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Wind farm layout

- What to consider?





Wind farm energy losses



Wake Effects



Seabed occupation



Transmission Losses



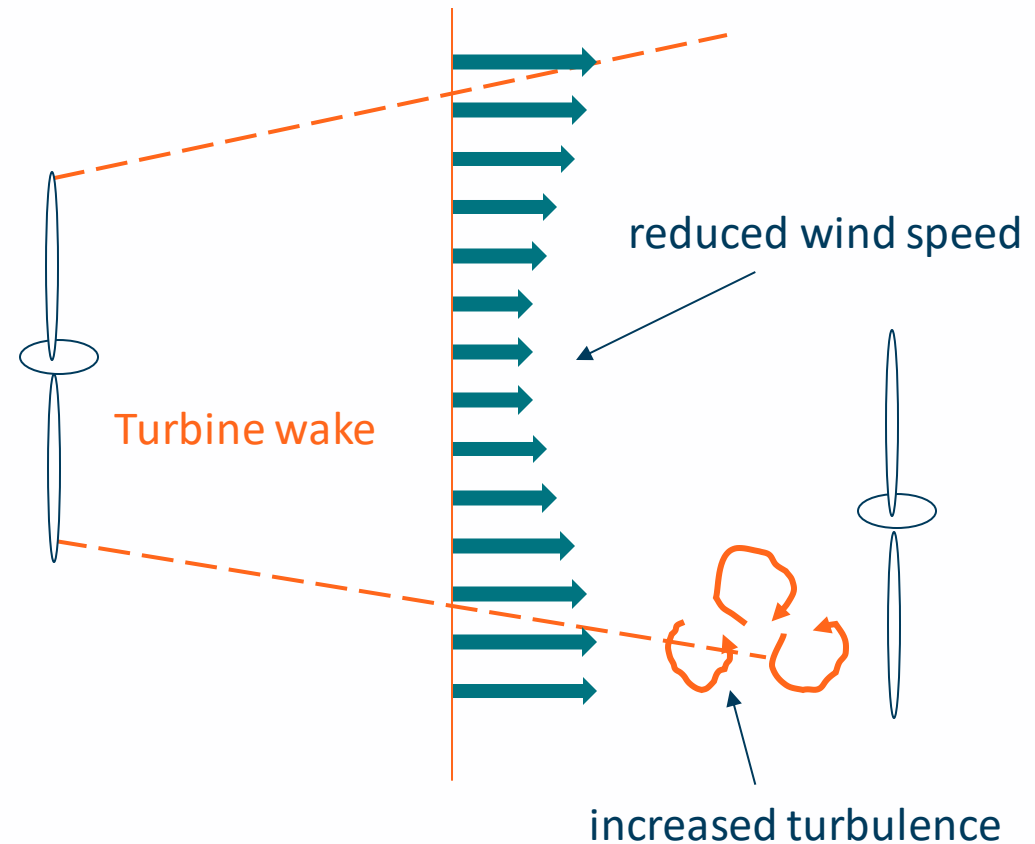
Wake effects







Wake effects: on/offshore

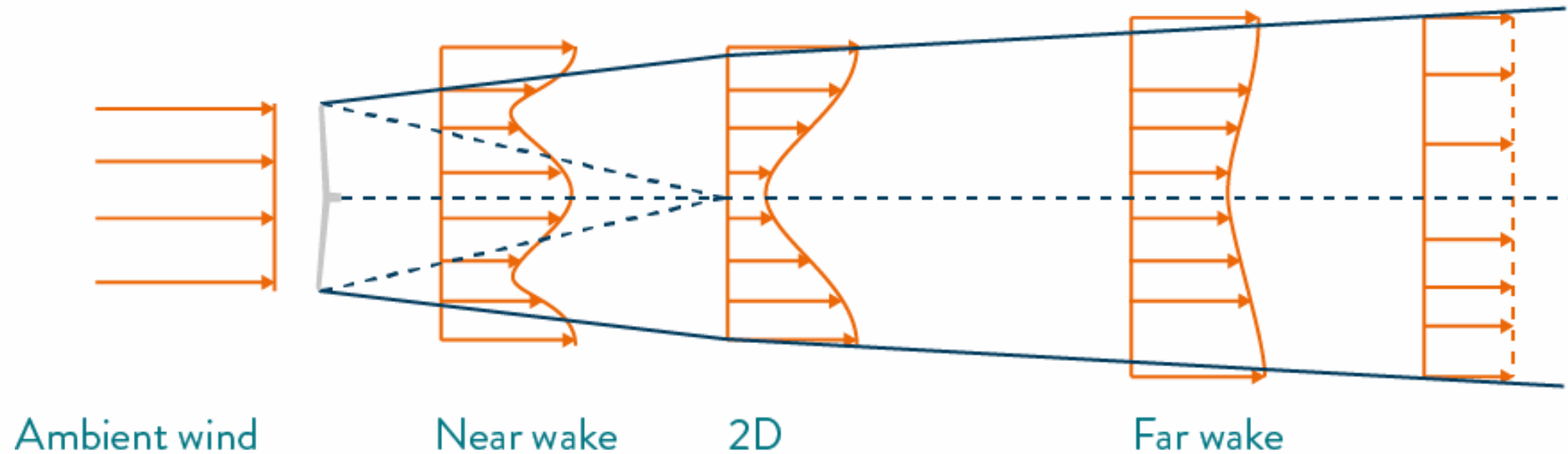




Wake development

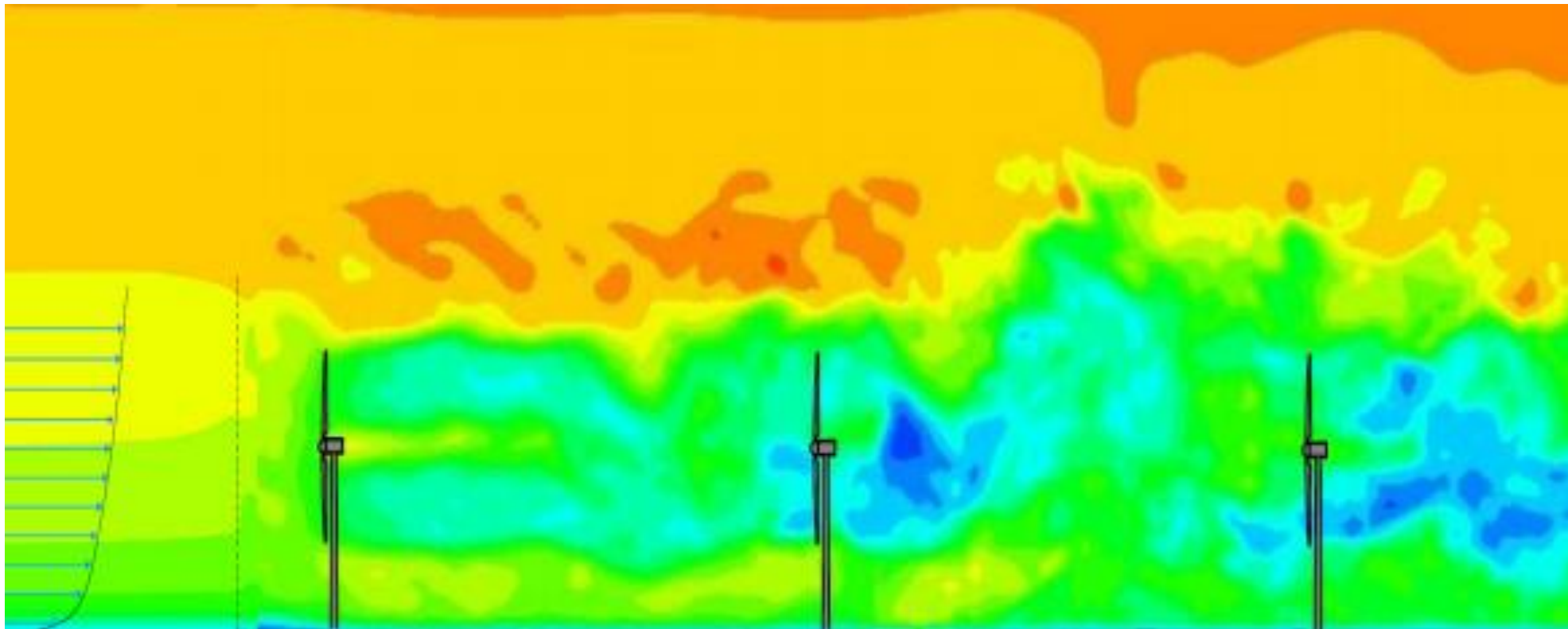
Velocity deficit

Bell shaped ('Gaussian')
velocity profile wind



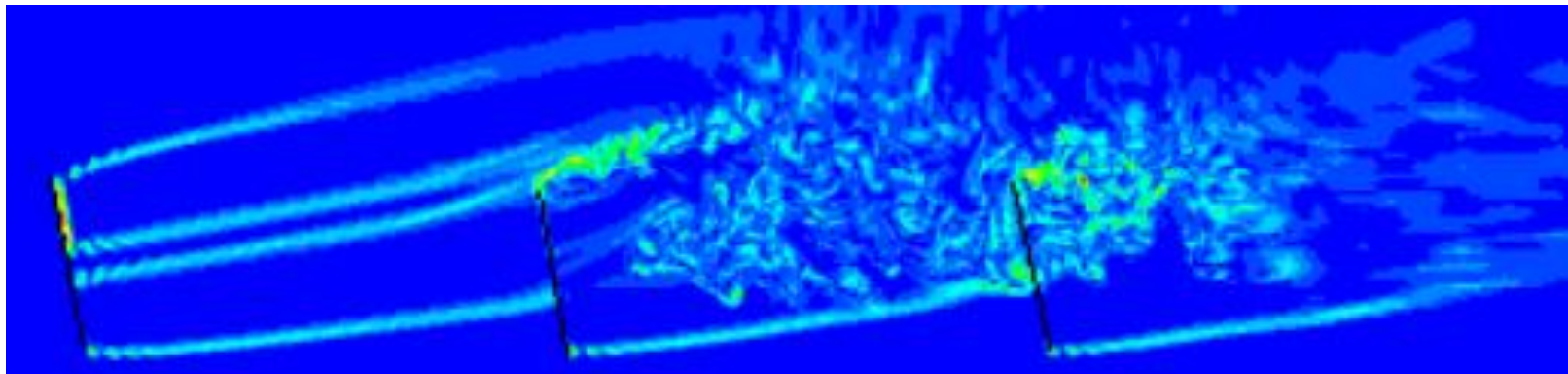
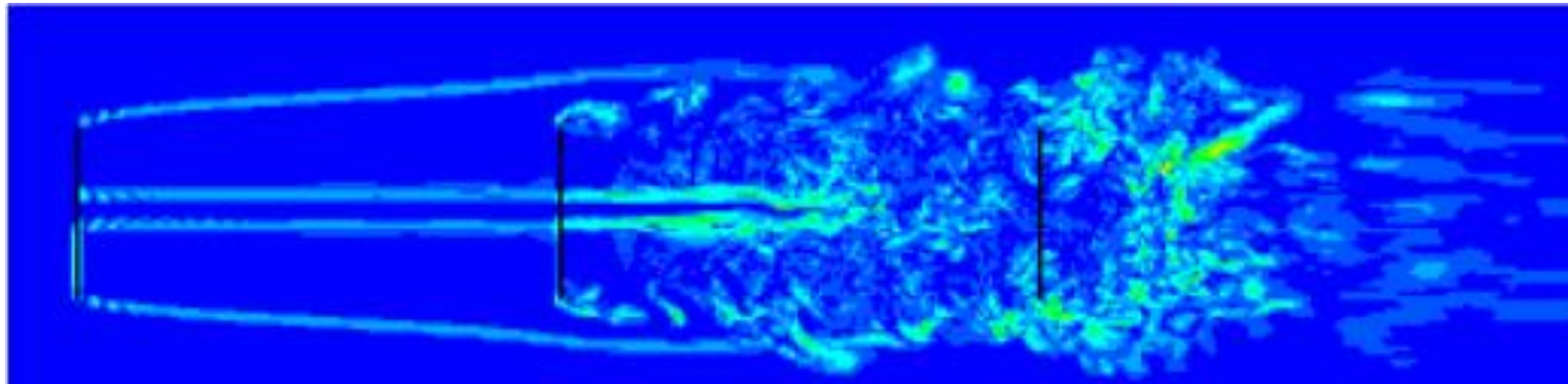


