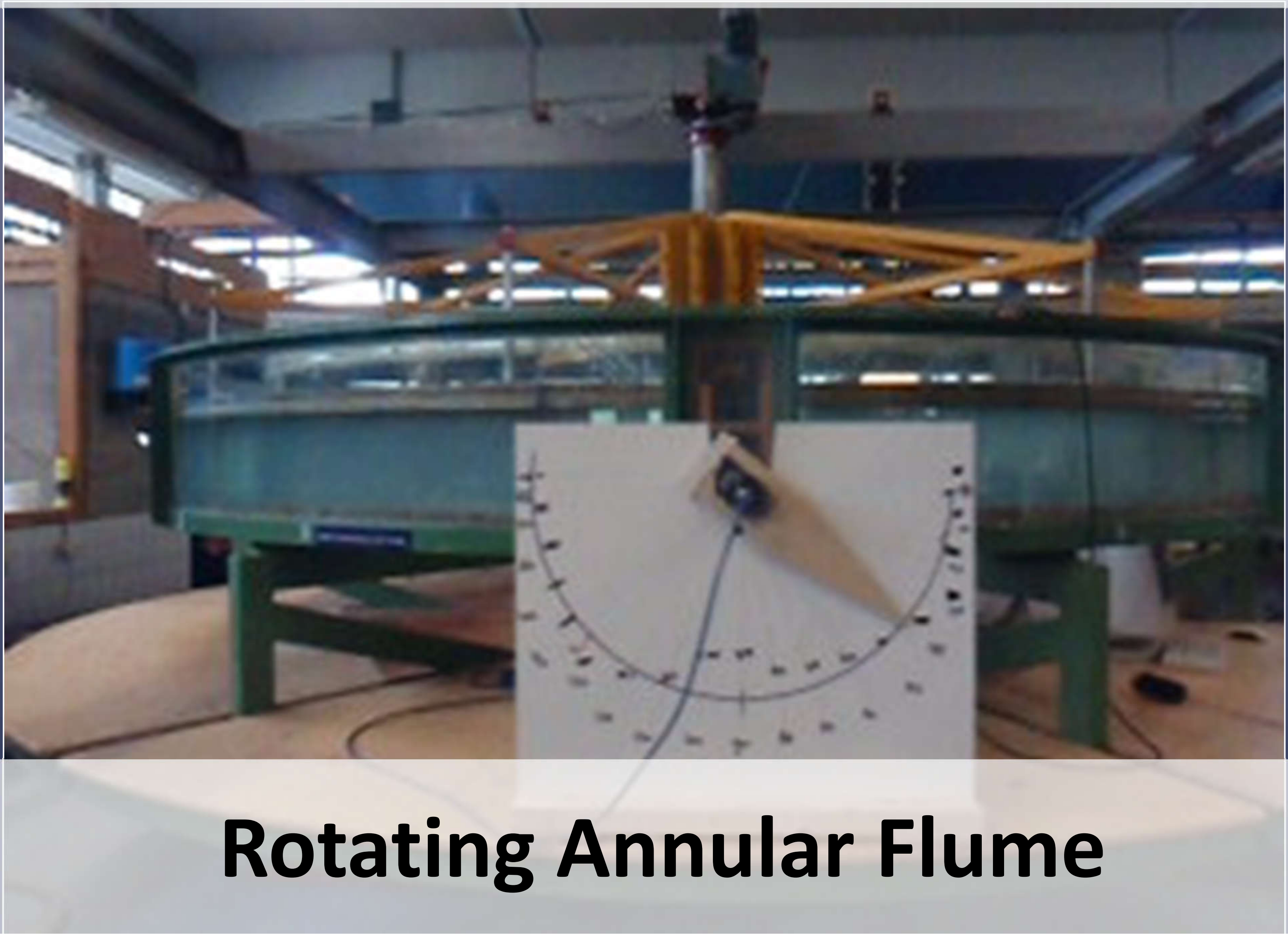
$C_1 = 38 \pm 3$
$C_{21} = 352 \pm 6$

C_1 constrained to be $C_1 > 16$
C_2 parameter linearly vary as a function of diameter($C_2 = C_{21}d$)

Setting Velocity Key Findings

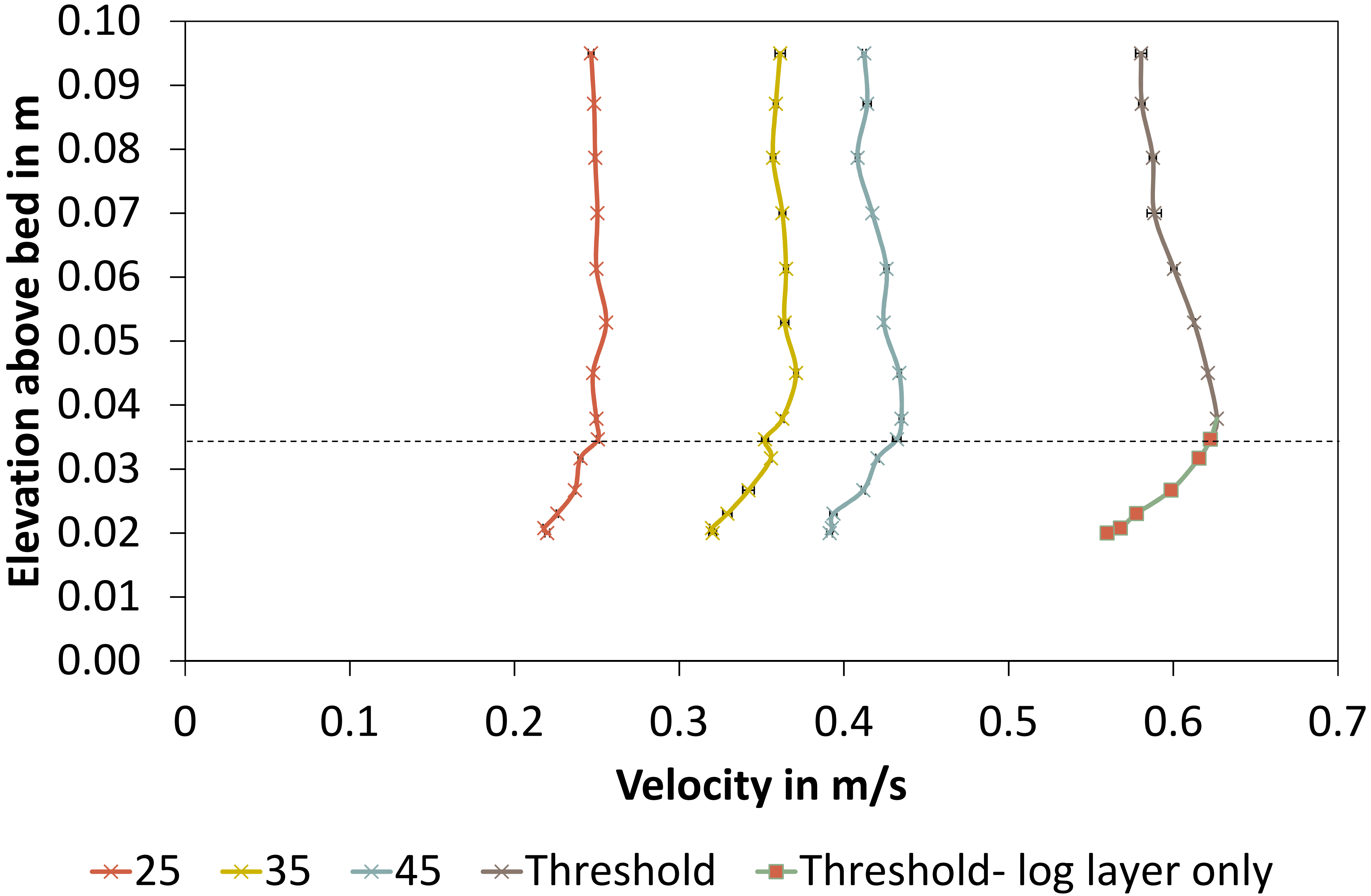
- Maerl has overall a lower settling velocity than quartz grains
- Settling velocity curve at diameters > 2mm for maerl is flat in comparison to the curve for quartz
- Grain shape parameters correlate with grain size and alter settling velocity with size, especially greater drag associated with convexity
- Modified Ferguson and Church shows theoretical model best fit with drag coefficient related C_2 parameter varying linearly with diameter
- Very Irregular shape leads to greater drag on grain, reducing the settling velocity (Komar and Reimers, 1978)

