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Circulation and hydrodynamics
Simple lake and estuary models

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Circulation and hydrodynamics
Simple lake and estuary models

Topics

- Why circulation matters
- Different types of circulation models, with examples
- Vertical mixing in lakes and how to model it
- Simple estuarine models
- Upscaling of hydrodynamic models
- Synthesis

Why circulation is important for environmental modelling

Examples

- Wind-driven circulation conditions outfall plumes
- Vertical stratification controls bloom development
- Connection between mixed layer and deep layer affects oxygen supply at depth
- Tidal currents in shallow estuaries and bays determine turbidity
- Current speed affects food supply for shellfish aquaculture

Ecological Modelling

Different dimensions, different scales

Dimensions

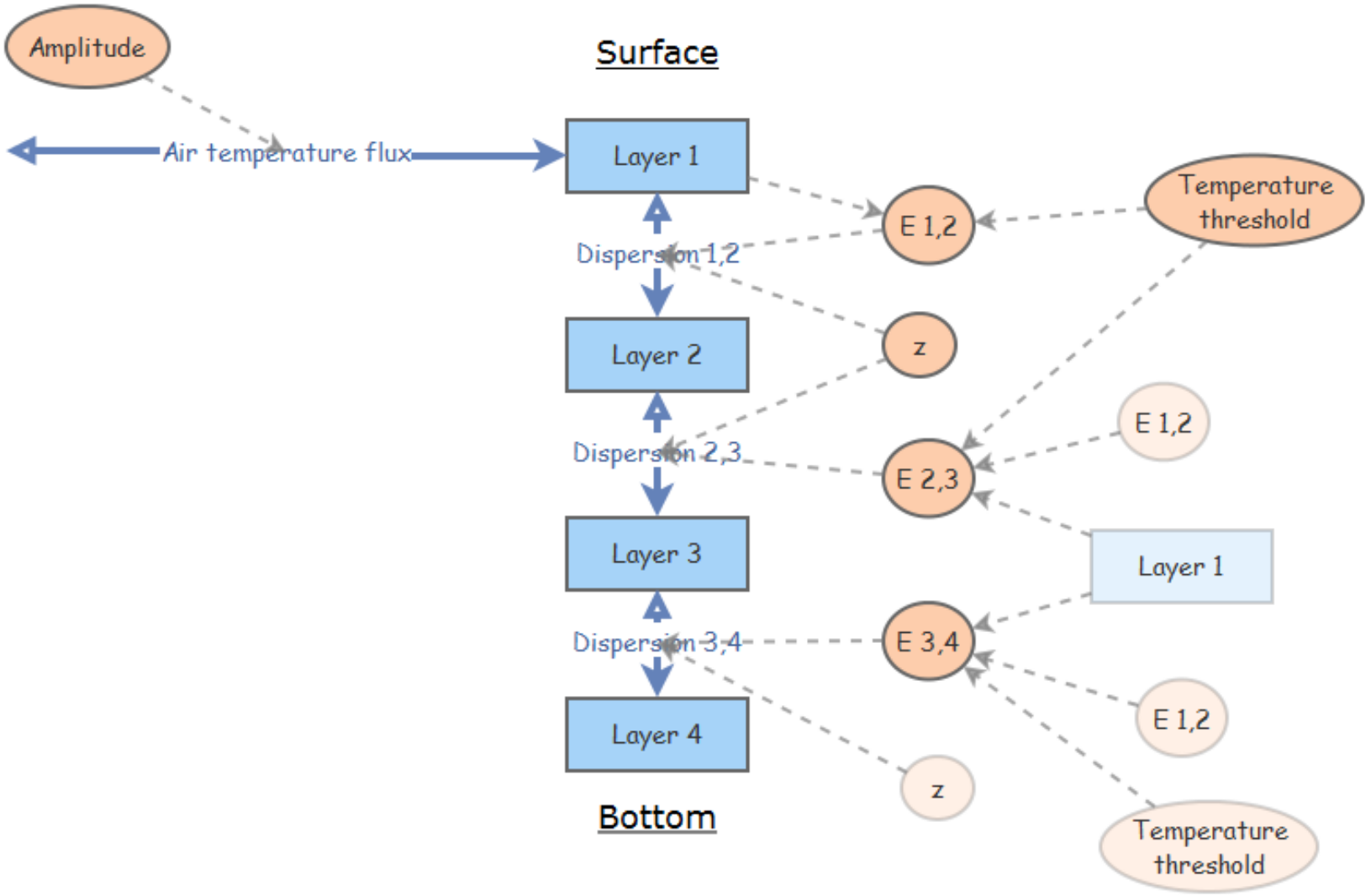
- Statistical
- Zero-dimensional (time only)
- One-D (rivers, narrow estuaries)
- Two-D (non-stratified estuaries, coastal areas)
- Three-D (systems with pronounced horizontal
- and vertical gradients)

Time and space scales

- Hydrodynamics - Small cells, short timestep and time scale
- (tidal cycles, spring-neap cycles, localised case studies)
- Ecology - Larger boxes, longer timestep and time scale
- (seasonal cycles, annual patterns, multiannual variation)

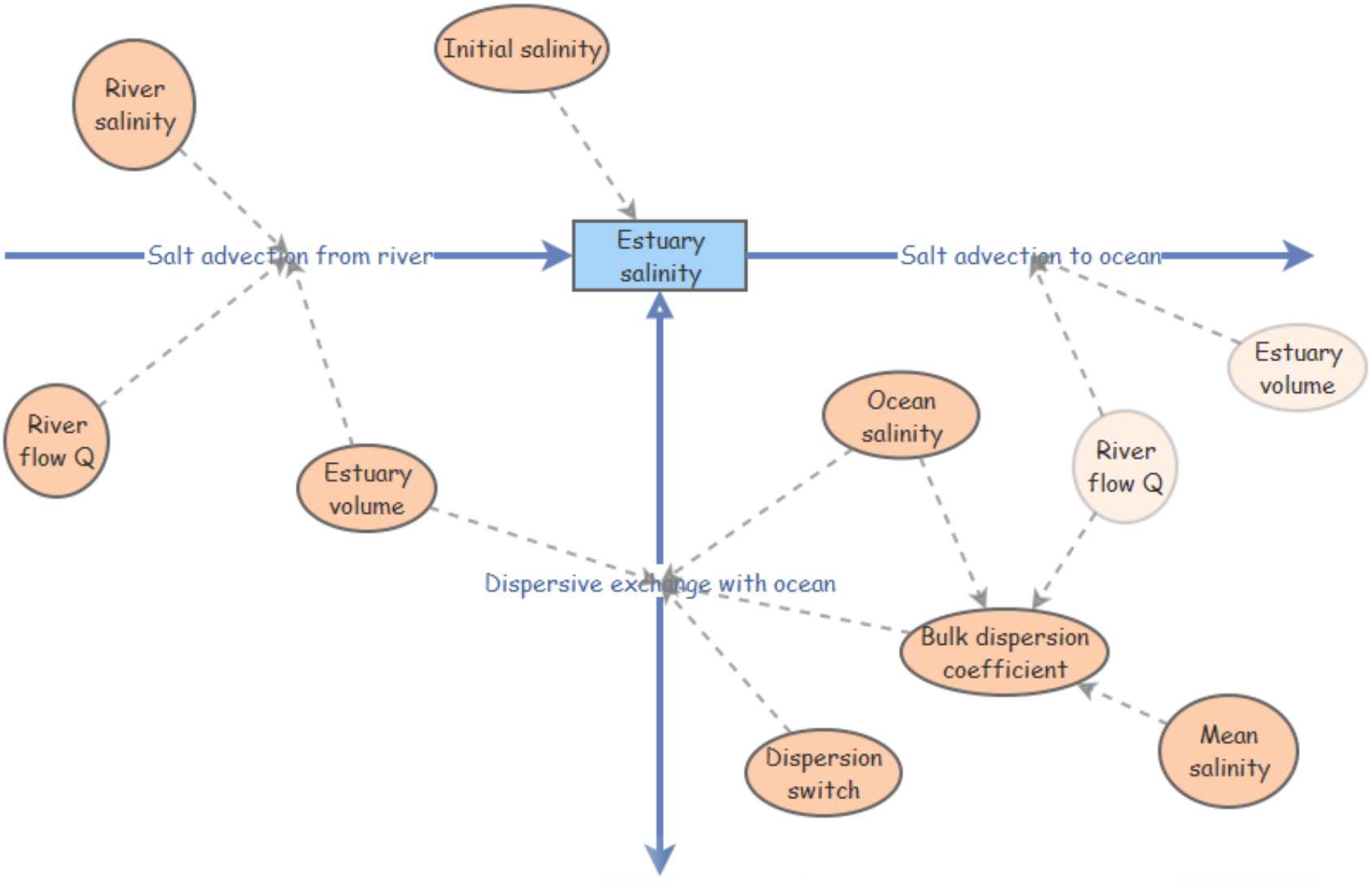
Most people don't solve the problem, they change the problem into something they know how to solve. This does not solve the problem.

Very simplified vertical dispersion model



This is an example of a model of model, i.e. the intent is to represent a phenomenon rather than model it deterministically.

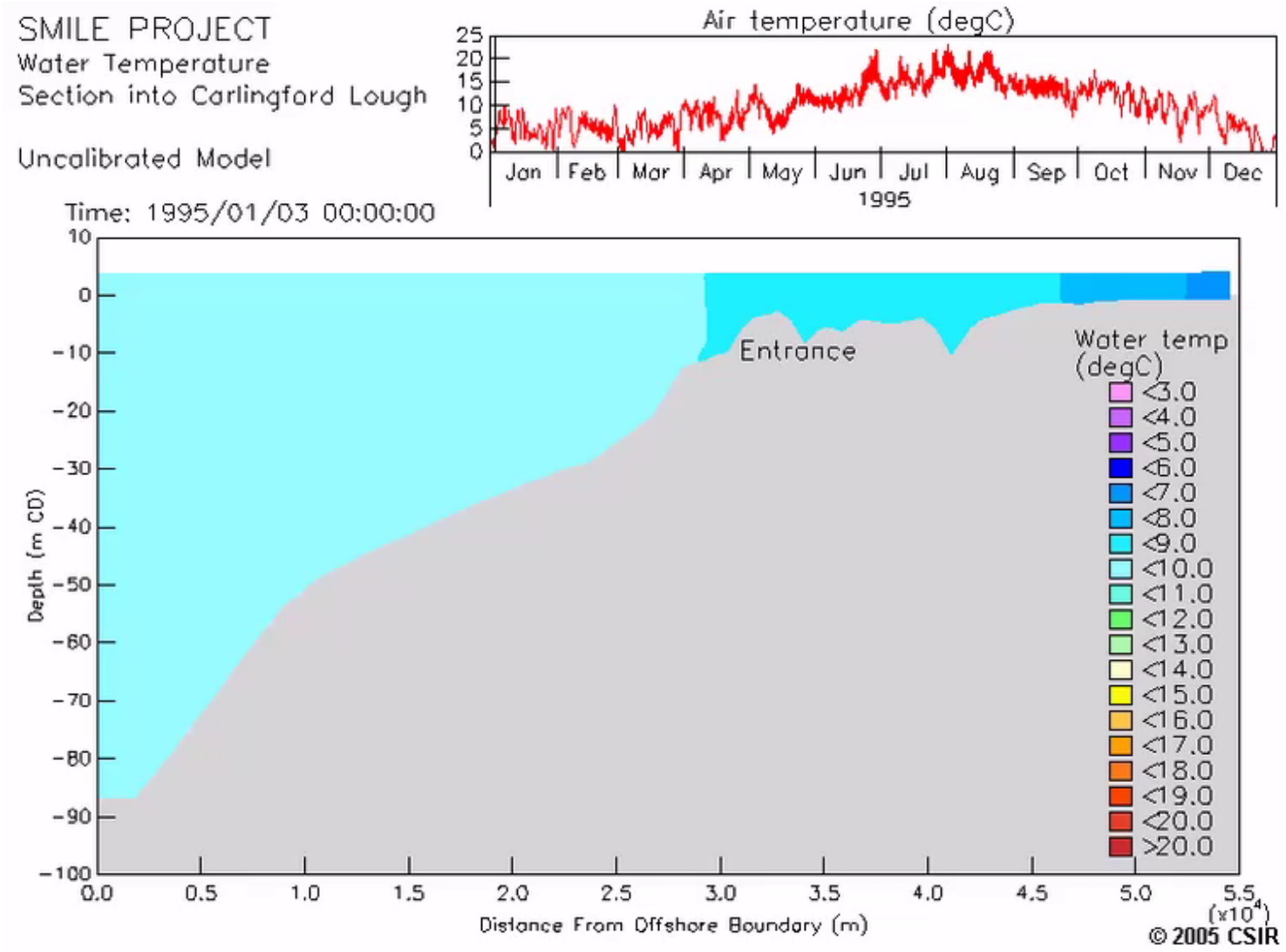
Simple 1-D estuarine transport model



This model can be easily extended to multiple boxes and non-conservative water properties such as dissolved nutrients and phytoplankton biomass.