Wake effects



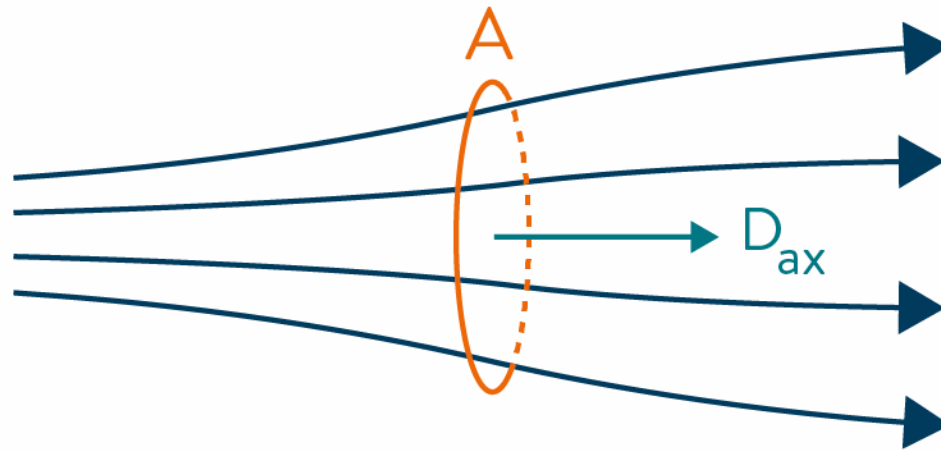


Wake effects: partial wakes





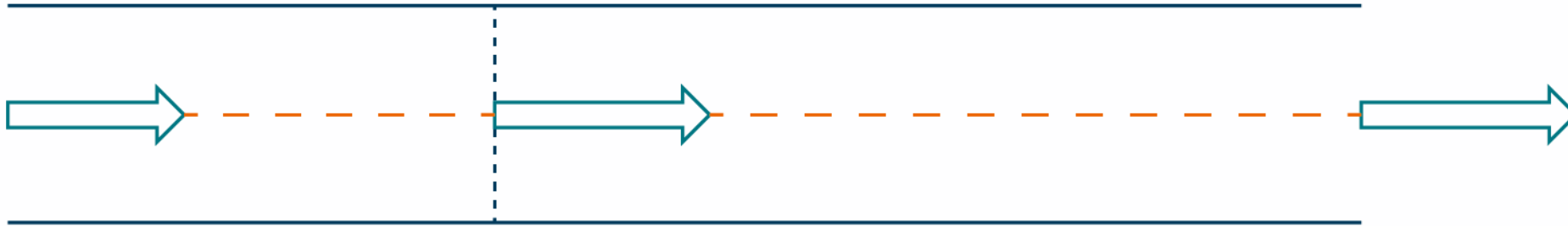
Wake effects: momentum theorem



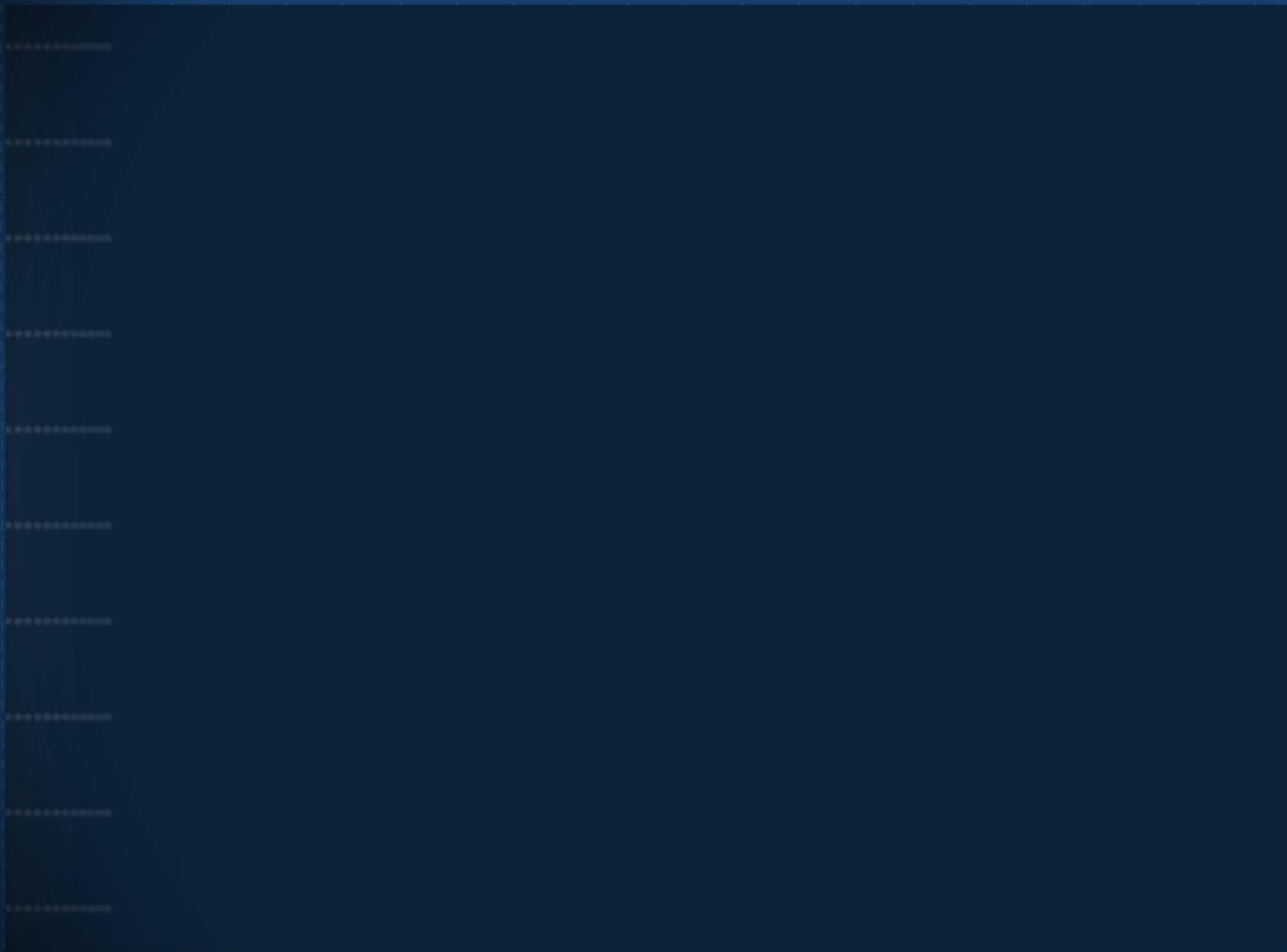