Critical Bed Shear Stress

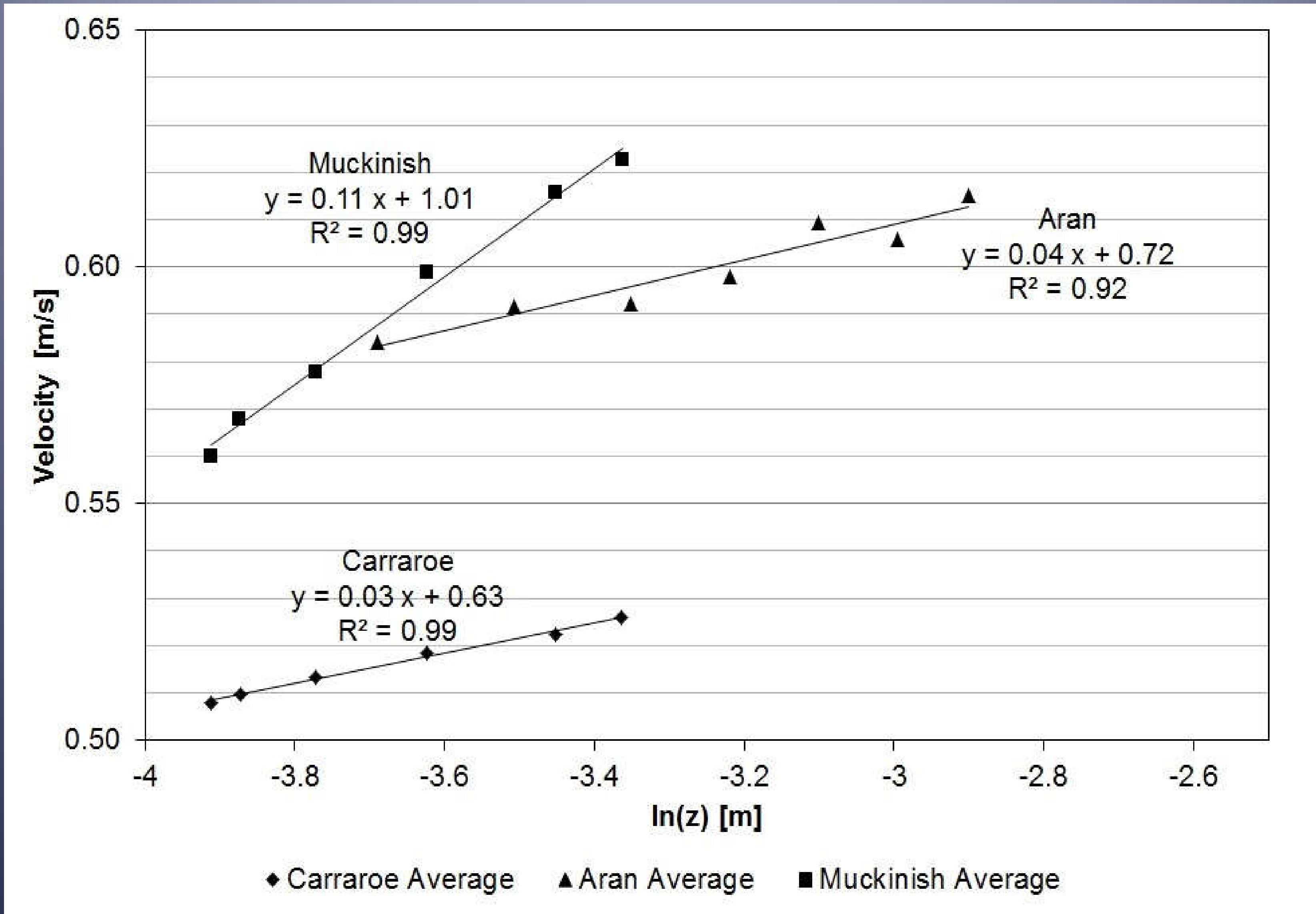


Rotating Annular Flume

Law of the Wall Results - Intertidal



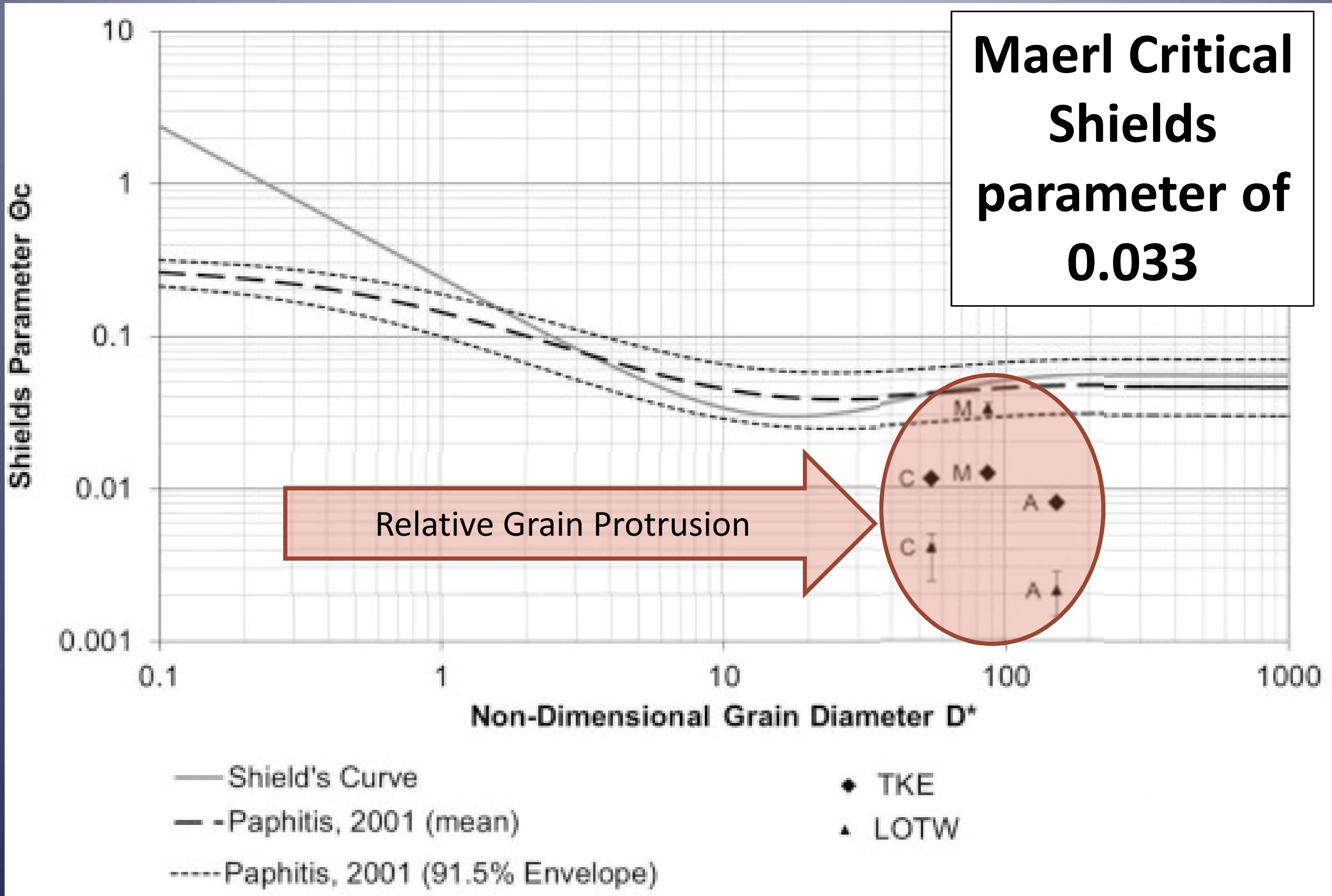
Log velocity profiles



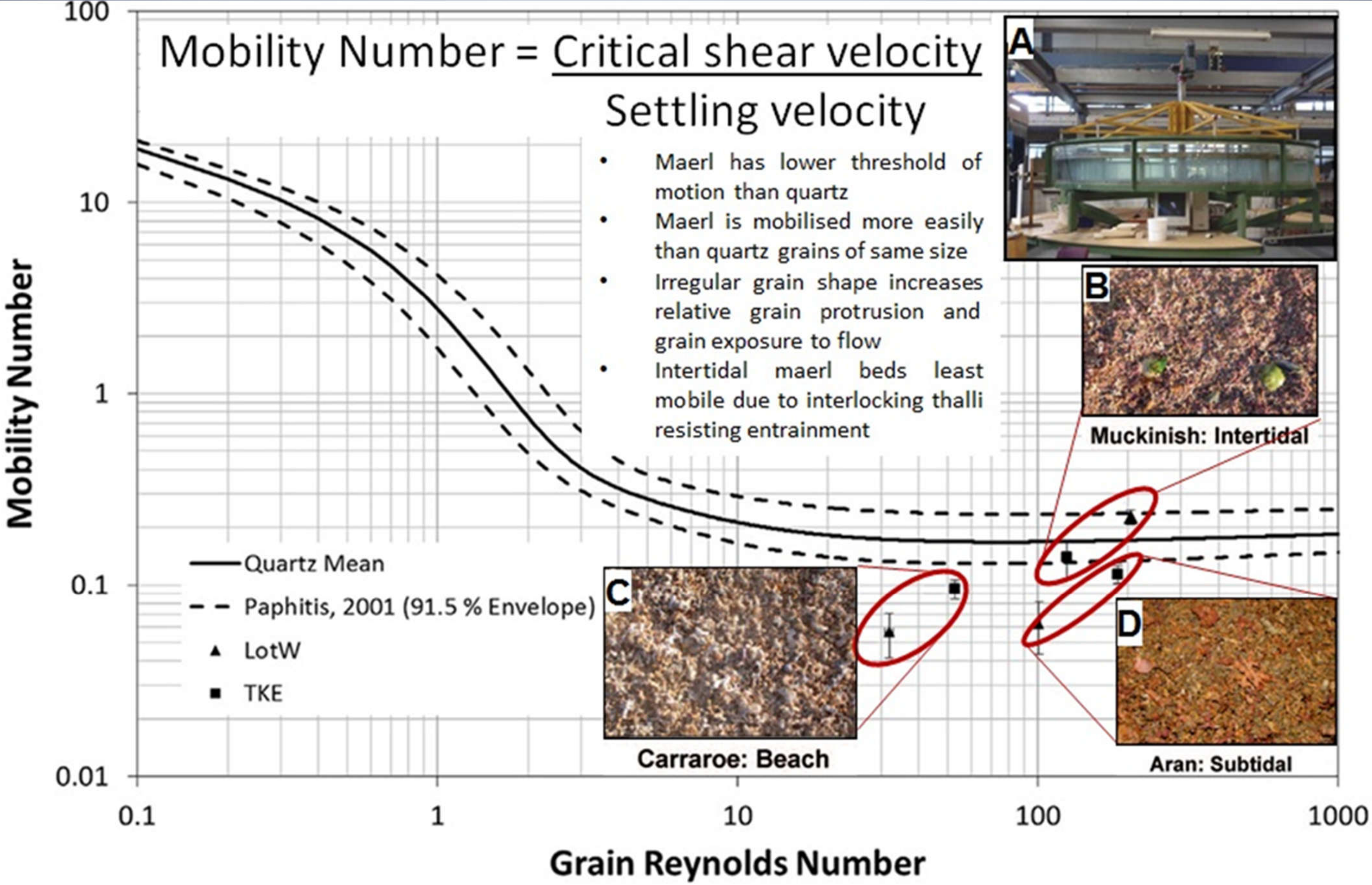
Critical Bed Shear Stress of Maerl

	Carraroe -Beach	Aran- Open marine	Muckinish -Intertidal
Law of the Wall (LOTW)	0.16 ± 0.06	0.22 ± 0.07	2.07 ± 0.19
Turbulent Kinetic Energy (TKE)	0.46 ± 0.01	0.75 ± 0.04	0.78 ± 0.05
Critical Shields Parameter (Based on LOTW)	0.004 ± 0.002	0.002 ± 0.001	0.033 ± 0.003