3D model of vertical stratification

Water temperature section into Carlingford Lough



Water column is stratified in the summer months but not in the lough.

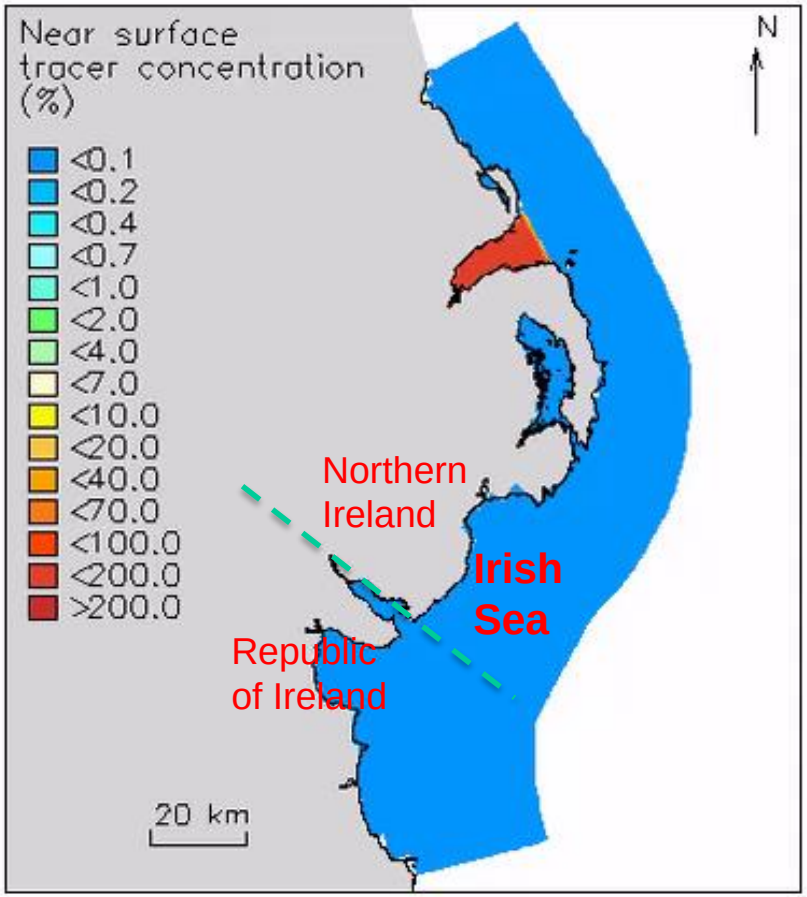
Three-dimensional hydrodynamic models

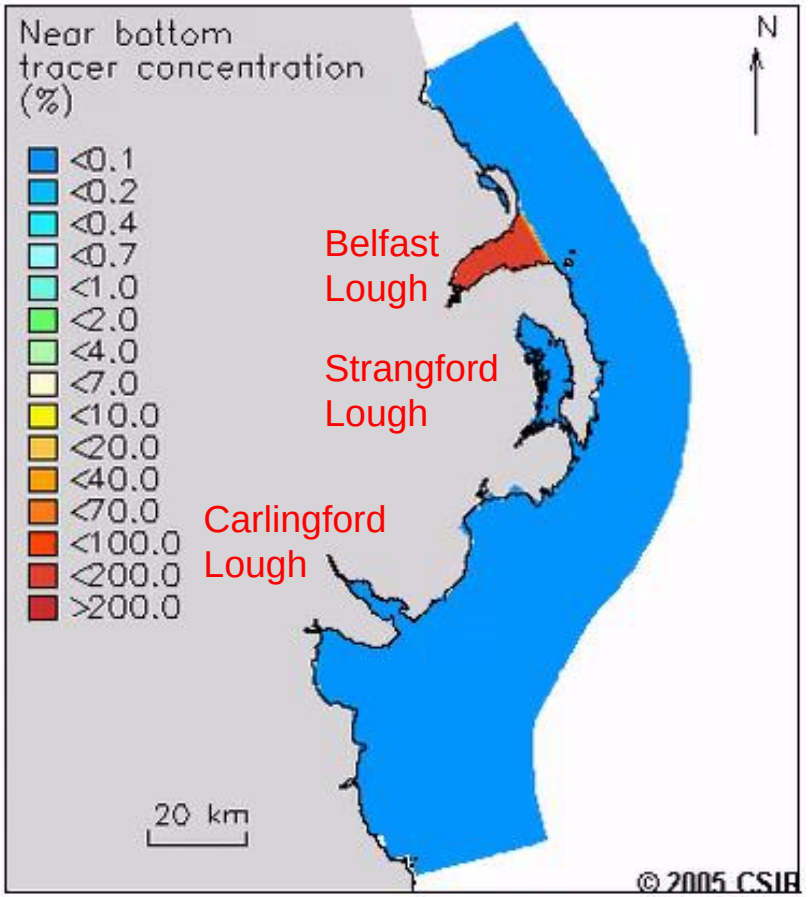
Circulation model – connected systems

SMILE PROJECT

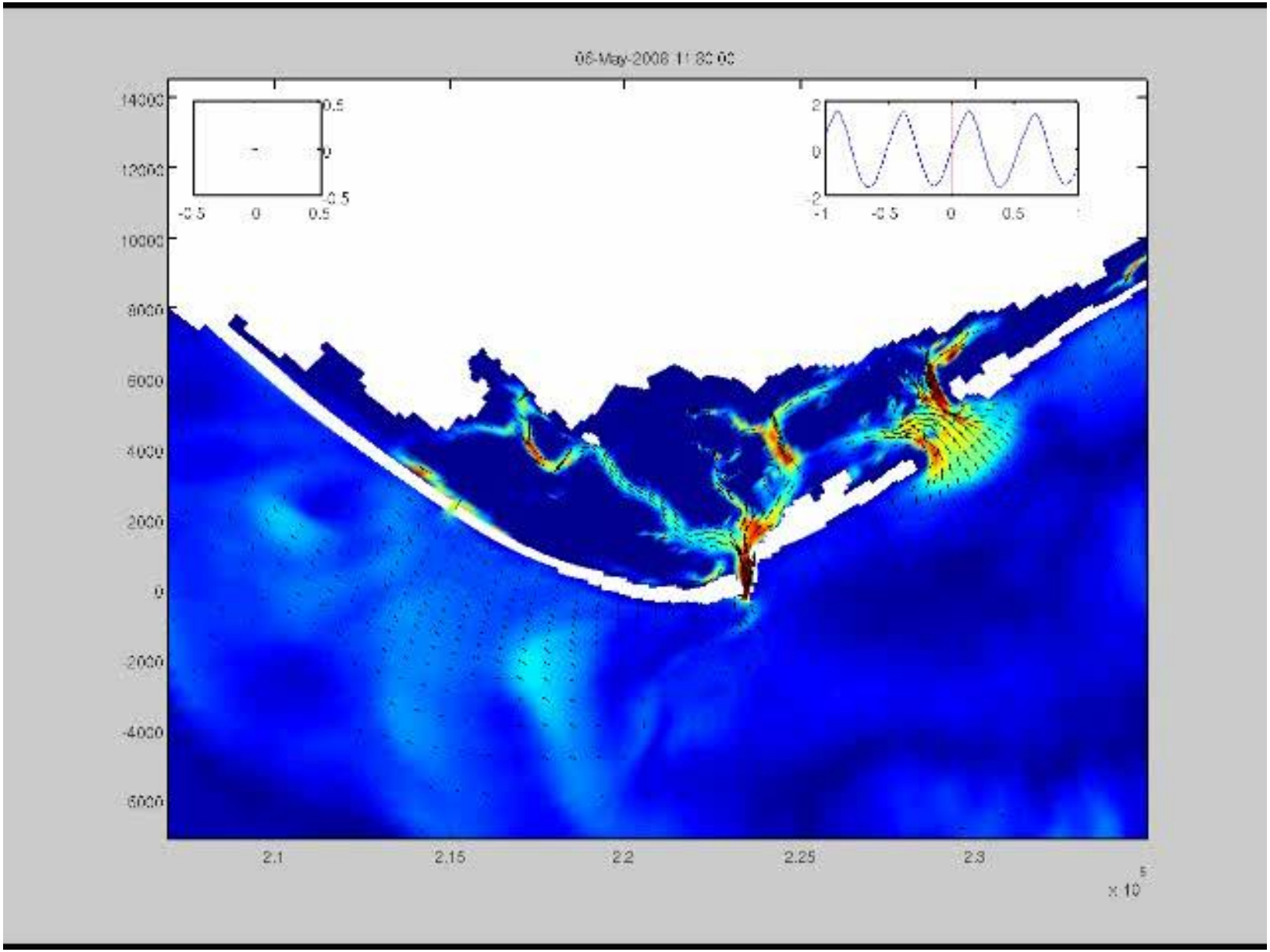
- Larval dispersal;
- Diesease;
- Xenobiotics.

Time: 1995/01/03 00:00:00





Connectivity: Offshore- Ria Formosa (circulation model)



Tidal circulation in the Ria Formosa, Algarve. Water residence time of 1-2 days.

The revenge of the killer mussels…

Huge mussel fouling in the summer of 2012. Spat from offshore culture?

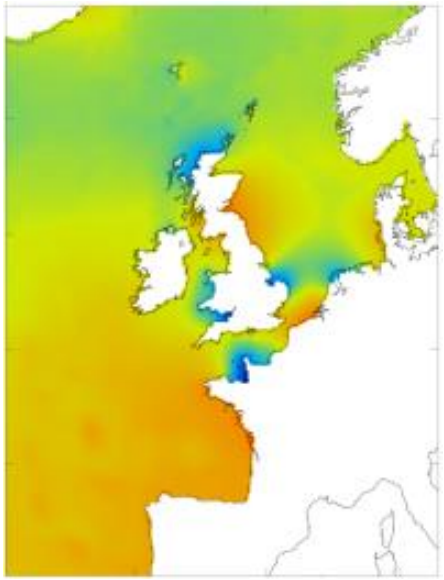
The revenge of the killer mussels – part II

February 19th 2013: mussel fouling on untreated fish culture nets. The nets sank under the weight of mussels.