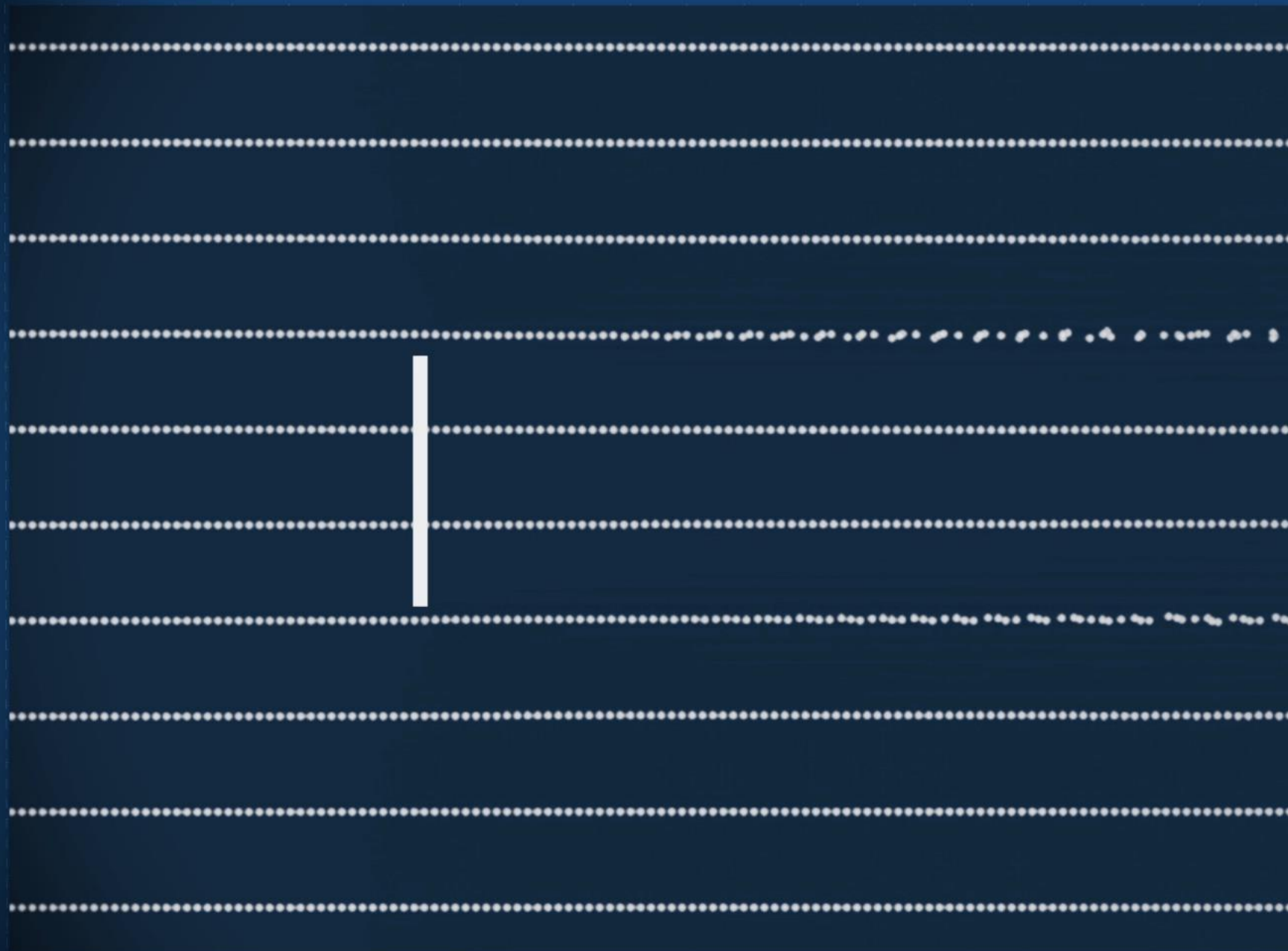
Stream tube

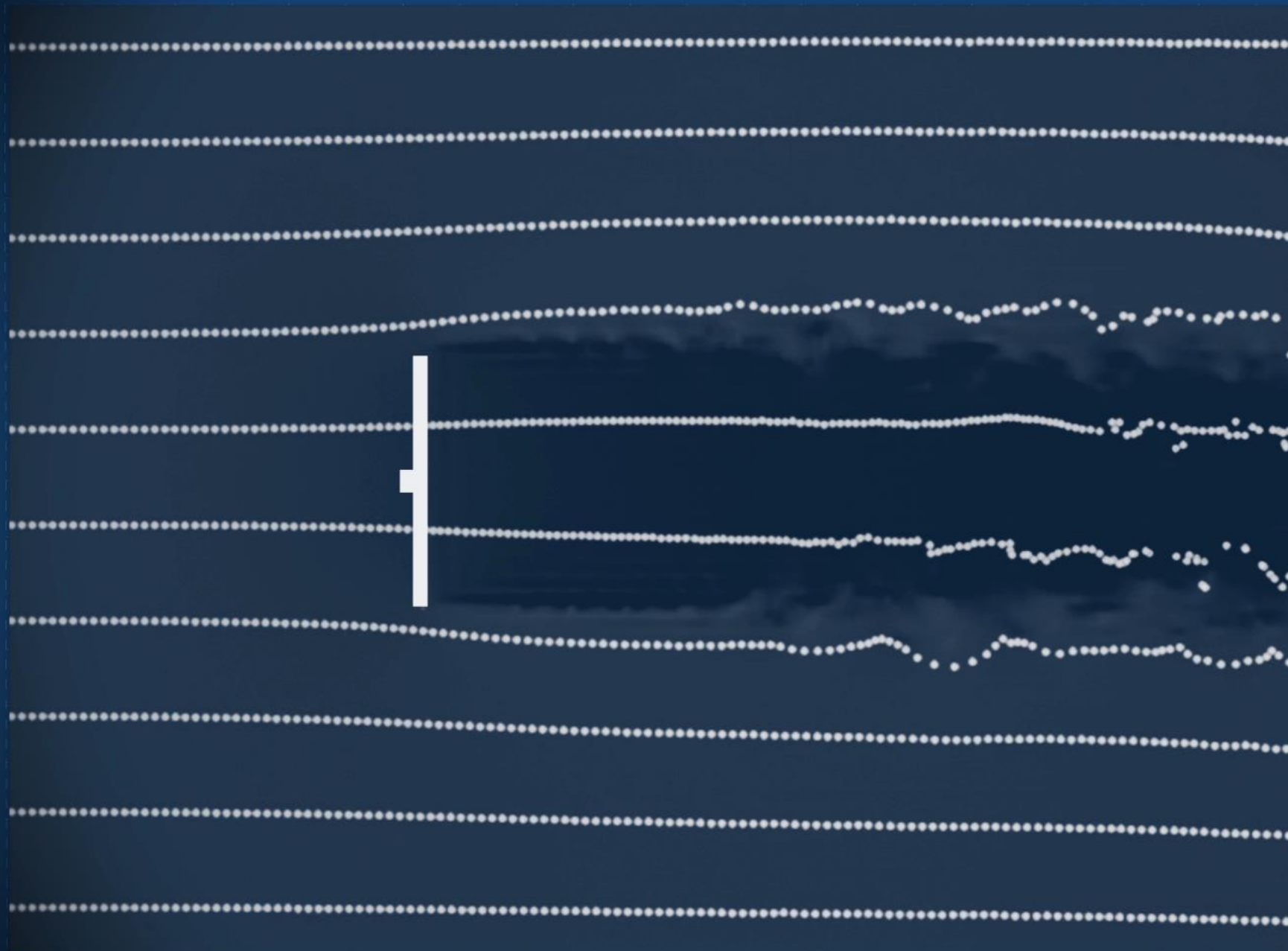
$$\text{Available wind power} = \frac{1}{2} \rho u_{\infty}^3 A \left[\frac{J}{s} \right]$$