Shields Curve with Maerl



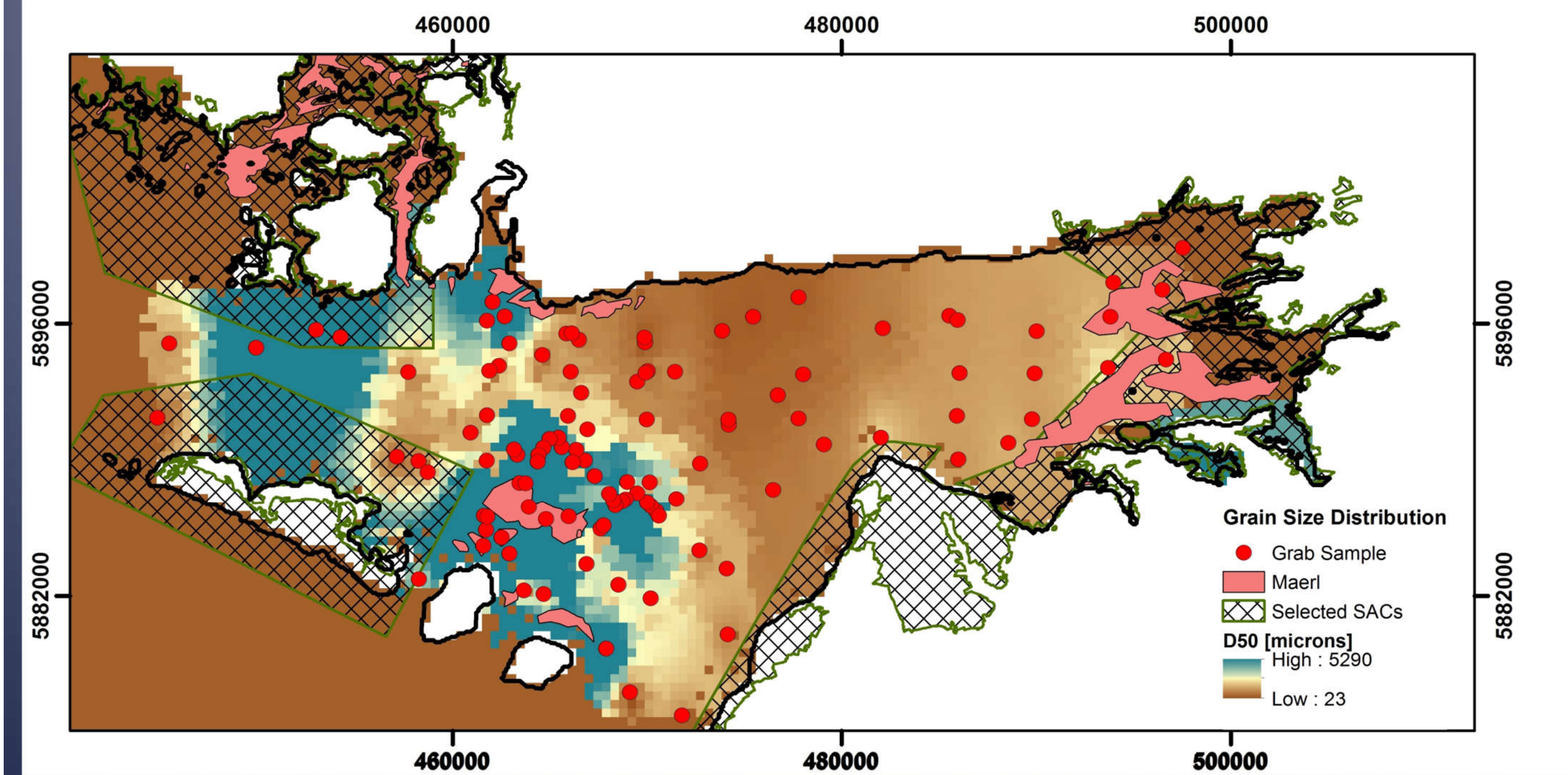
Mobility Number Curve



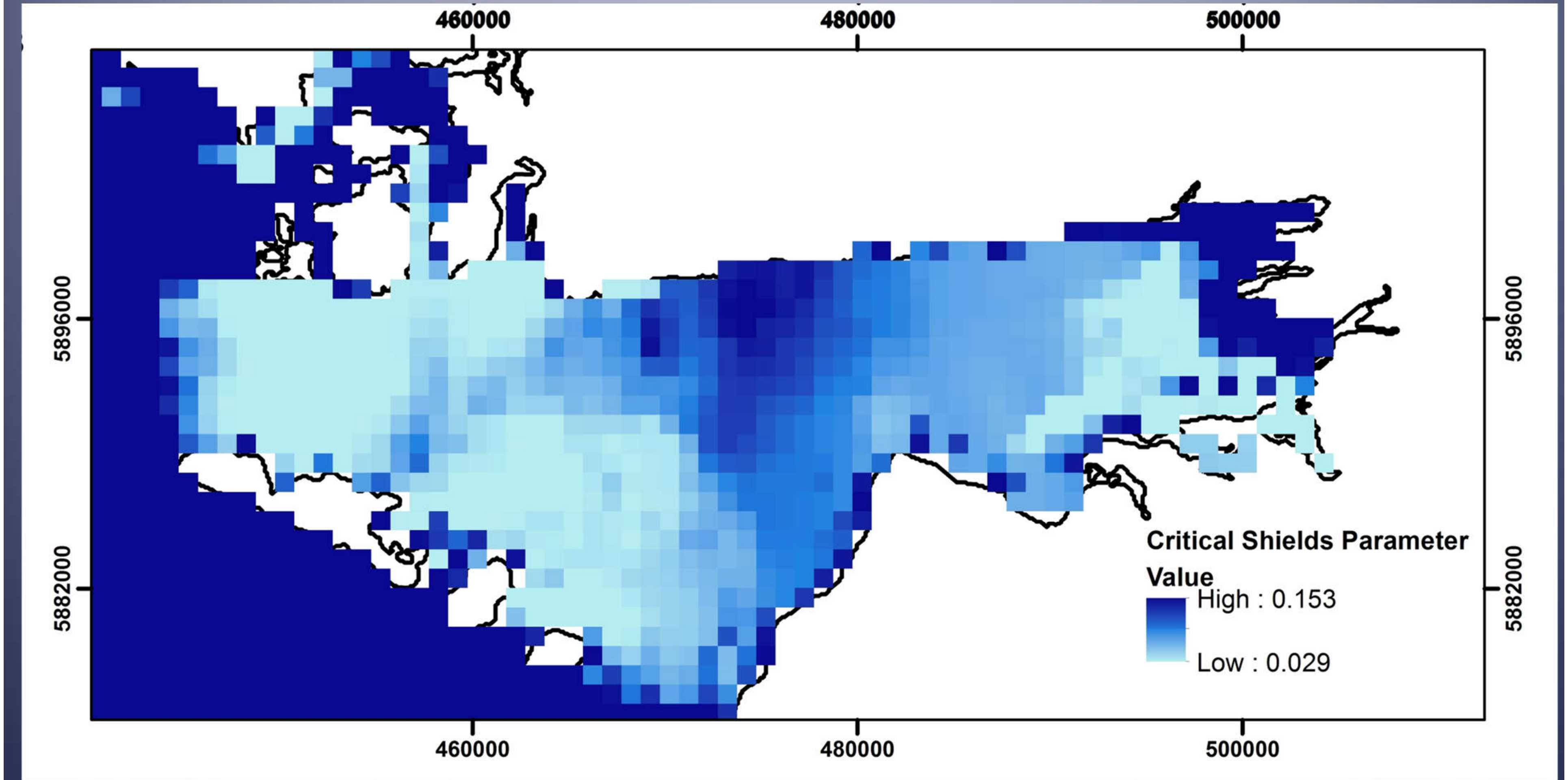
Critical Bed Shear Stress Key Findings

- Maerl has lower critical bed shear stress than quartz grains due to greater drag associated with grain shape
- Maerl in intertidal beds is least mobile with highest critical bed shear stress as interlocking thalli resist entrainment
- Law of the Wall methodology is most reliable with high R^2 values based on multi-level measurements
- TKE reliable, but is not able to distinguish the finer effects of grain shape between sites which is distinguished by Law of the Wall
- We show critical Shields parameter of 0.033 and depth averaged critical threshold velocities of 51-57 cm/s
- Maerl forms sub aqueous dunes at velocities 10 cm/s > critical threshold