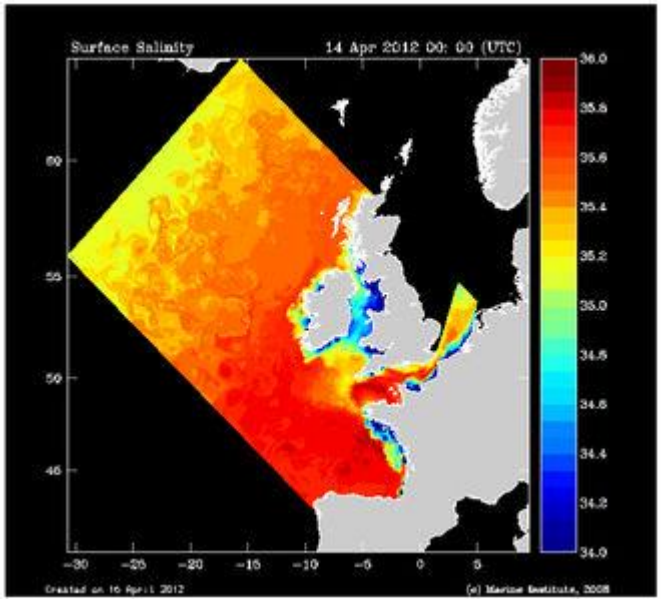
Lough Foyle circulation model

Regional Models

- FOAM AMM7 (MyOcean/Met Office)
  - NEMO Operational
  - 7 km, 32 levels
  - Hybrid S-sigma
  - 2011/05 - present



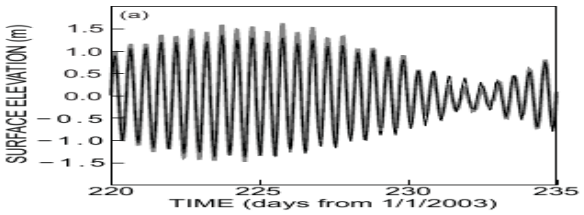
- NEAOM (IMI)
  - ROMS Operational
  - 2.5 km, 40 levels
  - Hybrid S-sigma
  - 2014/03 - present



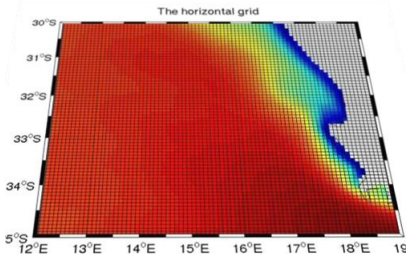
Hydrodynamic modelling for detailed circulation patterns

Delft3D - Flow

Atmospheric forcing



Tide



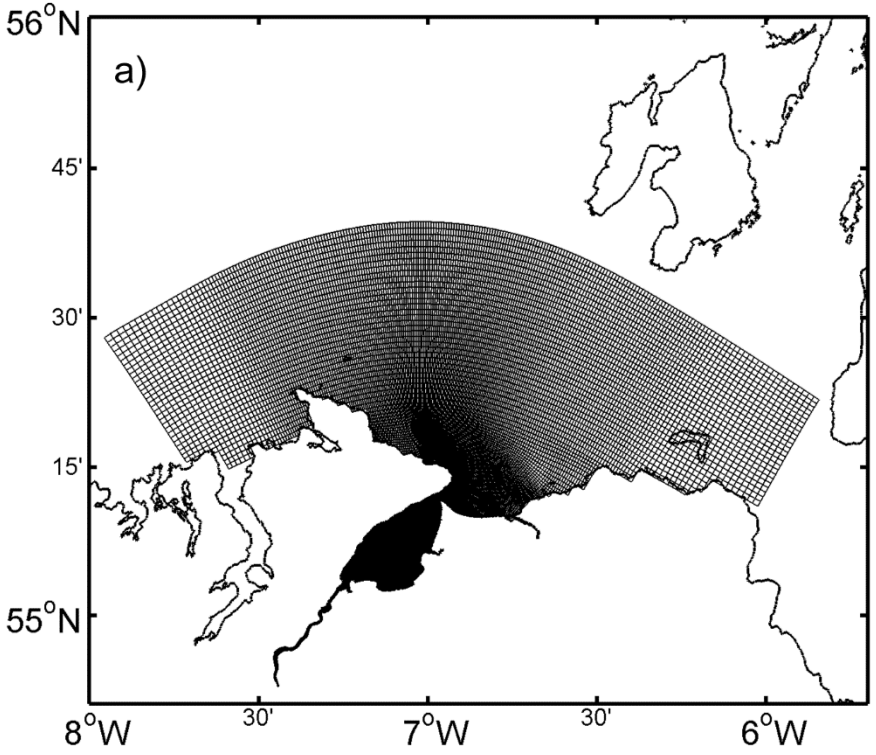
Flow

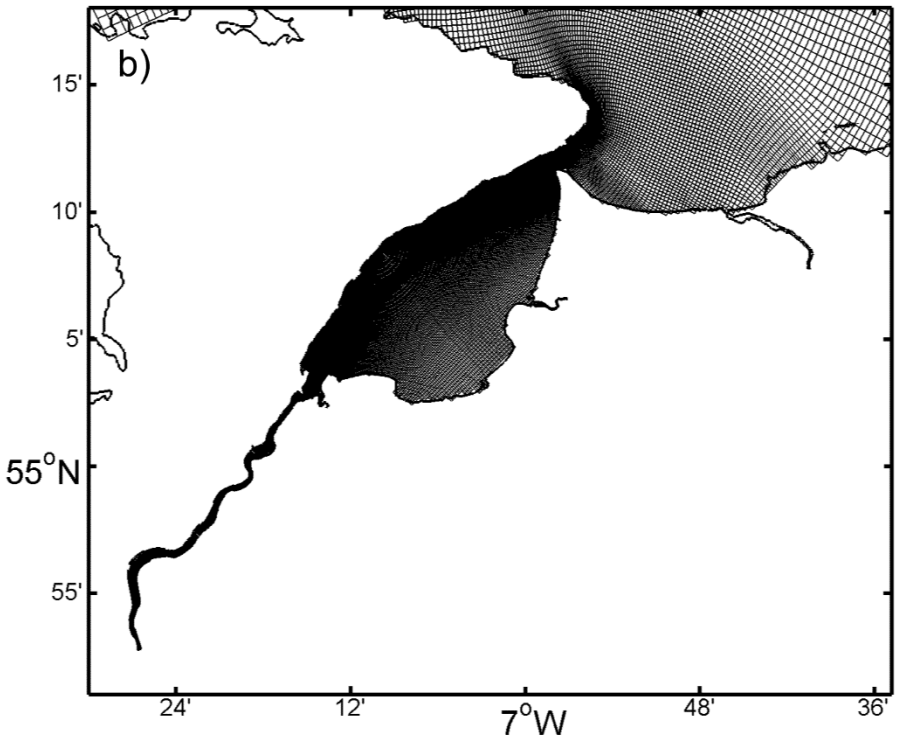
River flow

Water Quality / Ecological Modelling

Free and open source, tidal response, drying and flooding, evaporative processes, inner shelf circulation, shelf stratification.

Model components - Grid

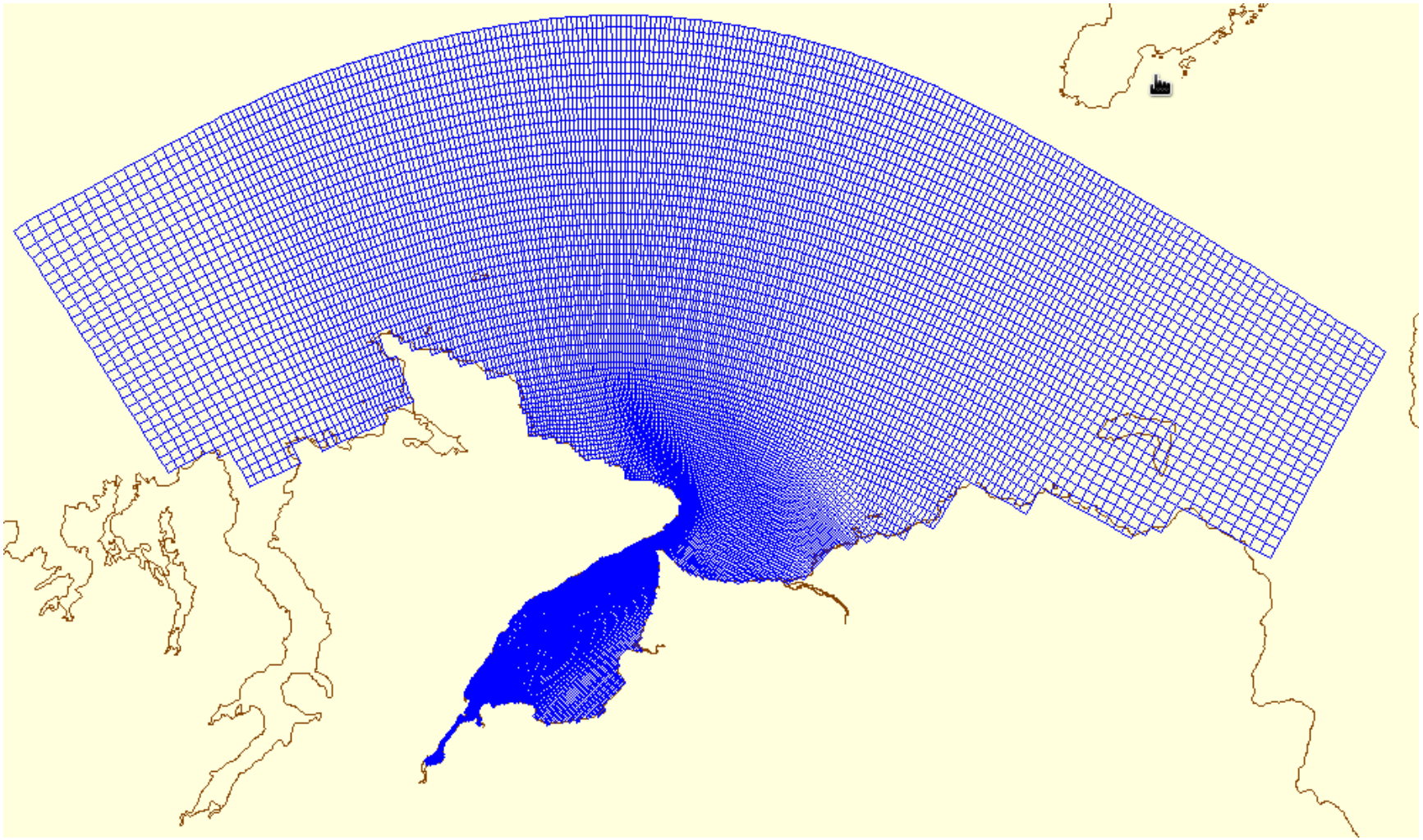




Layer	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
% Depth	2	3	4	5	6	8	8	8	8	8	8	8	8	8	8