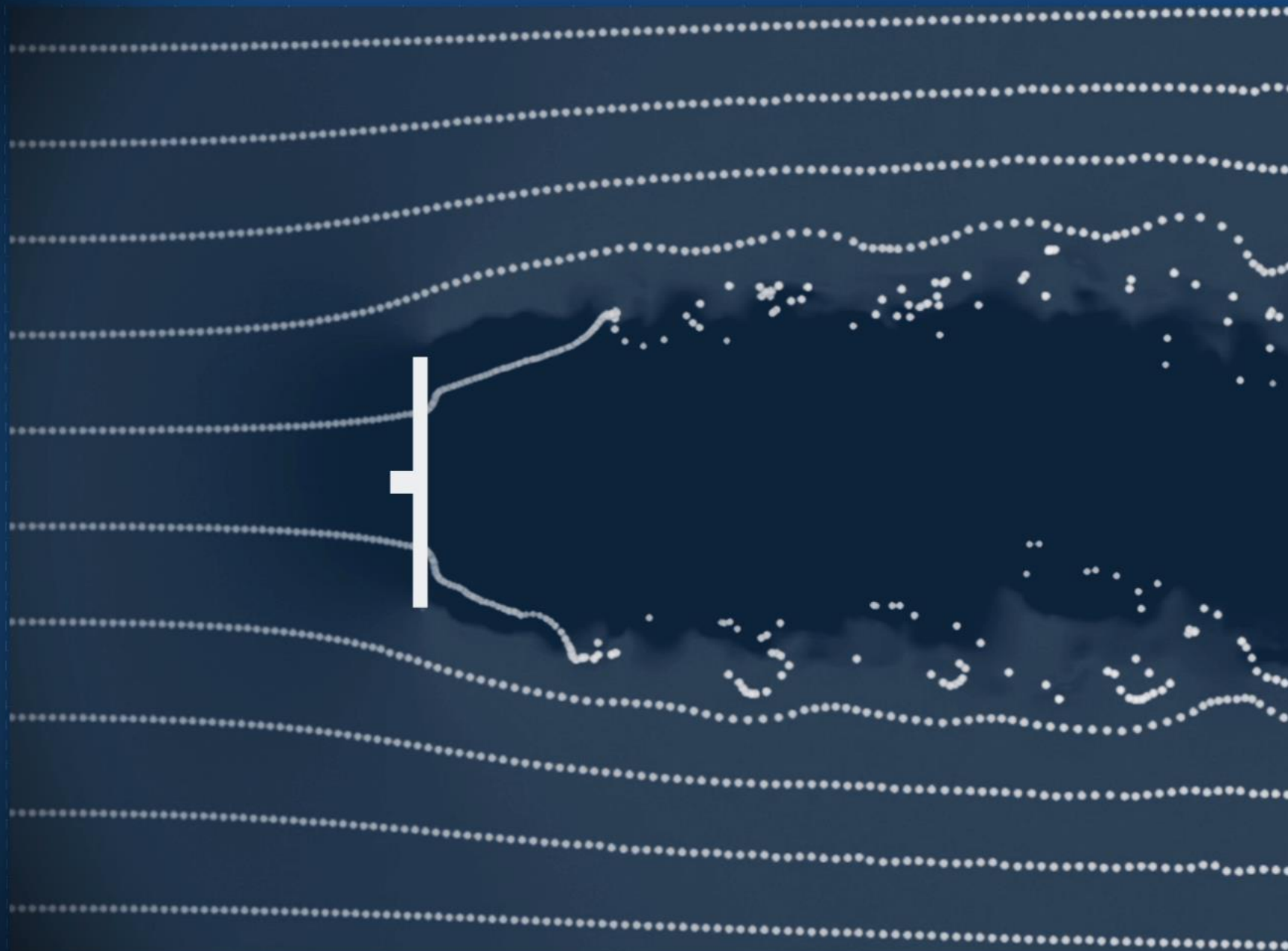


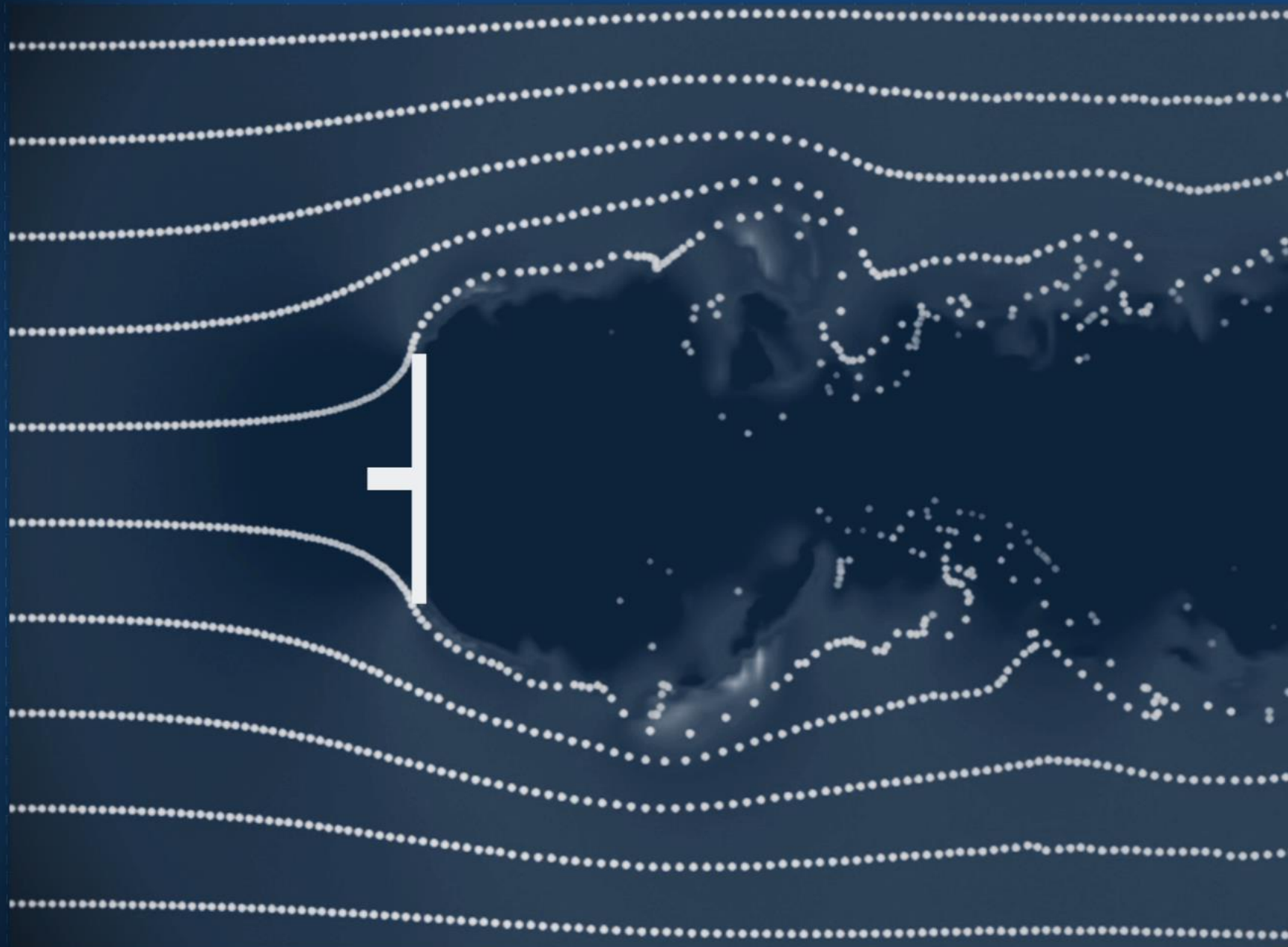
$$\text{Stream tube area } A = \pi R^2 \text{ [m}^2\text{]}$$