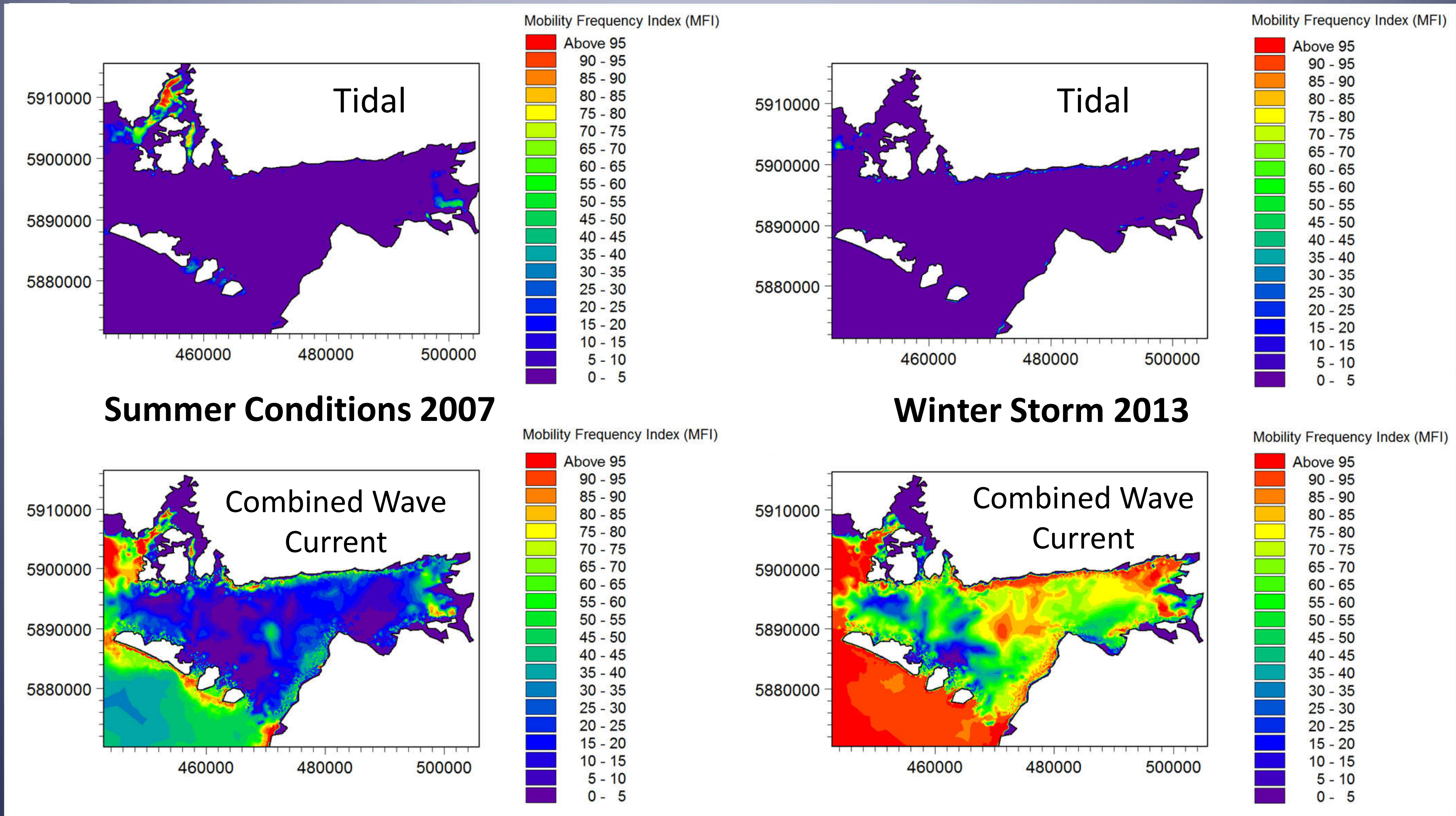
Grain Size and Sediment Mobility



Spatially Varying Critical Shields Parameter

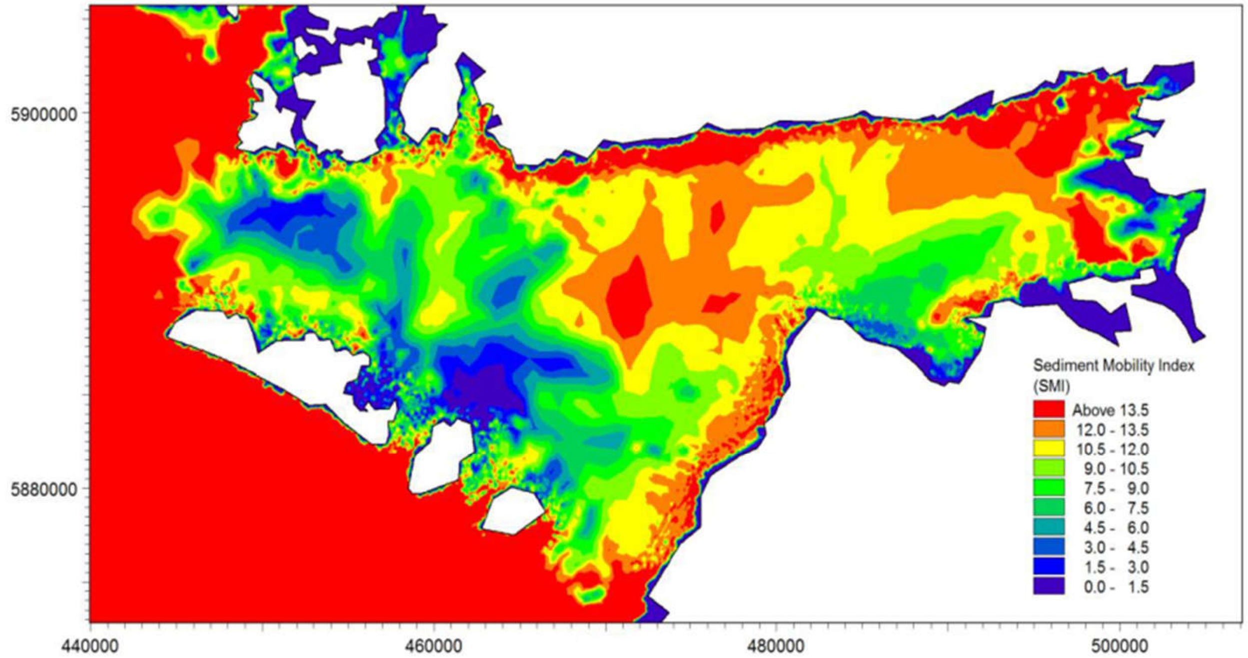


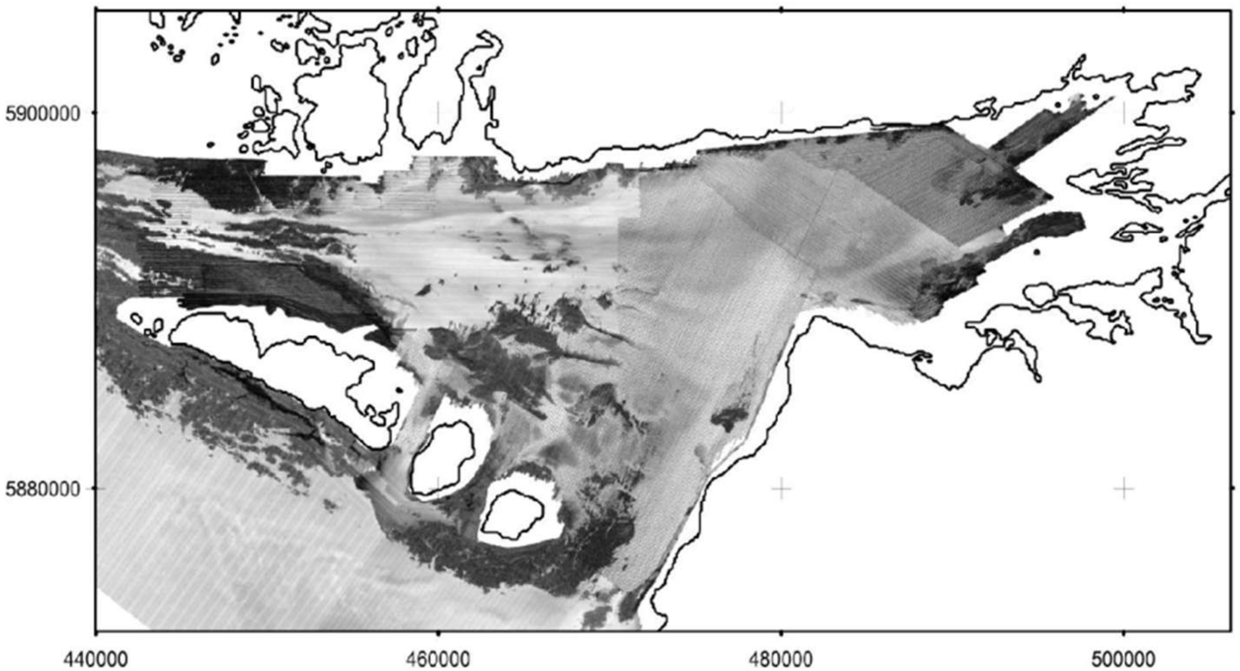
Sediment Mobility Modelling



- Mobilization Frequency Index is percentage of time grains of a particular size are mobilised in a spring-neap tidal cycle according to the Shields Criterion.
- Peak combined wave-current induced MFI during storm is best physical surrogate for maerl