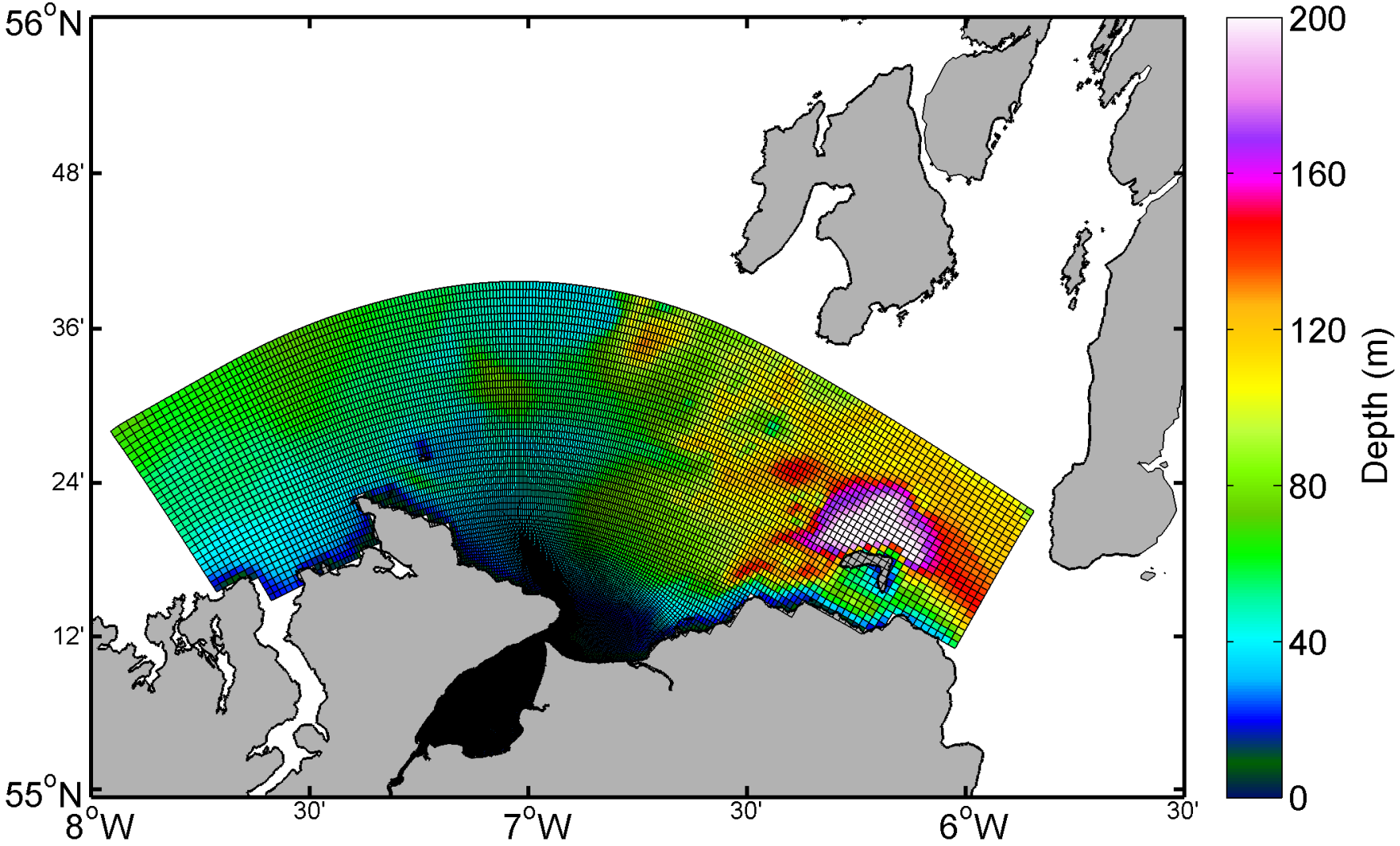
Ocean boundary conditions extracted from the FOAM model.

Lough Foyle: Grid Design



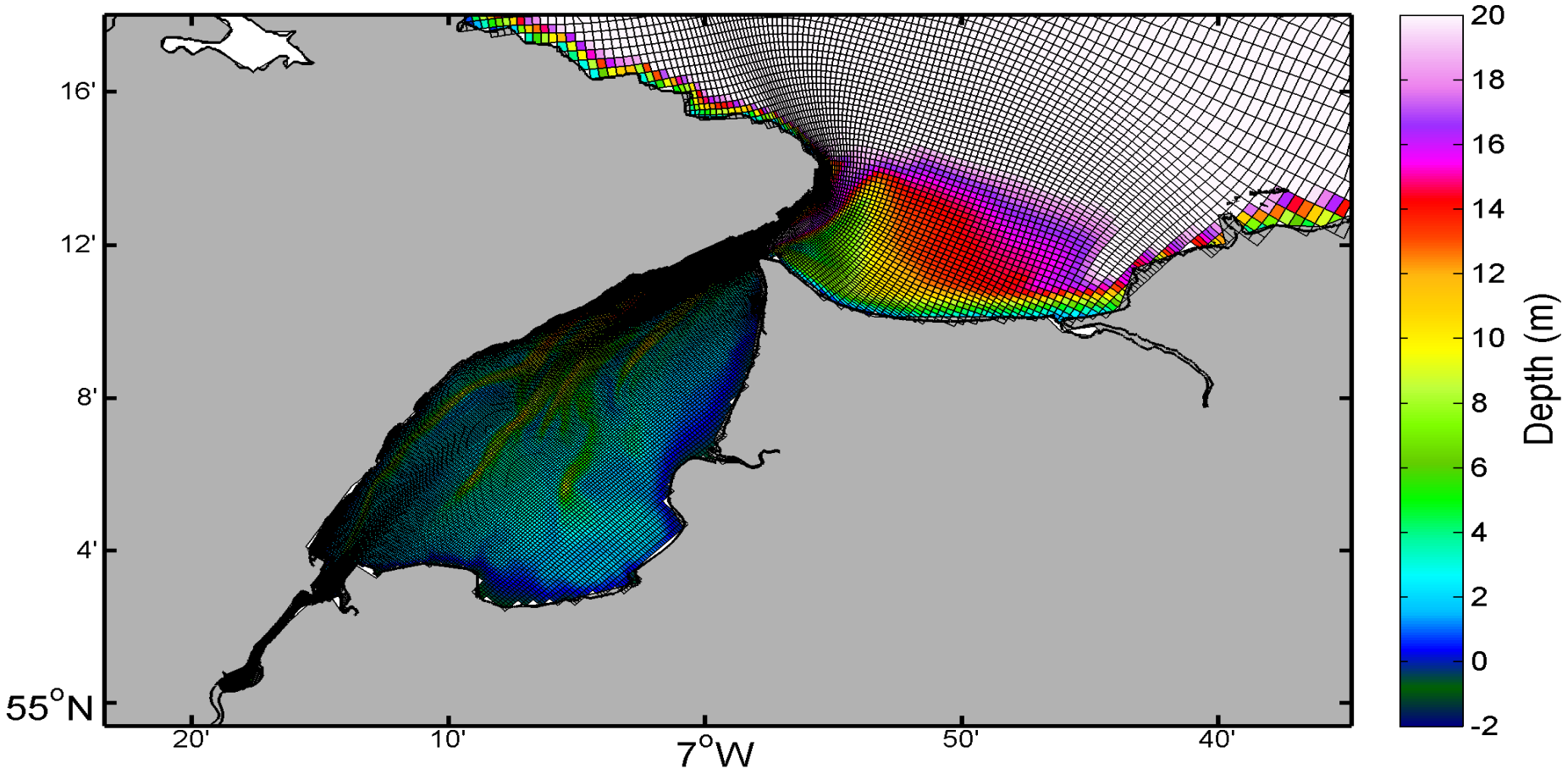
The grid design usually includes not only the domain of interest but also a wider area, because what happens *outside* a system (mesoscale) is generally important.

Bathymetry of the shelf



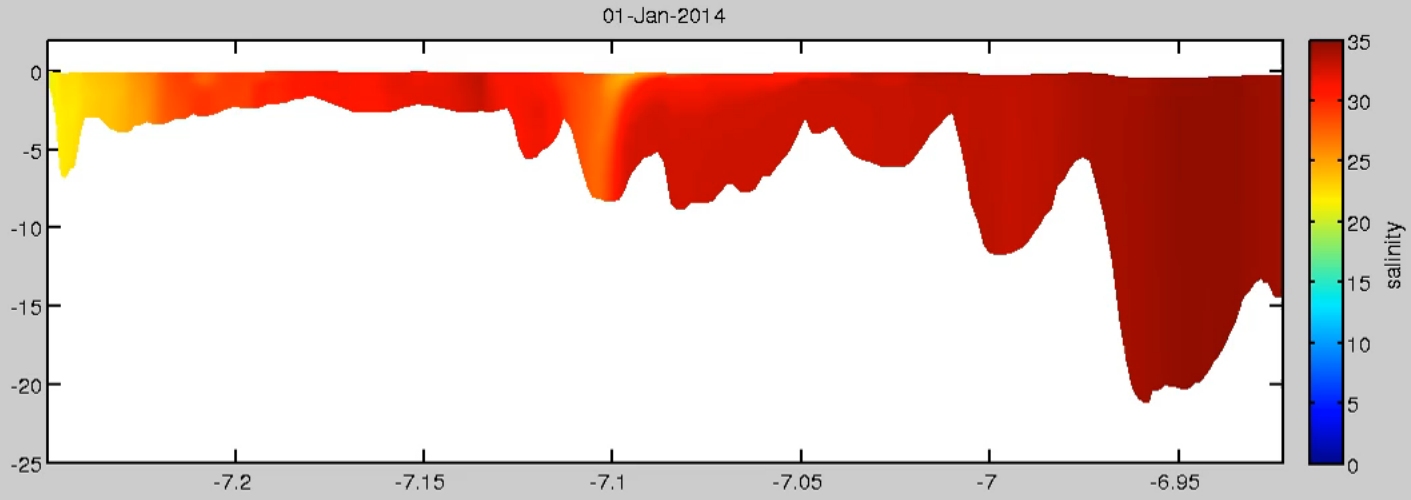
Bathymetry data supplied by the UK Hydrographic Office.