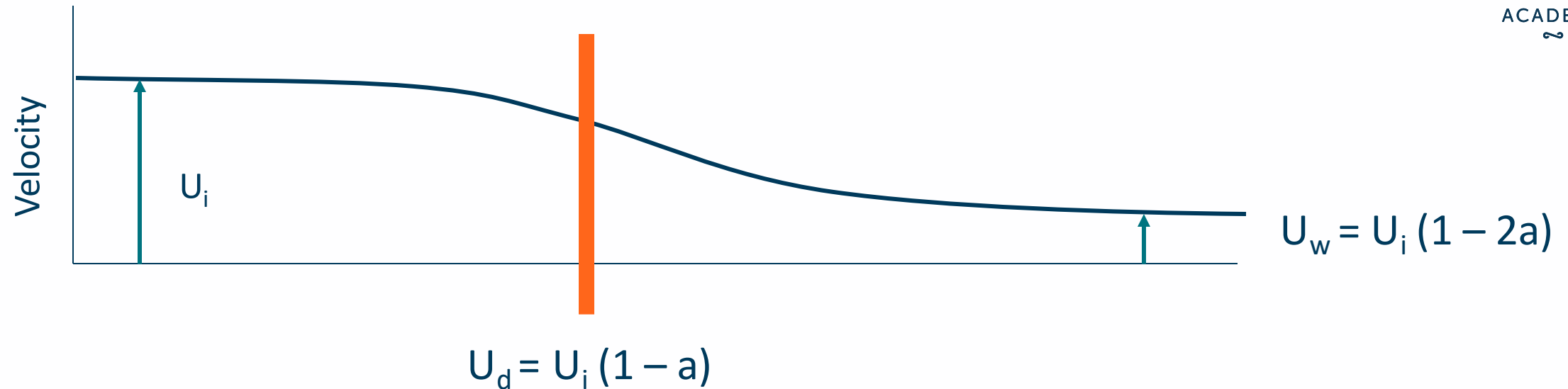








Wake effects: momentum theorem



Starting point Jensen's model, i.e.
near wake

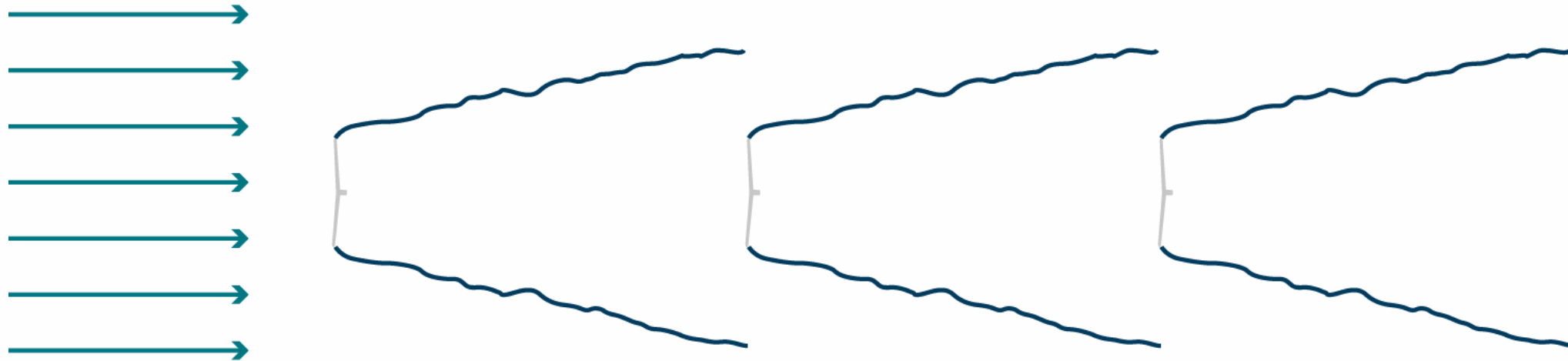
$$C_p = 4a^*(1-a)^2$$

a = induction factor, value
between 0 and 1



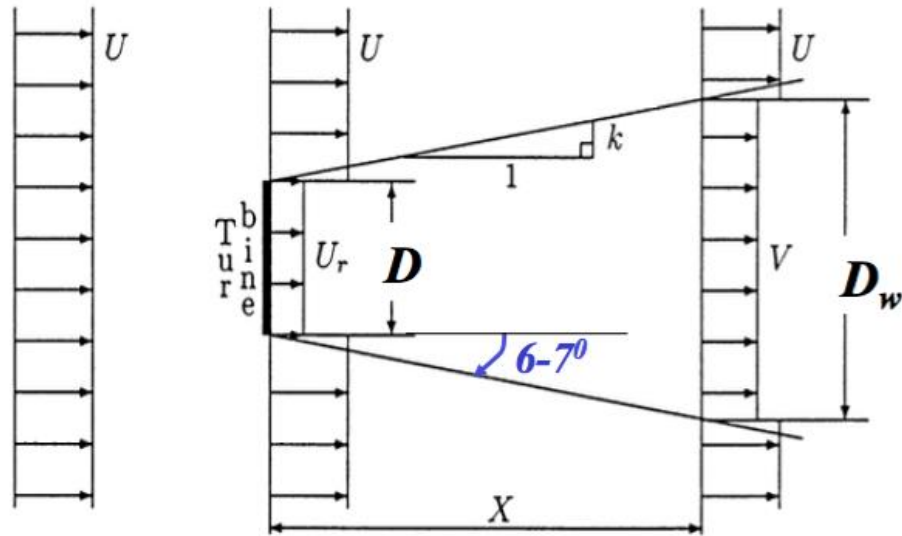
Wake effects

Wind





Jensen wake model



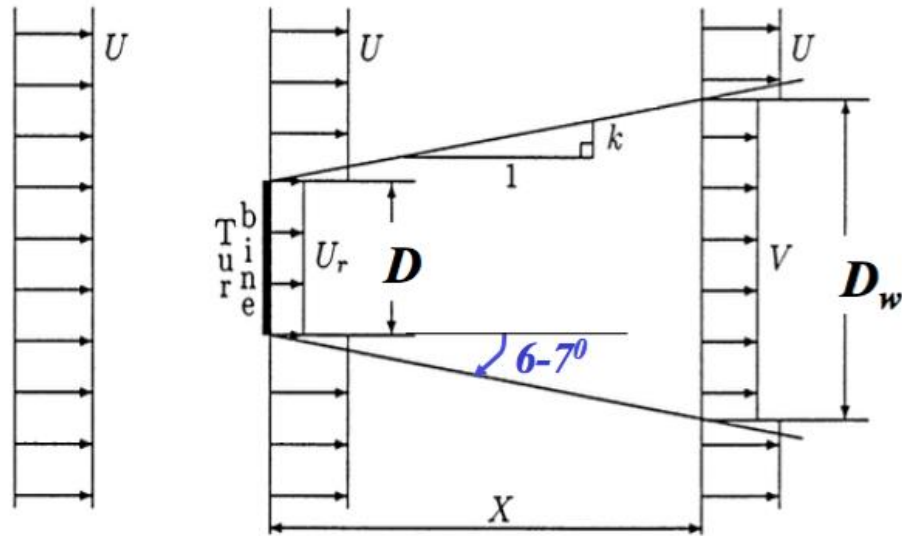
$$D_w = D + 2 k X$$

$$k = 0.075 \text{ onshore}$$

$$k = 0.05 \text{ offshore}$$