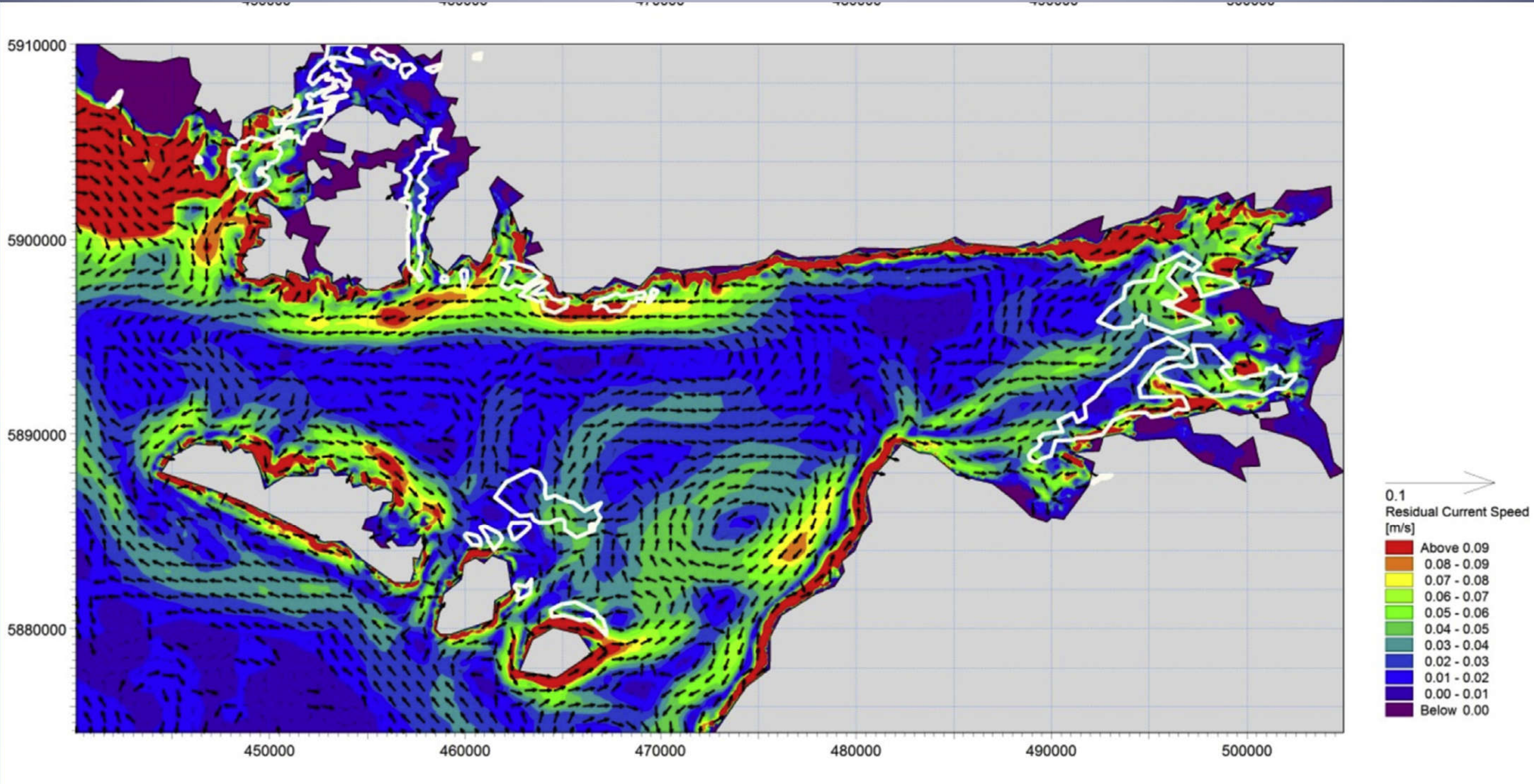
COMBINED WAVE-CURRENT SEDIMENT MOBILITY INDEX (SMI) IN WINTER STORM CONDITIONS



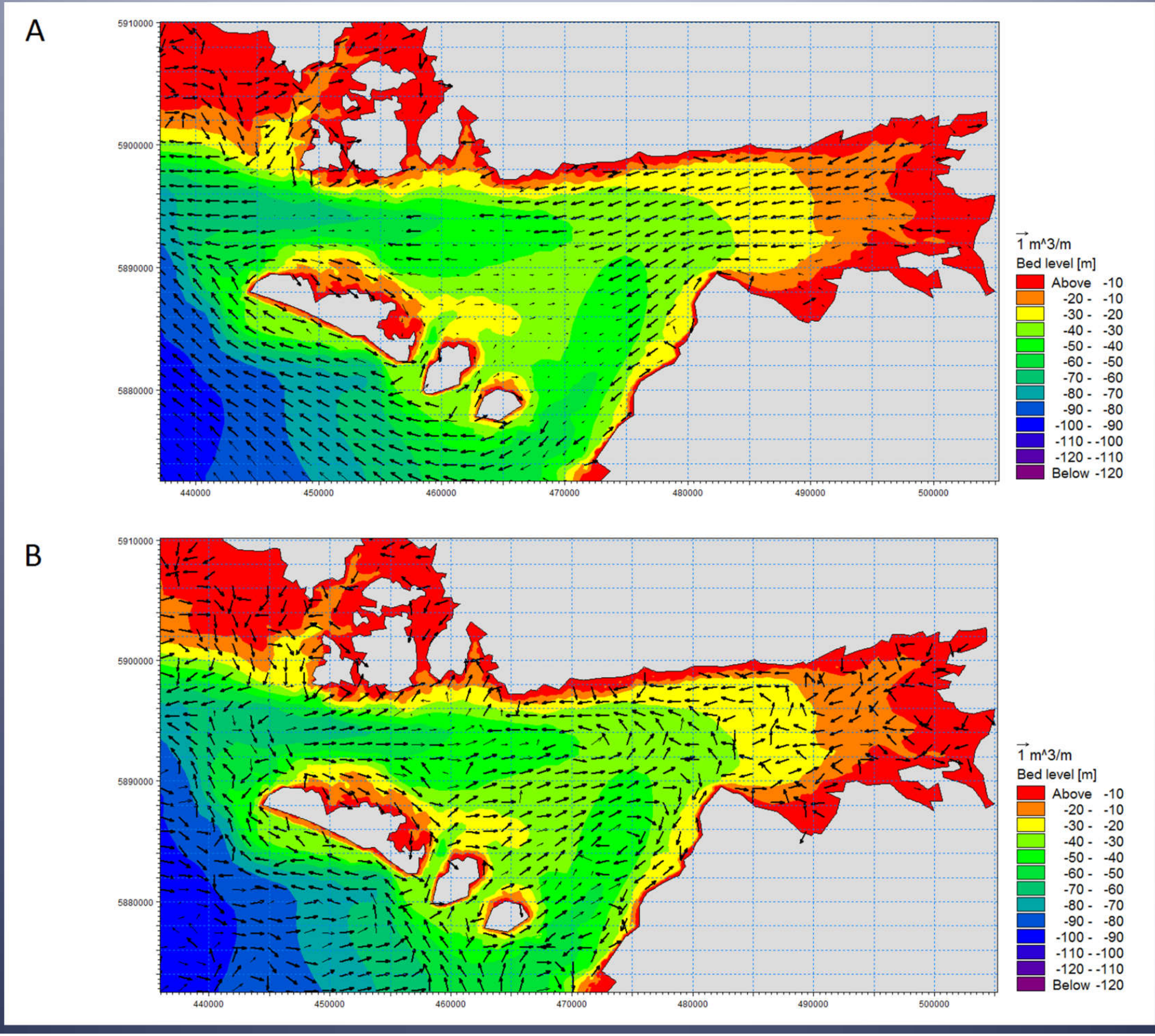


- SMI takes magnitude and frequency of disturbance into account
- SMI partially correlated with MBES backscatter
- Patchiness of Aran maerl beds due to reoccurring disturbance