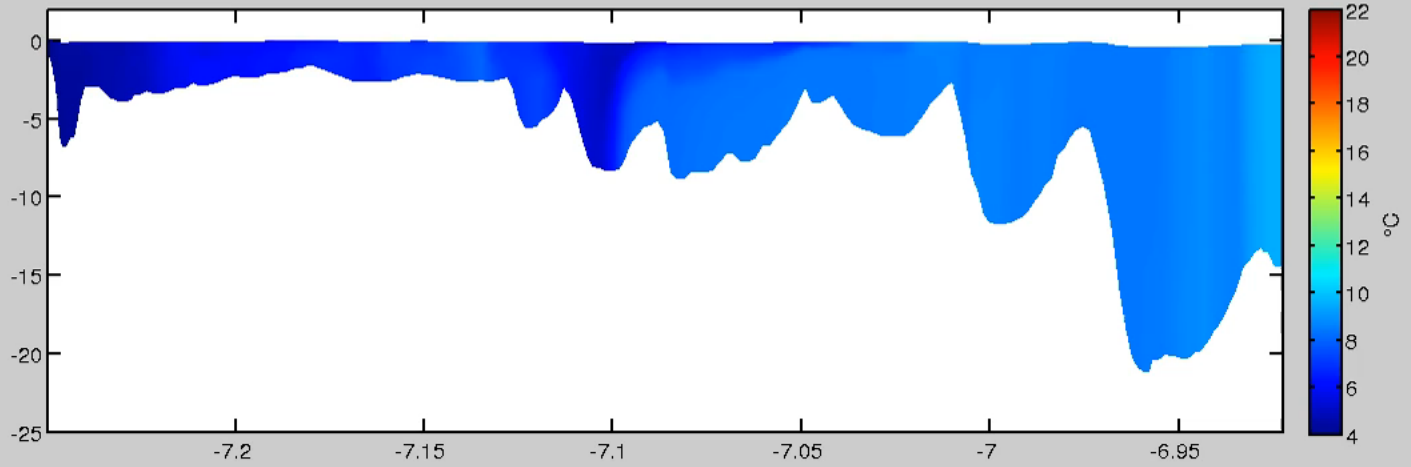
Bathymetry of Lough Foyle



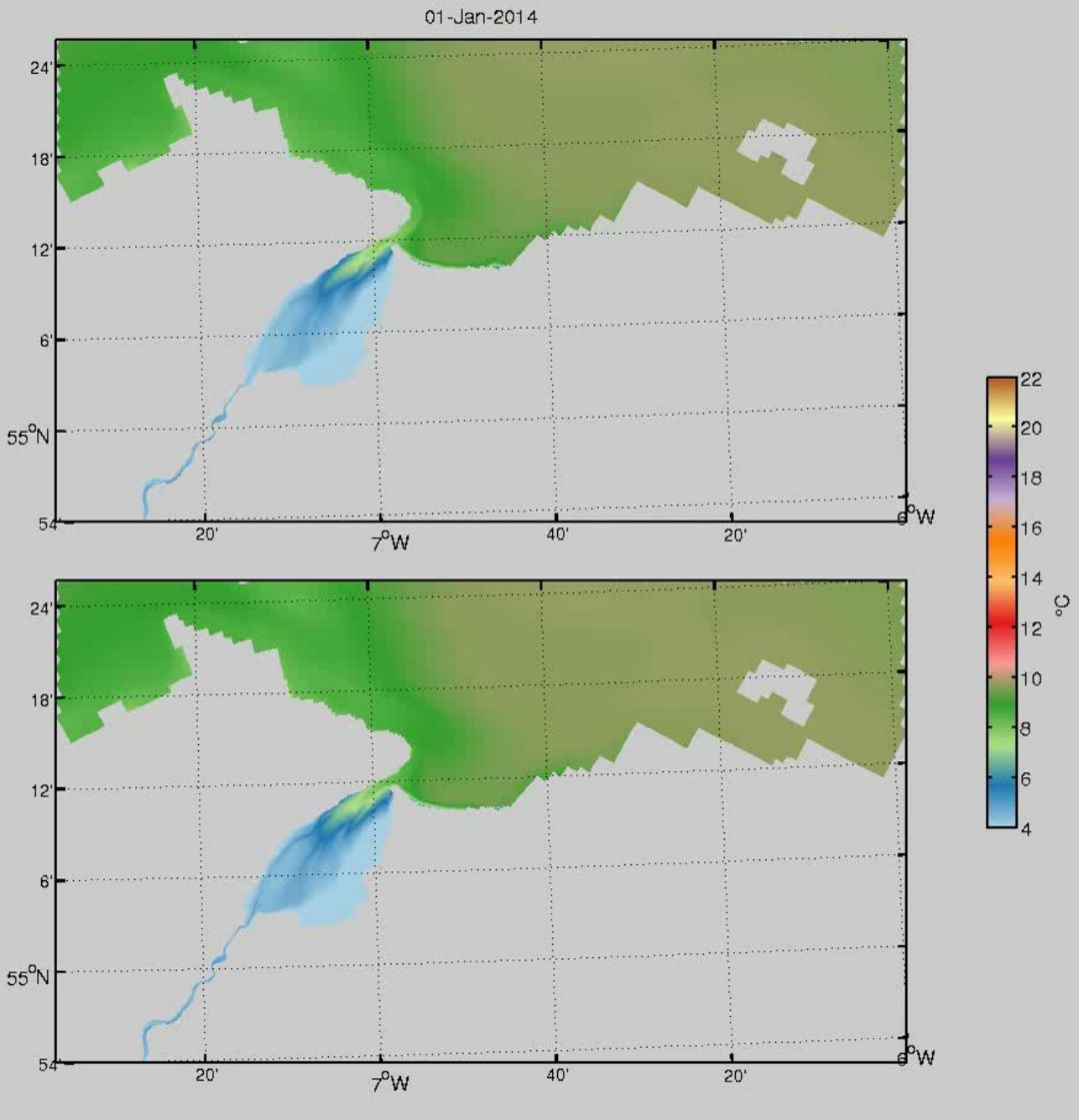
This is the physical basis for the hydrodynamic model. This model, developed in Delft3D, allows the calculation of water and material fluxes at a broader scale.

Lough Foyle – Vertical temperature profiles Delft 3D





Some Like It Hot!



Local-scale modelling

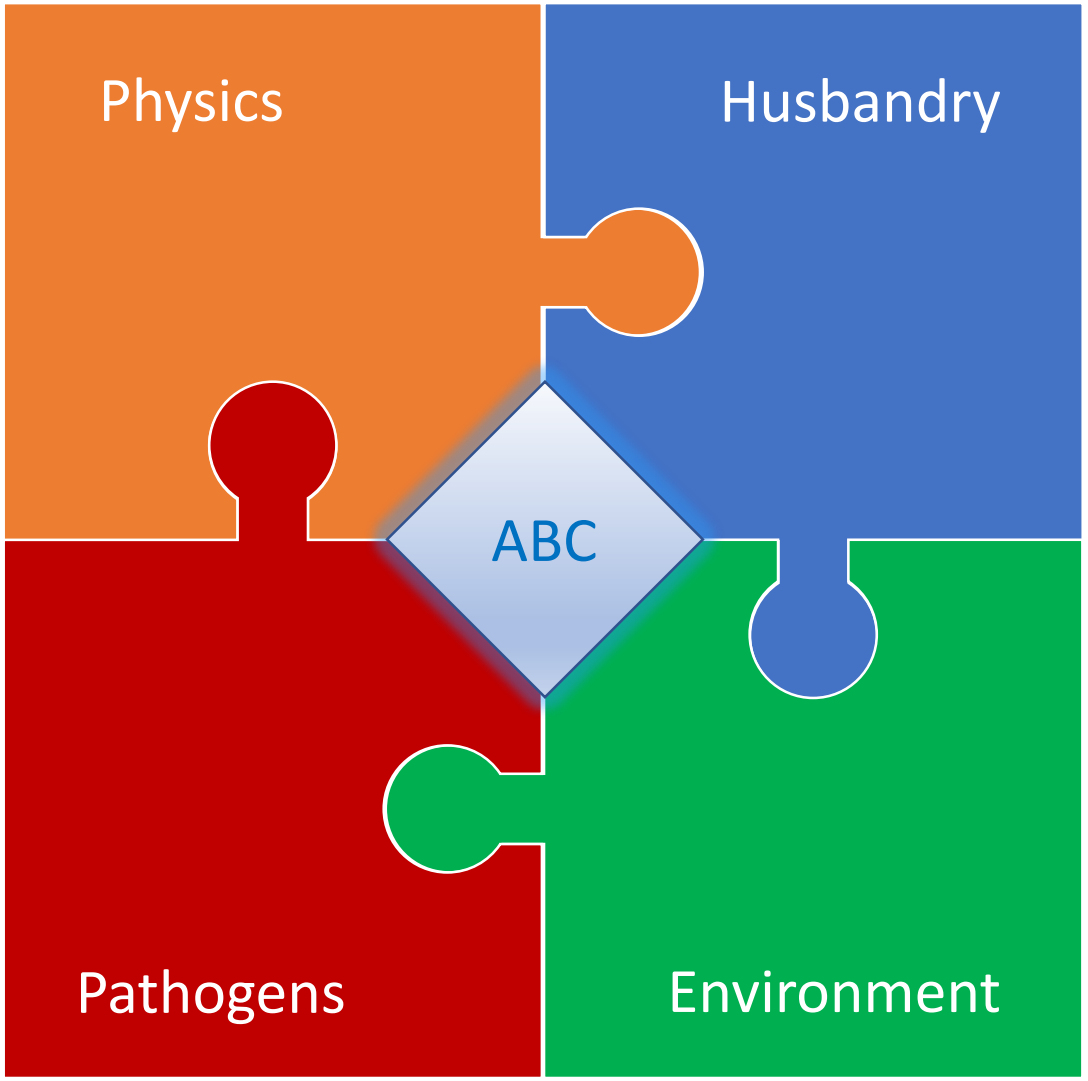
The Aquaculture, Biosecurity, and Carrying Capacity (ABC) model (and friends)

Effects of advection (current speed) and dispersion (mixing)

- Drives oxygen supply for finfish aquaculture
- Drives food supply for shellfish aquaculture
- Influences pathogen connectivity
- Determines patterns of waste dispersal
  - Particulate waste (vertical, near-field)
  - Dissolved waste (horizontal, far-field)

Different problems, different models. Don't use a hammer when you need a wrench…

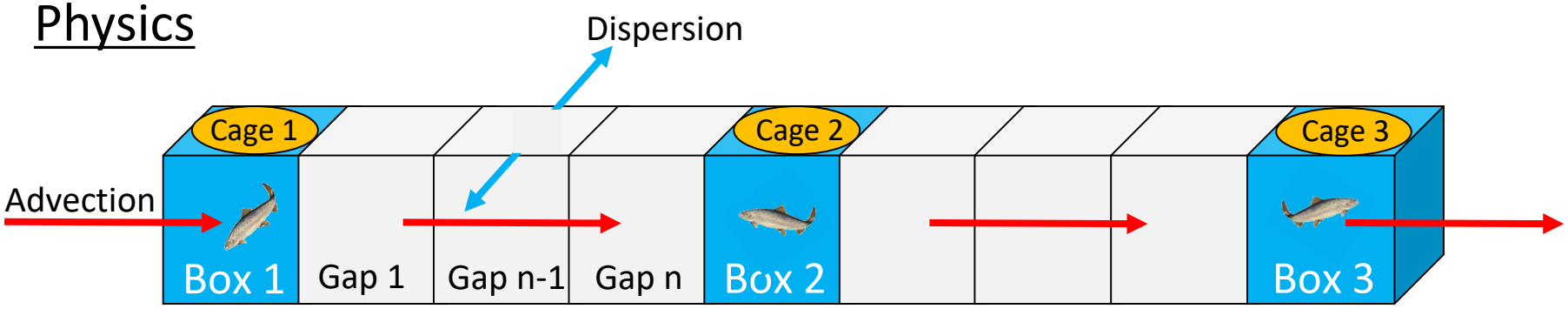
Integrated carrying capacity modelling



ABC integrates the four pillars of carrying capacity modelling for aquaculture.

ABC – General Approach

Physics



Husbandry

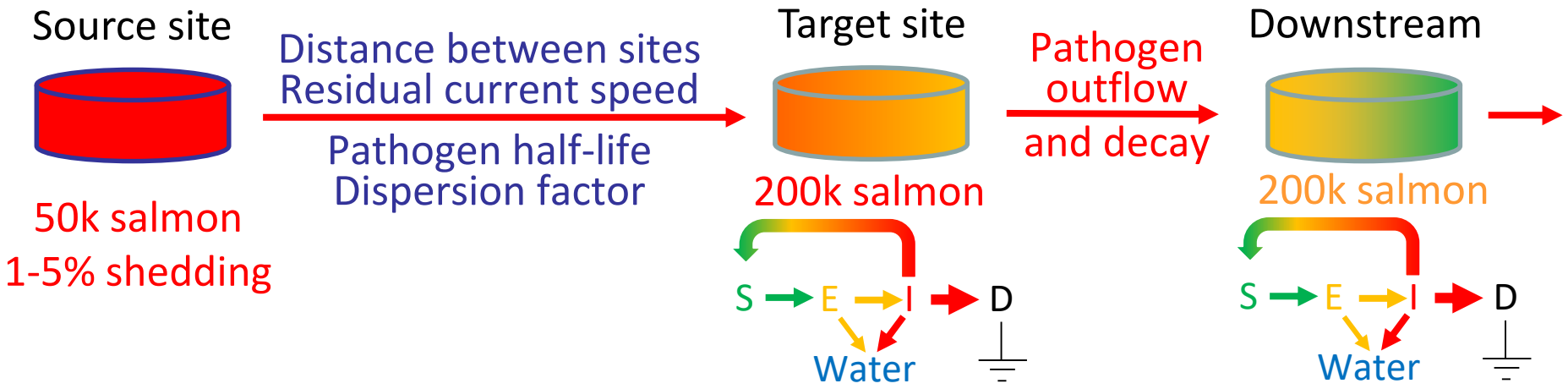
- IBM approach
- Feeding
- Growth
- Precision harvest
- Size-dependent mortality

Environment

- Environment on aquaculture
- Aquaculture on environment
- Key factors: dissolved oxygen, dissolved nutrients, organic waste, phytoplankton depletion

Pathogens

- Infection parameters
- Hill function for IHNv and OHv
- Physical and biological decay
- Response to climate change
- Waterborne or relay