Jensen wake model

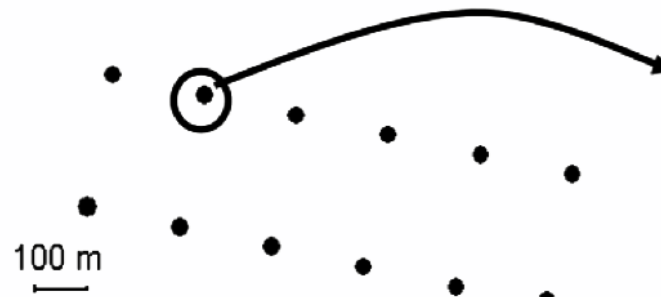
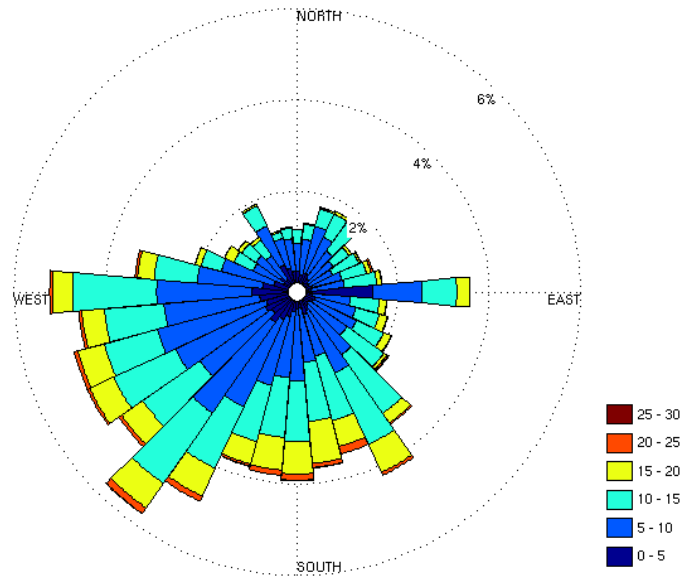


$$V = (U_r - U) D^2 / D_w^2 + U$$

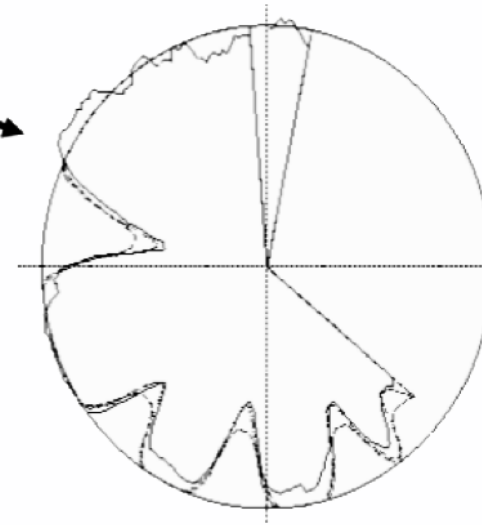
$$V = U [1 - (1 - U_r / U) D^2 / D_w^2]$$



Wind farm wake losses



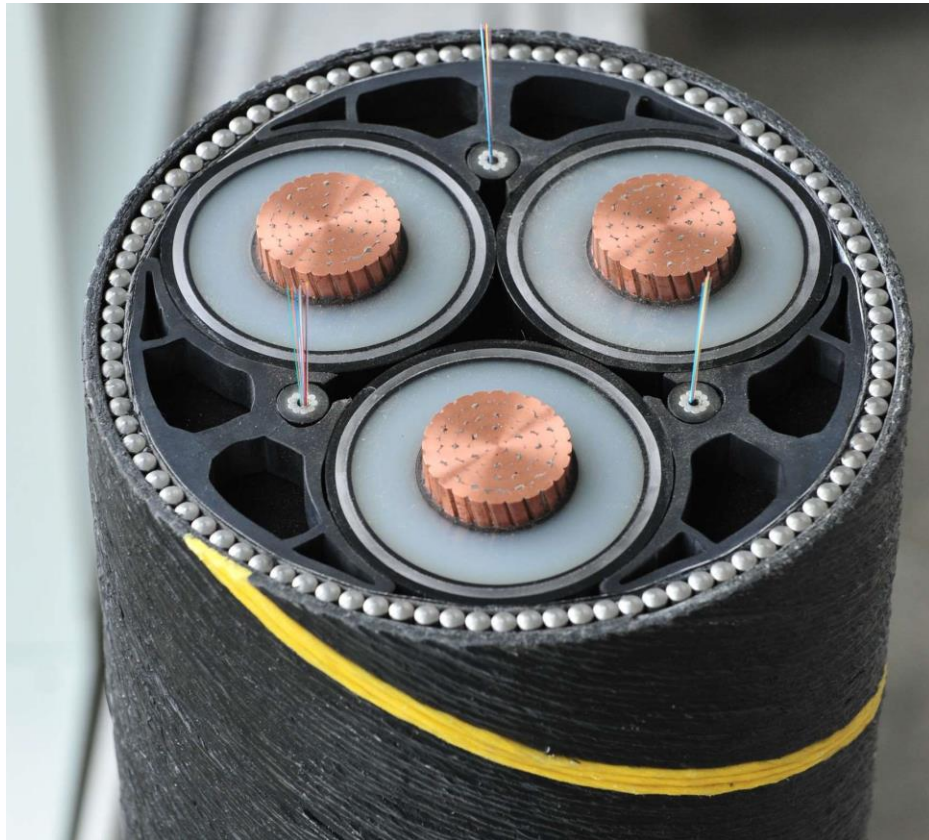
Wind farm layout



Direction dependent power output

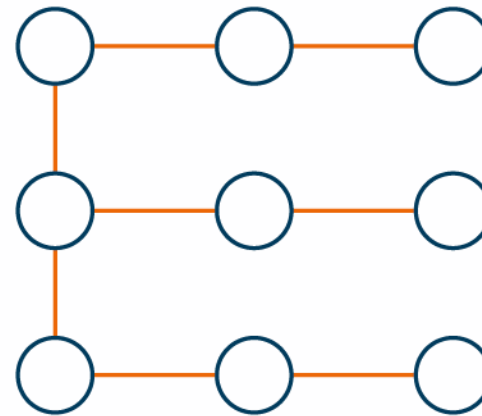
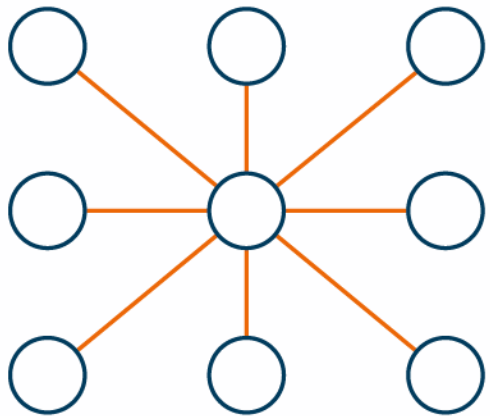