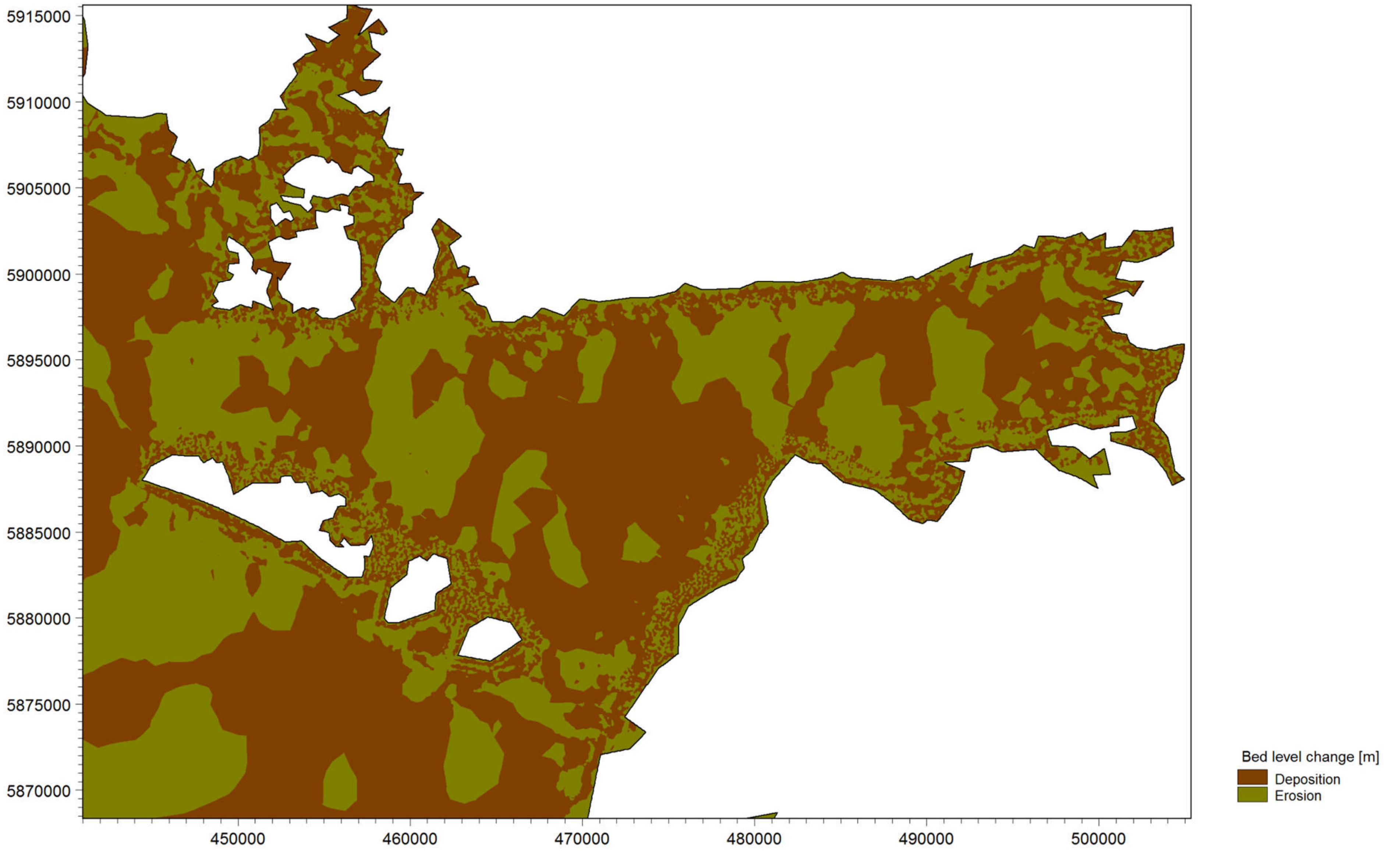
Residual Currents with Maerl: Winter



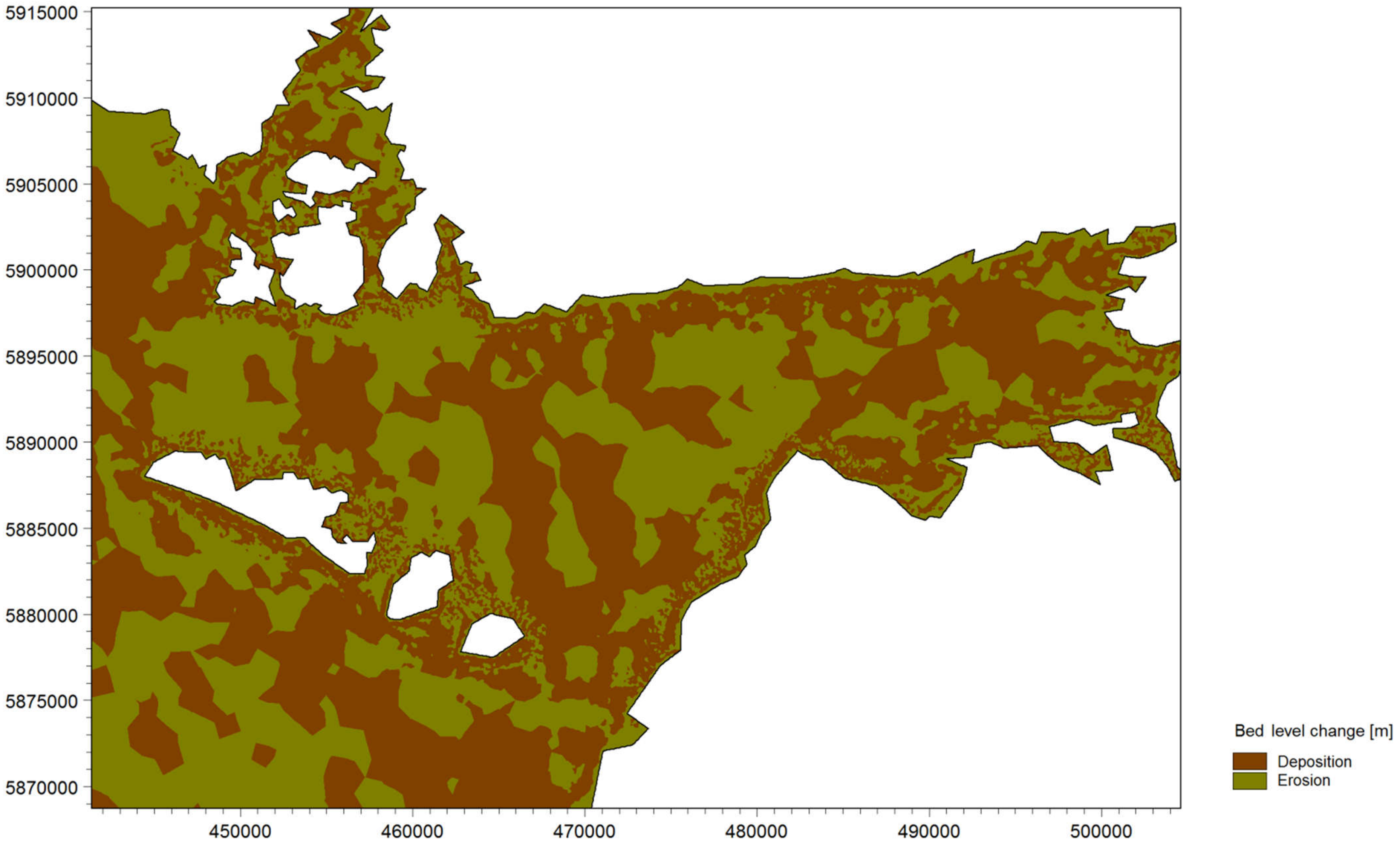
Sediment transport vector map



Erosion- Deposition Model- Summer

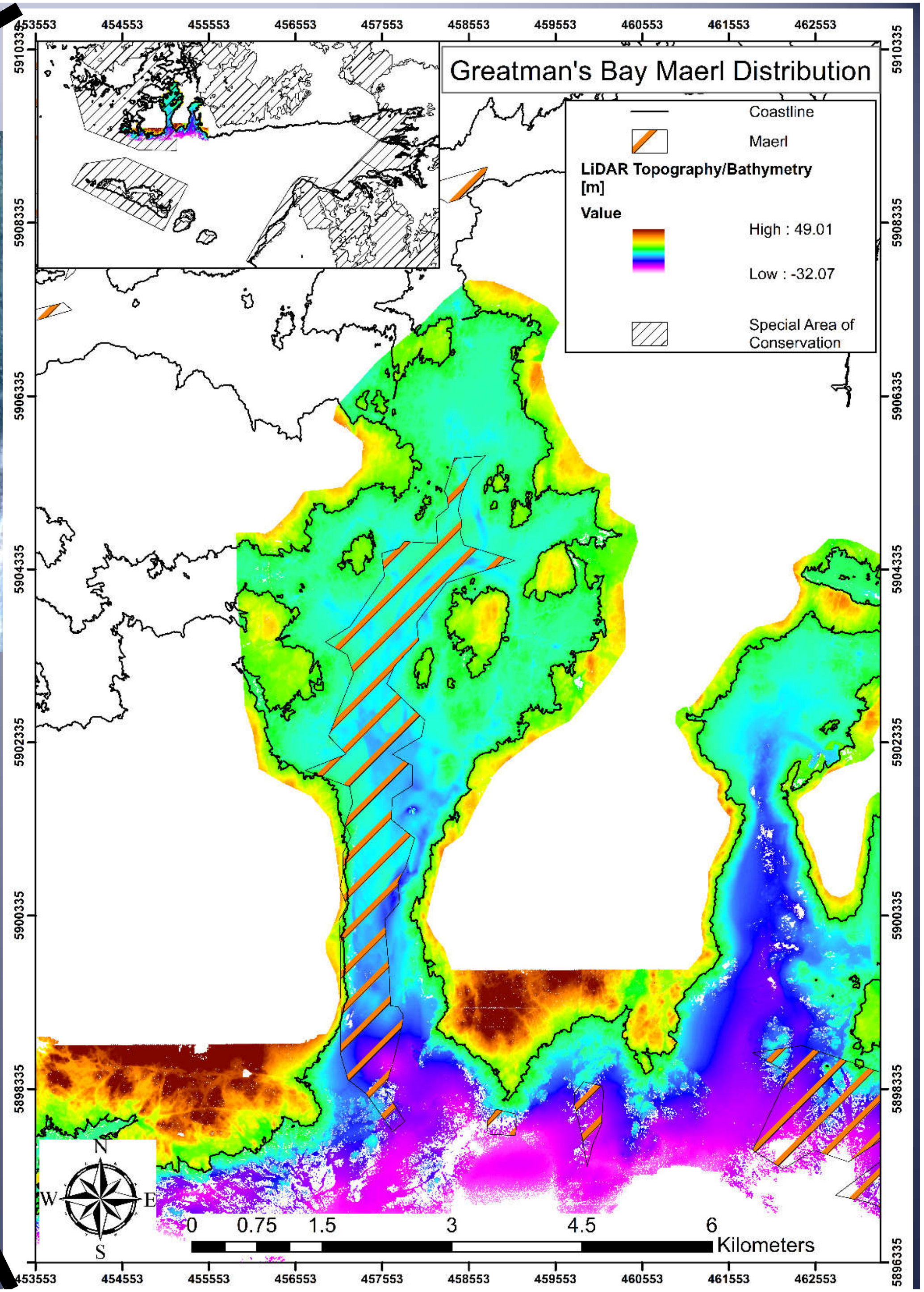


Erosion-Deposition Model- Winter



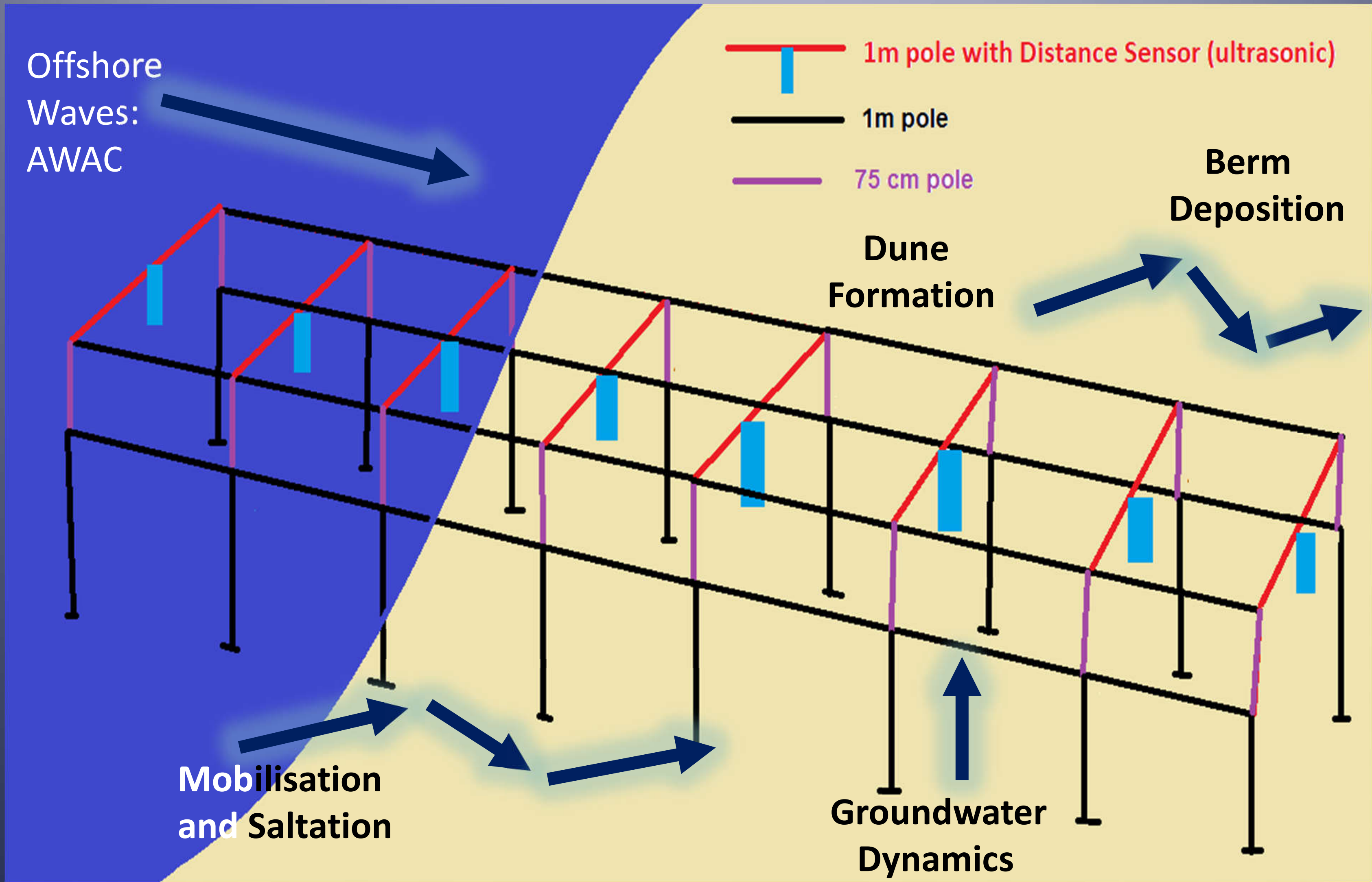
Sediment Mobility Key Findings

- Wave-dominated disturbance regime
- Peak combined wave-current induced Mobilization Frequency Index during storm conditions is best physical surrogate for maerl-siliciclastic mixtures
- Maerl prefers intermediate sediment mobility
- Sediment Mobility Index partially correlated with MBES backscatter revealing patchiness of dynamic seafloor
- Mud mobilisation in severe storm conditions



Maerl Beach Morphodynamics Experiment in Greatman's Bay, Carraroe Trá an Doilin

Beach Morphodynamics Experiment: Measurement frame with 8 sensors






Thank You and Questions?

- Joshi S., Duffy G. and Brown C. (2017b) Critical bed shear stress and threshold of motion of maerl biogenic gravel, Estuarine, Coastal and Shelf Science, 194,128-142. https://dx.doi.org/10.1016/j.ecss.2017.06.010

- Joshi S., Duffy G. and Brown C. (2017a) Mobility of maerl-siliciclastic mixtures: Impact of waves, currents and storm events, Estuarine, Coastal and Shelf Science, 189,173-188. https://dx.doi.org/10.1016/j.ecss.2017.03.018

- Joshi S., Duffy G. and Brown C. (2014) Settling velocity and grain shape of maerl biogenic gravel, Journal of Sedimentary Research 84,718-727. http://dx.doi.org/10.2110/jsr.2014.51

Maerl: A Rare Seabed Habitat Documentary

https://www.vimeo.com/seabedhabitats/maerldocumentary

Password: Muckinish