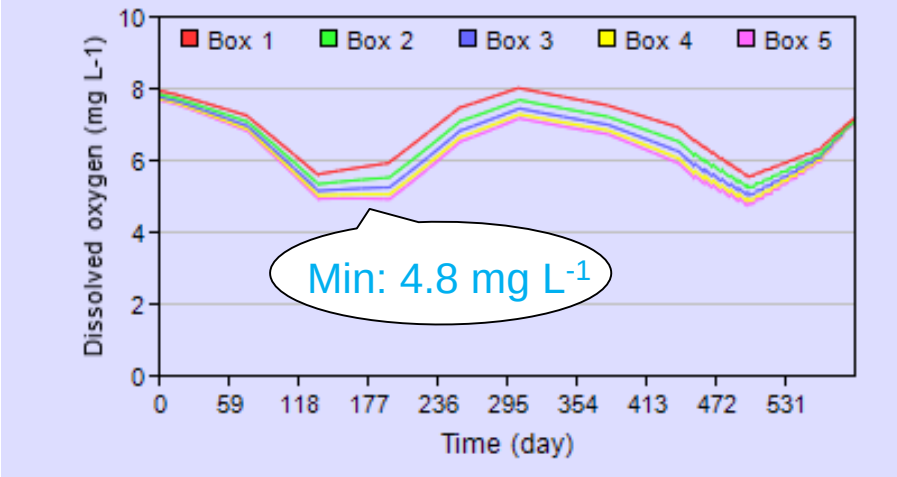


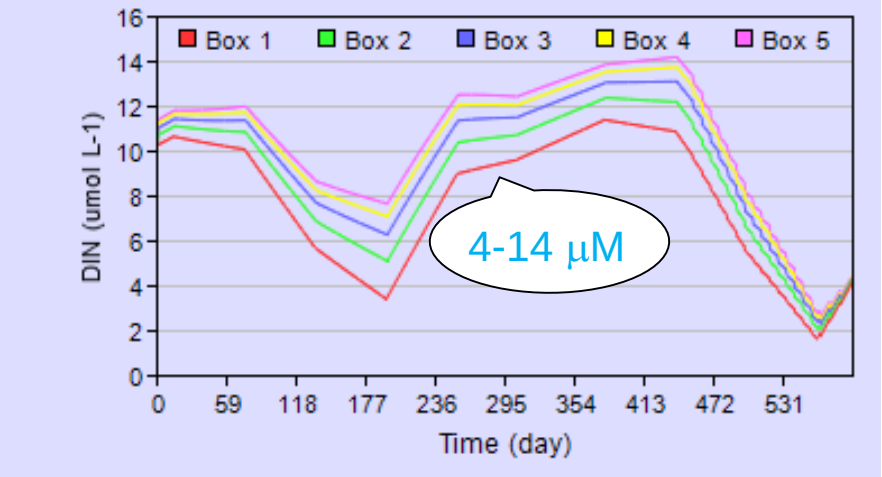
ABC integrates physics, husbandry, environment, and pathogens.

Environment – Dissolved oxygen and DIN for finfish

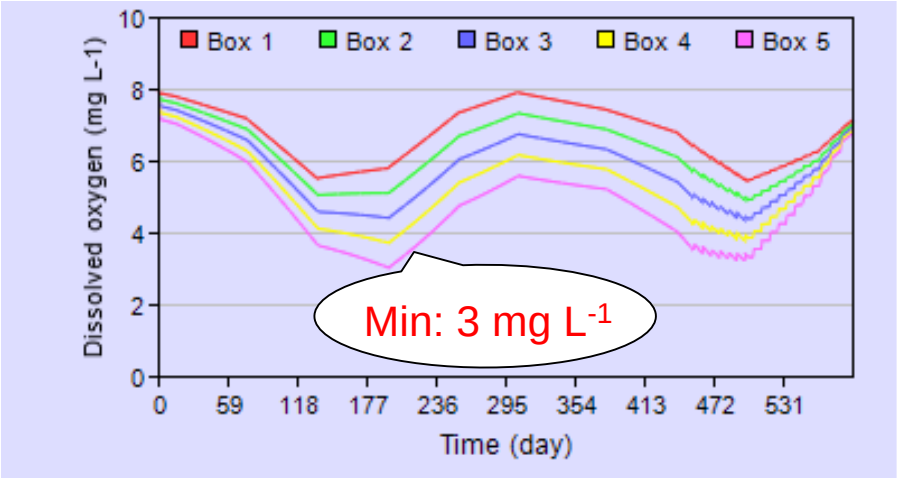
5 culture areas,100 m separation, one million gilthead per area

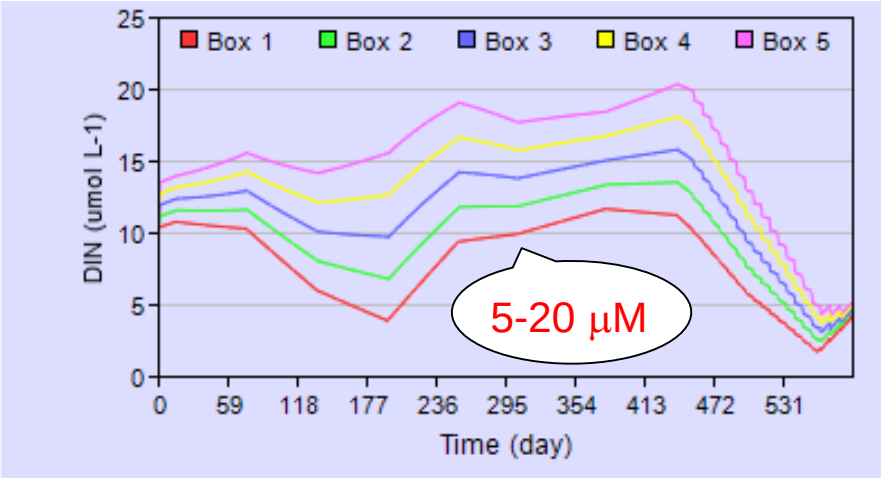
Farm simulated with lateral exchange of water properties (high dispersion)





Farm simulated with no lateral exchange of water properties (low dispersion)



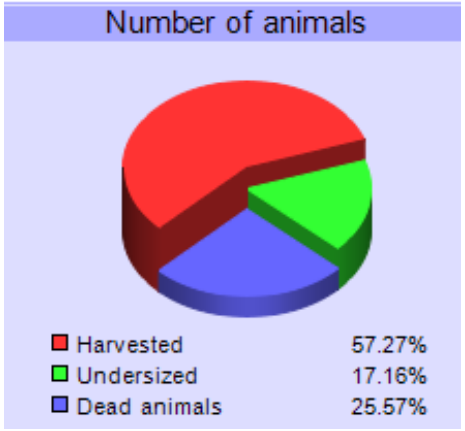


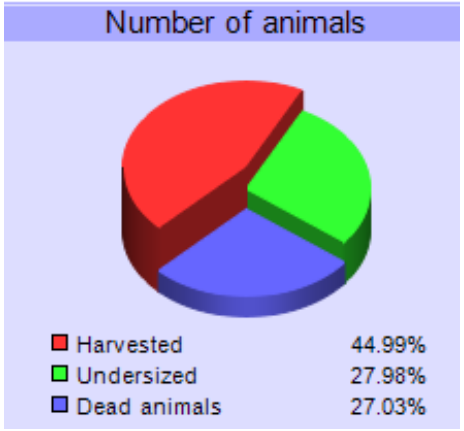
Fish culture depletes oxygen and increases DIN within the farm area. Turbulence, stronger currents, and wider gaps help offset impact.

Husbandry – Food depletion for Pacific oysters

Three 1 ha culture areas with 100 m gap, 200 oysters per m^2

Area 1 → Area 2 → Area 3

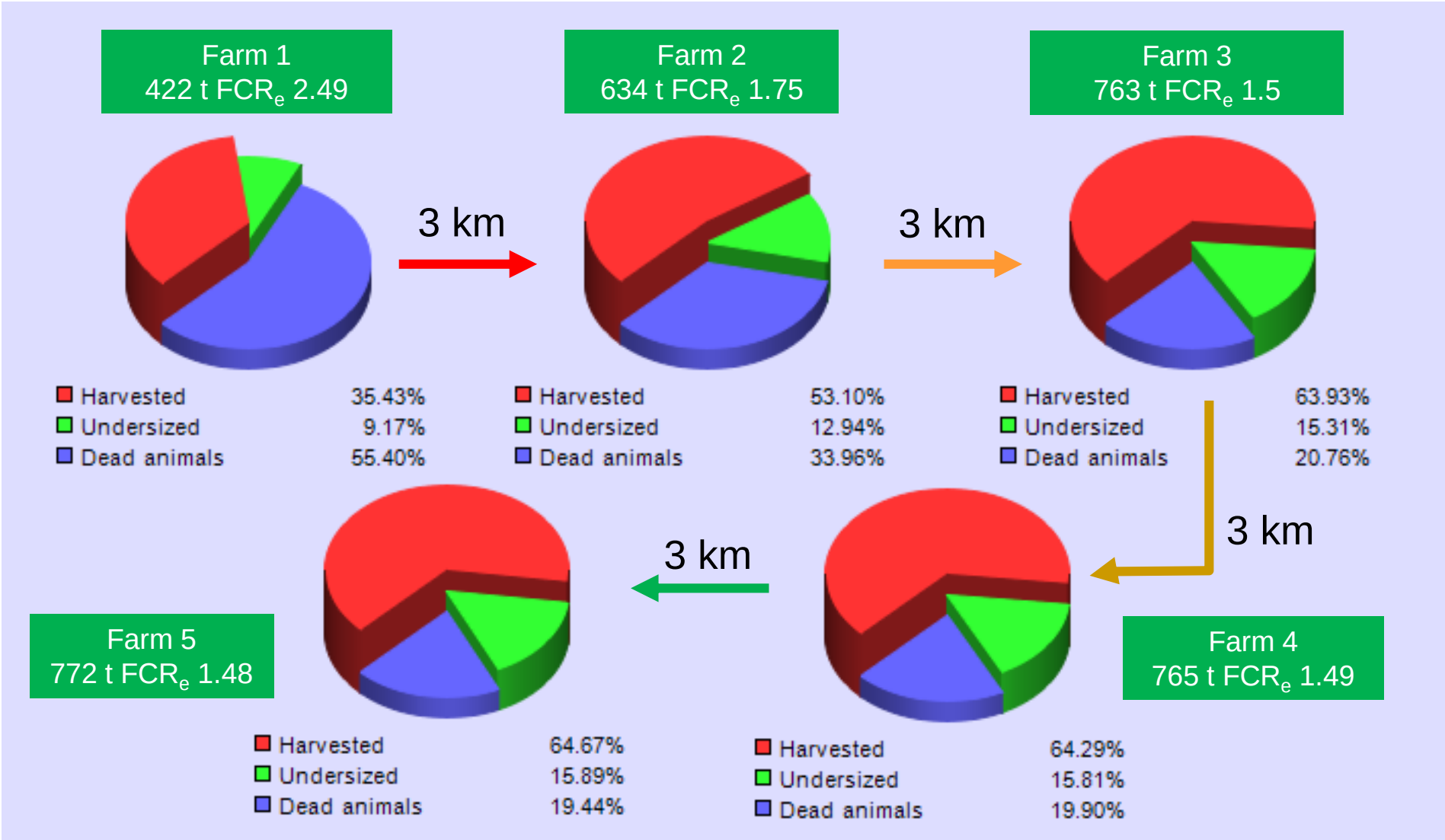




Indicator	Area 1	Area 2	Area 3	Total
Seed (kg)	1300	1300	1300	3900
Harvest (Total Physical Product, kg)	*80,200*	62,998	42,400	185,598
Average Physical Product (APP)	61.7	48.5	32.7	-
Non-harvestable oysters (kg)	21,880	34,113	*47,894*	103,887
Clearance rate (m^3 $X10^6$ per cycle)	24.1	25.6	26.7	76.0
Net N removal as % of production	2.99	3.18	3.40	-
Net N removal as % of harvest	3.80	4.90	*7.26*	-