Transmission losses & cable costs



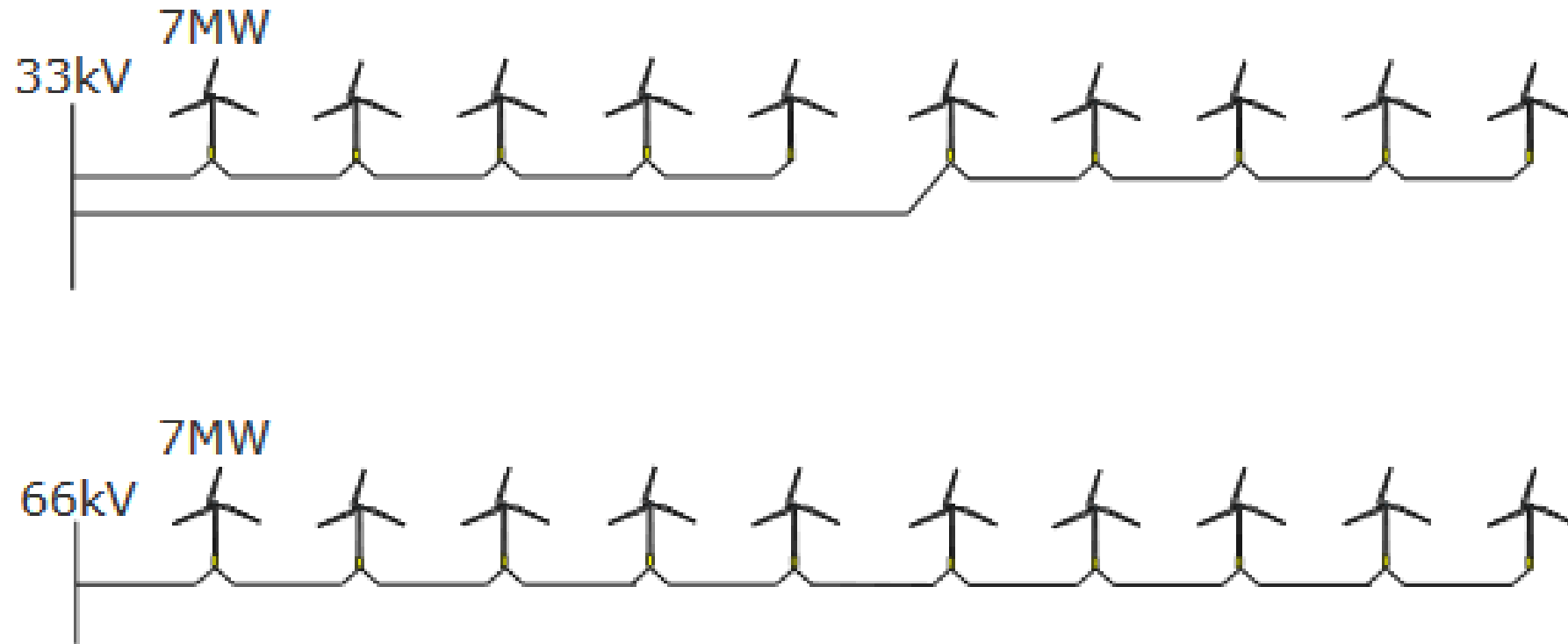


Grid Topology





Comparing cable size

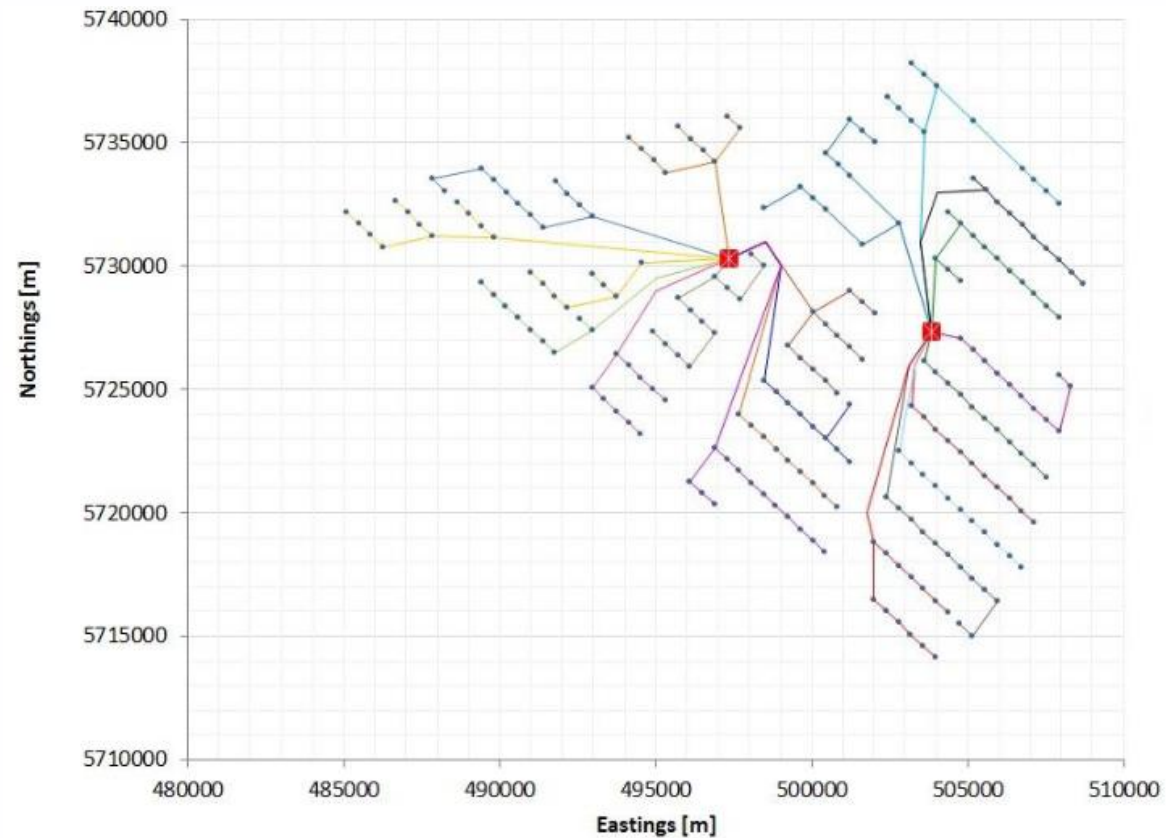




Cable costs Borselle

Borselle Wind Park (I to IV)

- -2 Substations
- -Interarray cables
- -Expected costs?



TenneT (2015)



Cable costs Borselle

	66 kV		33 kV	
	630 mm ²	240 mm ²	800 mm ²	240 mm ²
Cable length	124.990 m	185.730 m	315.840 m	122.000 m
Cable costs per meter	€425	€200	€465	€180
Total costs	€53 million	€38 million	€147 million	€22 million
Total costs		€91 million		€169 million

TenneT (2015)



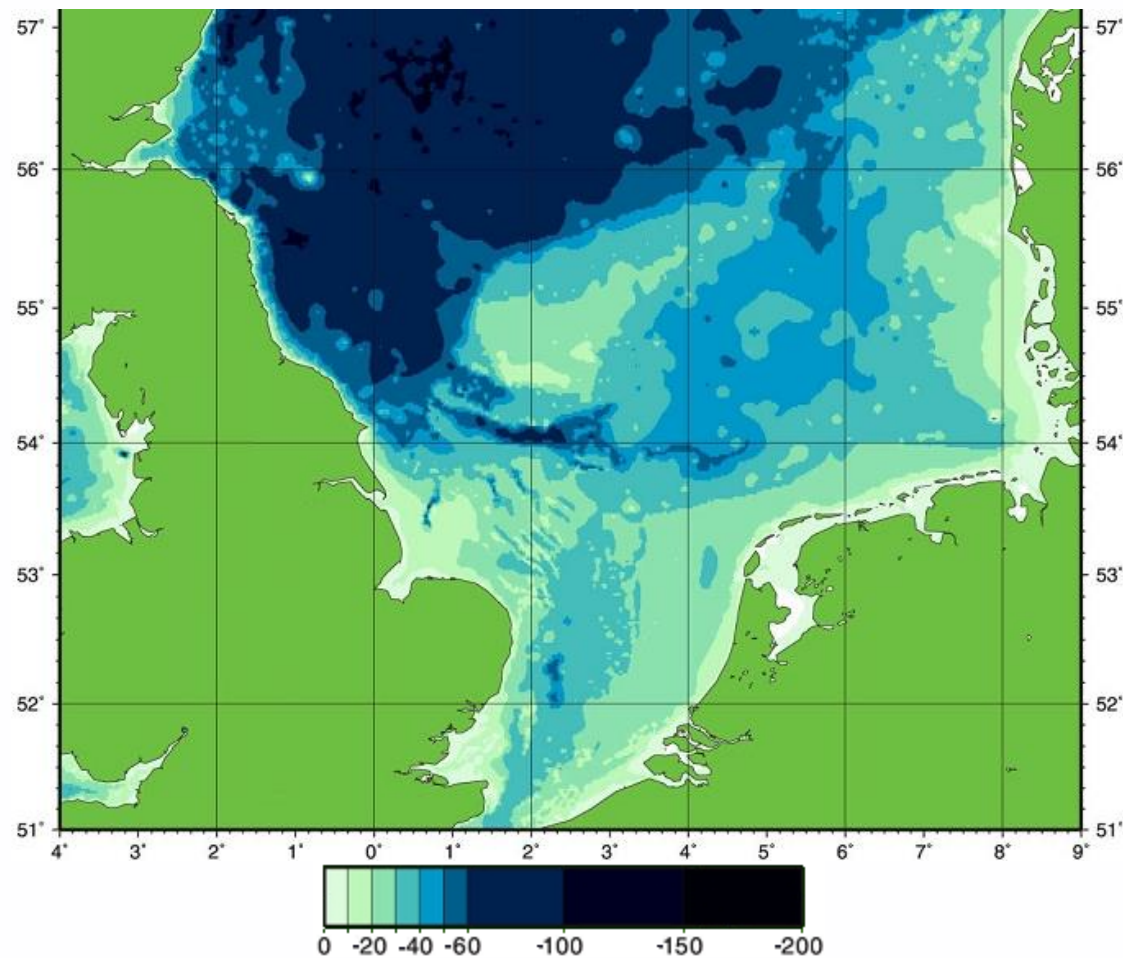
Cable costs Borselle

66 kV system	630 mm ²	240 mm ²	Total
Cable length	124.990 m	185.730 m	310.720 m
Cable costs	€425 /m	€200 /m	€91 million
Installation costs	€300 /m	€300 /m	€93 million
Total costs	€725 /m	€500 /m	€184 million