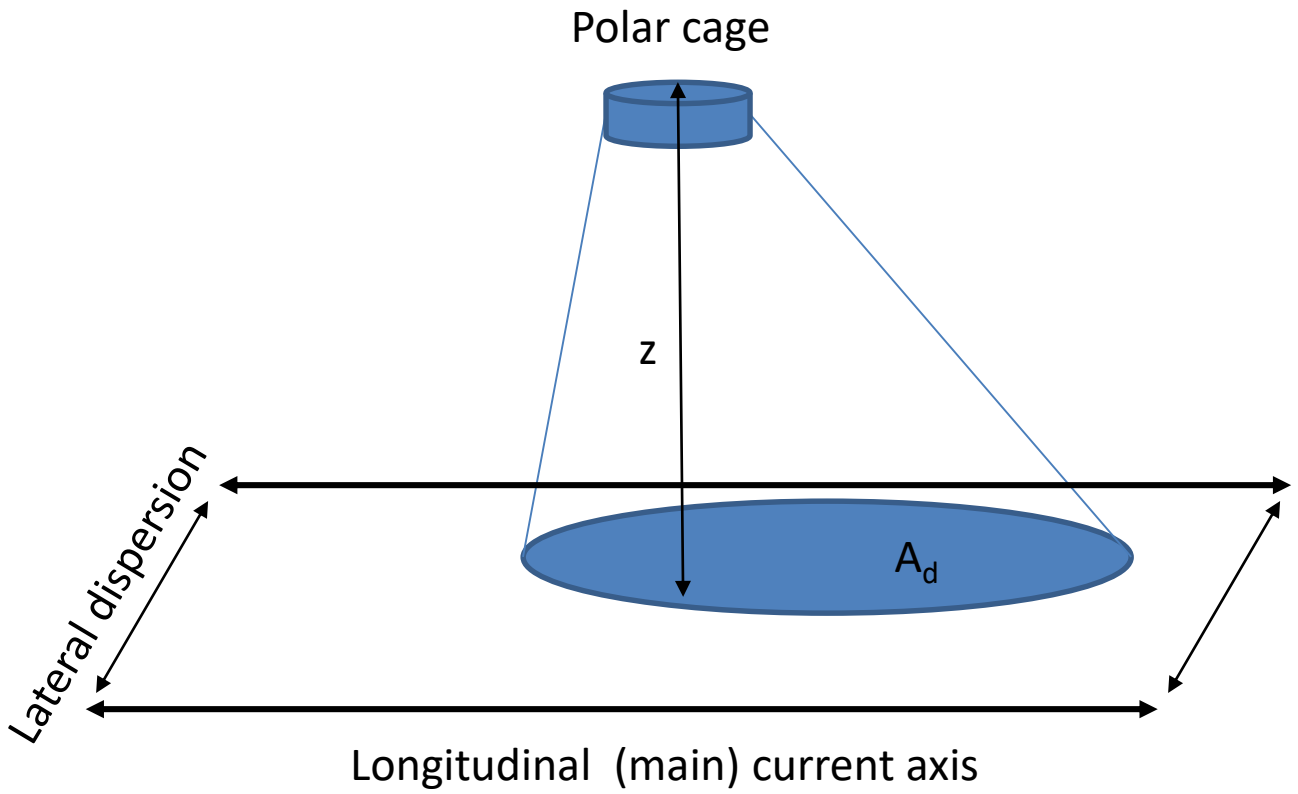
500 day growth cycle; weight at harvest: 70 g; precision aquaculture (HWR).
Mean clearance rate per oyster: 1.06-1.46 L h^{-1}

Culture performance in 5 salmon farms spaced 3 km apart. Pathogen emission begins 405 days after culture start



Yield in the last farm (15 km from pathogen source) is 83% higher than in the first farm. Farm 5 mortality is 35% of Farm 1, very similar to a background run.

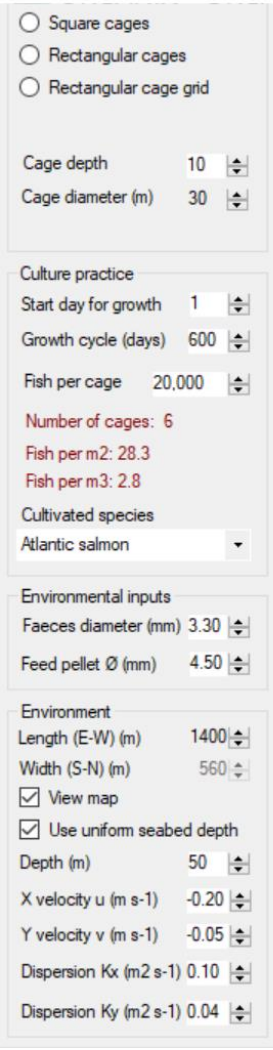
Allochtonous supply of organic material to deposit-feeders under a fish cage

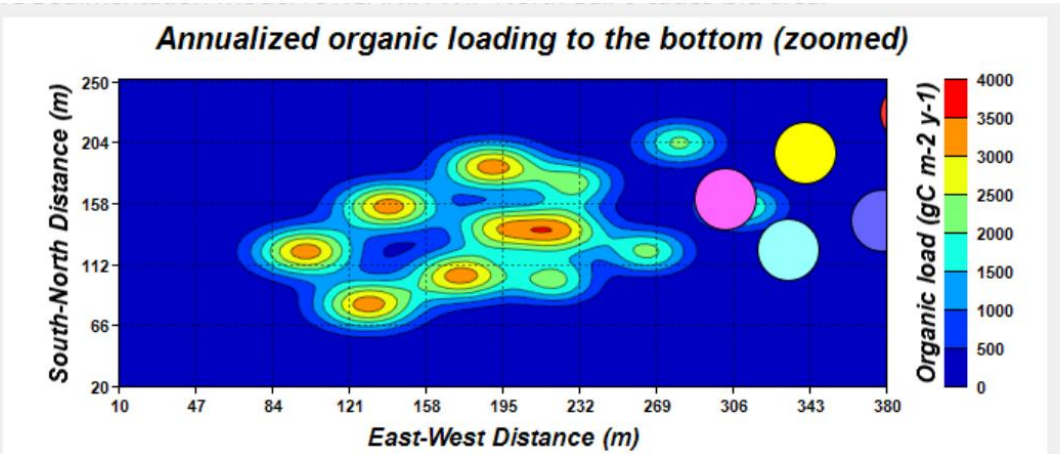


Advection shifts the dispersion footprint as a function of the residual current.

Organic loading from finfish cages in the bay

ORGANIX model





	A	B	C
5	Total number of fish	120000	ind.
6	Faecal settling velocity	3.58	cm s-1
7	Faecal deposition time	20.96	minutes
8	Feed settling velocity	6.65	cm s-1
9	Feed deposition time	11.27	minutes
10	Unit waste feed load	21.39	g POM (DW) c
11	Unit faeces load	17.64	g POC cage m-
12	Total waste feed load	90700	g POM (DW) c
13	Total faeces load	74814	g POC d-1
14	Total loading from cages	65568	kg POC cycle-1
15	Total loading to bottom	65568	kg POC cycle-1
16	Non-compliant area	25840	m2 (annualize
17	Mean above threshold	1479	g m-2 d-1

General / Probability

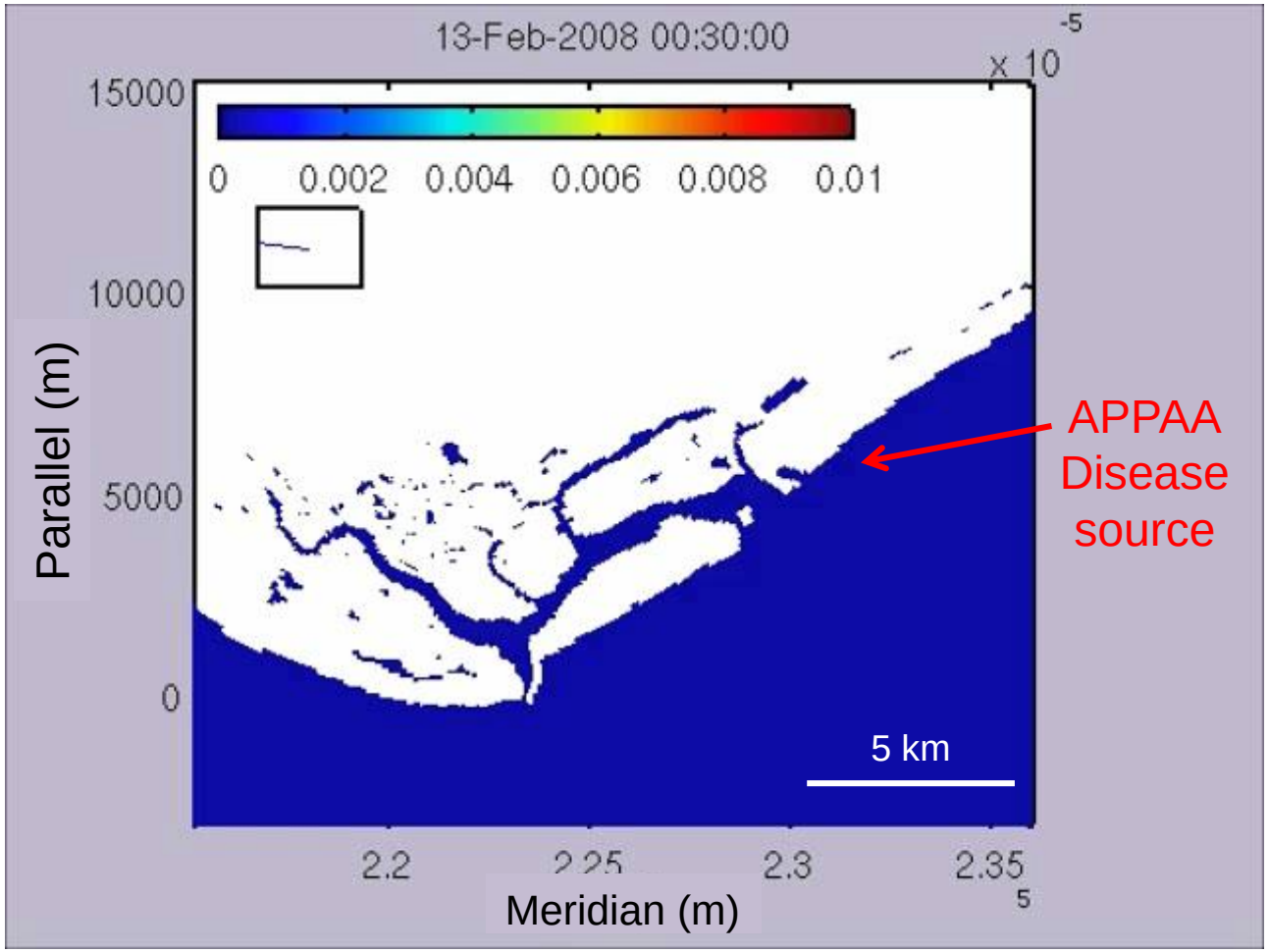
Results

Benthic load (gC m-2 y-1) / Benthic load (gC cell.cycle-1) / Faeces load bottom (g POC d-1) / Feed l

ORGANIX is a screening model which is ideal for assessment of benthic impacts of cage culture in data-poor environments. Non-compliant area: 25840 m^2.

Virus Particle tracking – Delft3D model

Ratio between concentrations at XYZ and emission concentration



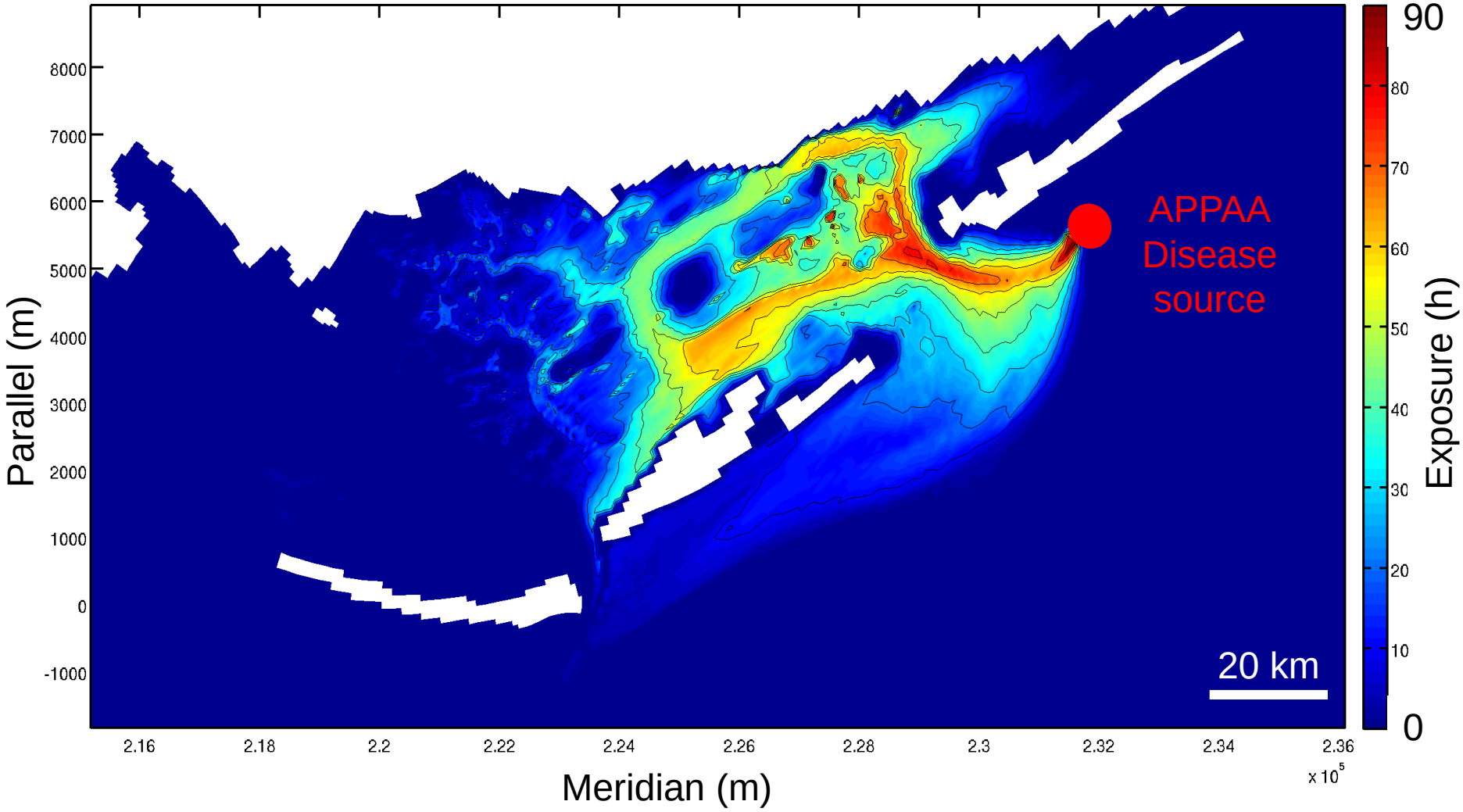
- Disease source: APPAA
- Virus concentration:

Up to 2×10^{6} ml^{-1}

- Forcing functions wind and tide
- No decay
- 6 day model run
- Release in mid-water layer

Background virus release the first 2 days, high release on days 3,4 and 5, then a reduction by a factor of a hundred on the last day.

Virus exposure



Number of hours of exposure to 0.5% of the shedding concentration as a measure of potential infection.

Synthesis

- Water moves in three dimensions
- The physics of aquatic systems plays a huge role in the ecology
- It is now computationally possible to model fine-scale circulation
- Very detailed models have huge spatial grids and a small timestep. They take a long time to run and generate huge output files
- Predictions with a circulation model are always limited by our inability to predict the weather forcing (e.g winds, rainfall, air temperature)
- Not all ecology should (or needs to) be modelled at a fine scale, which is why we upscale

All slides
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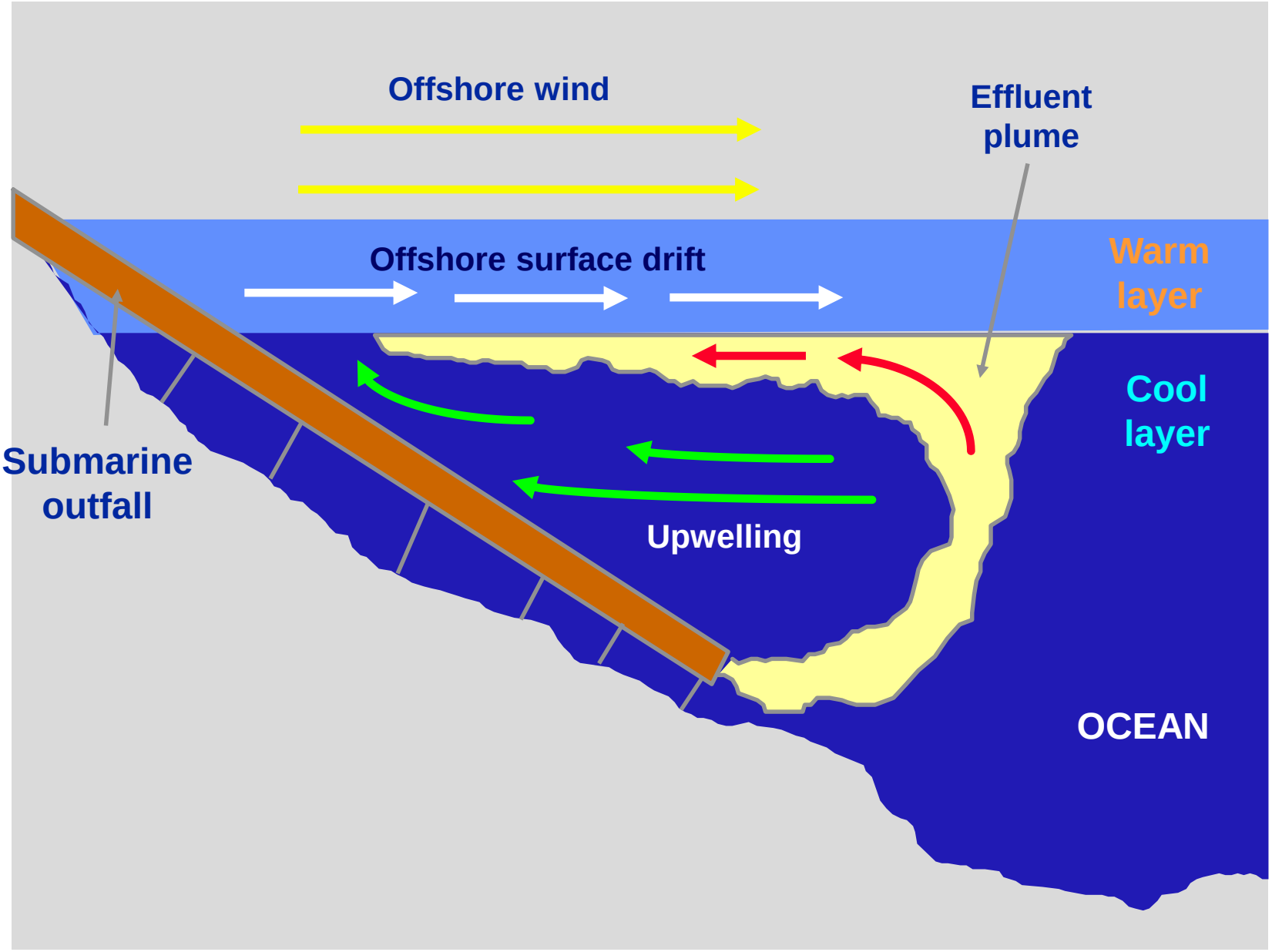
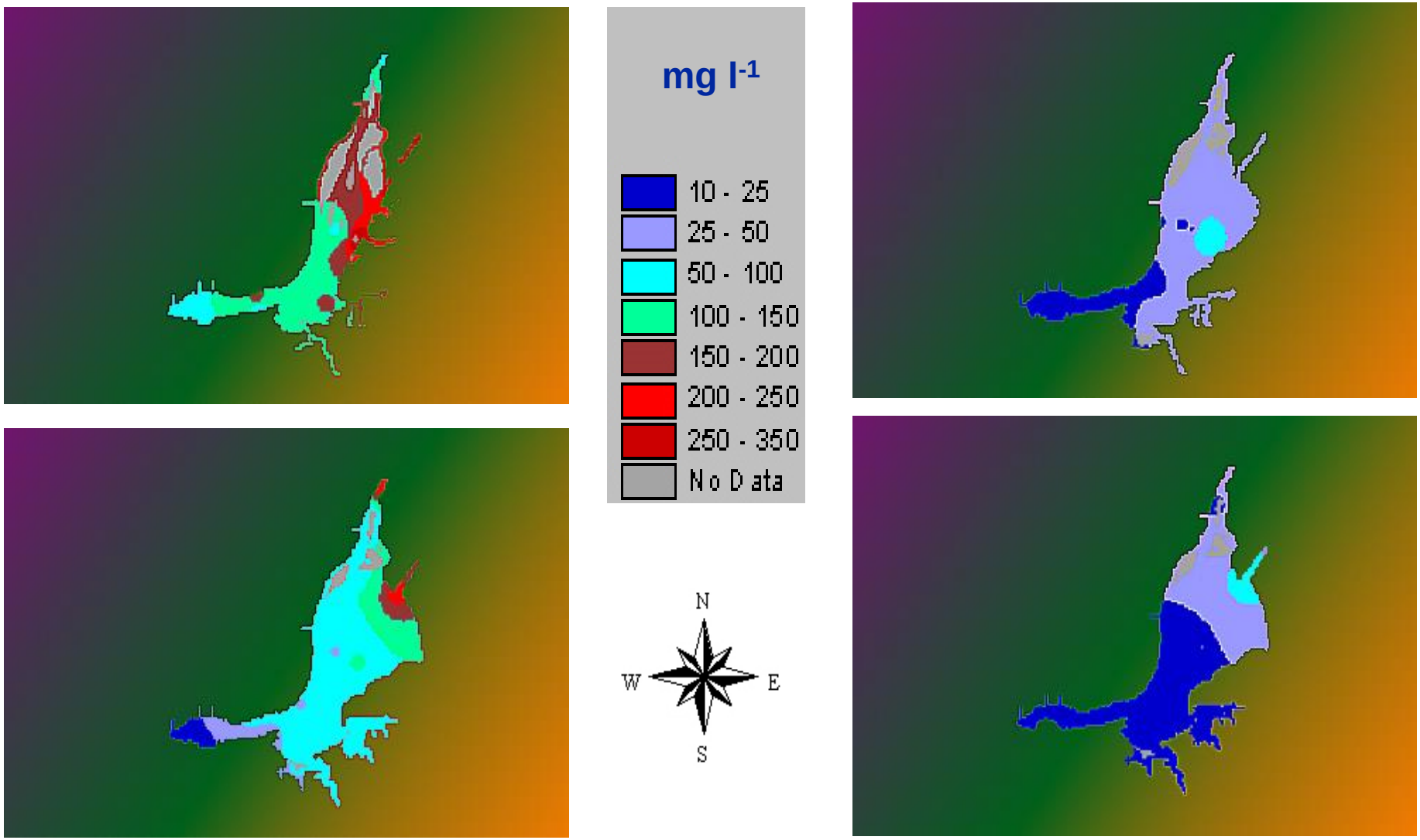
Dispersion of plume with offshore winds



Effluent is trapped in the lower layer and quickly moves inshore.

Concentration of suspended particulate matter



Water is most turbid at spring low tide due to tidal currents and bed shear stress.