TenneT (2015)



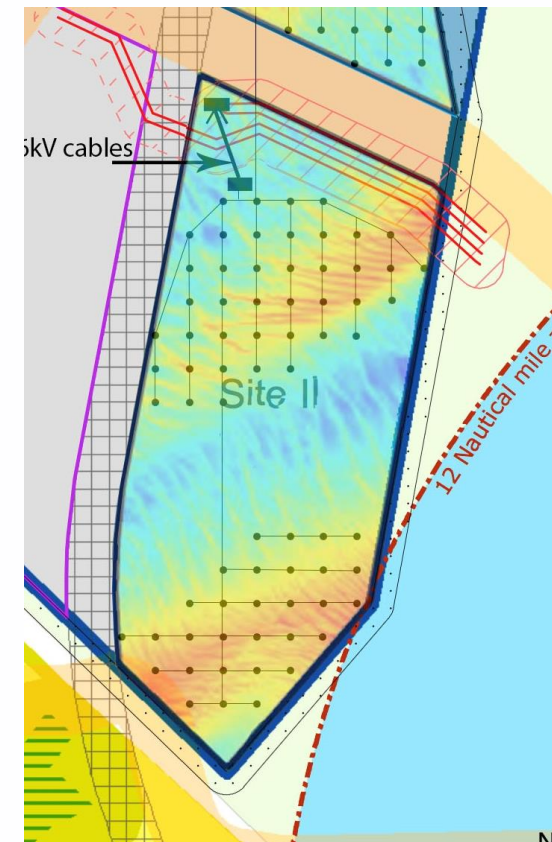
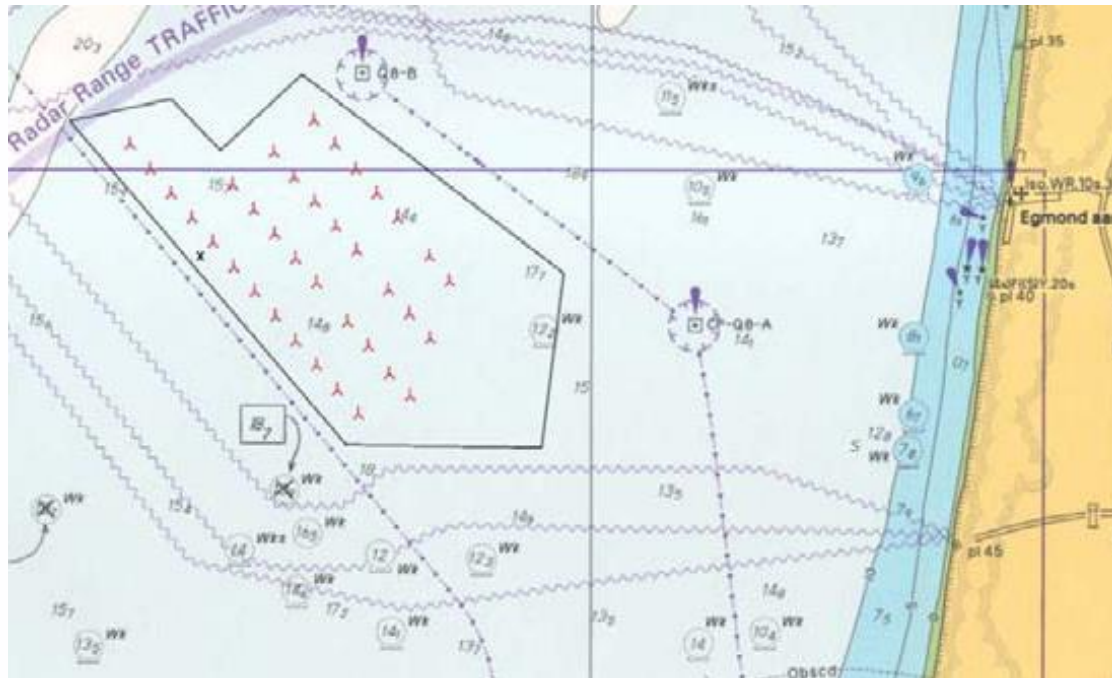
Bathymetry





Bathymetry

Consequences of water depth & soil type versus wake losses

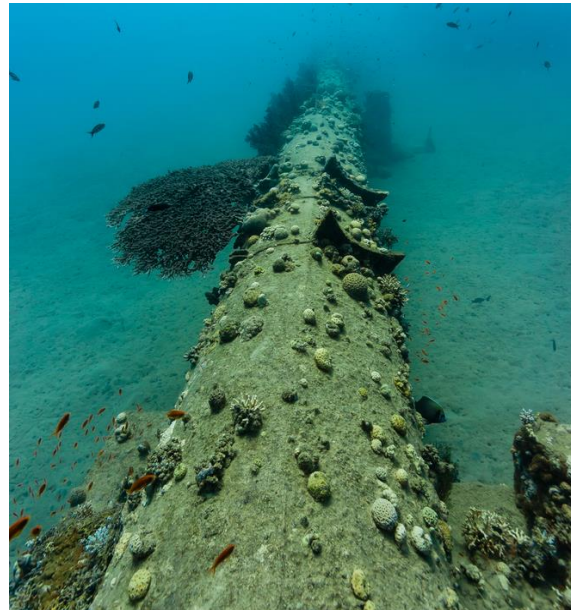




Seabed occupation



Rocks



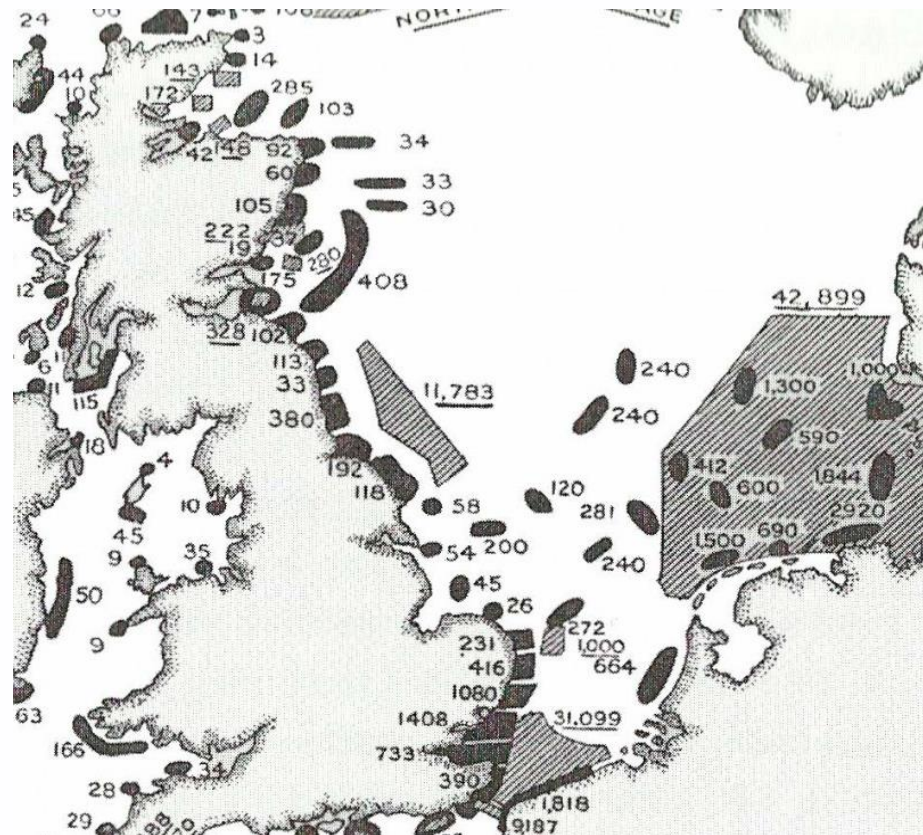
Cables and pipelines



Shipwrecks



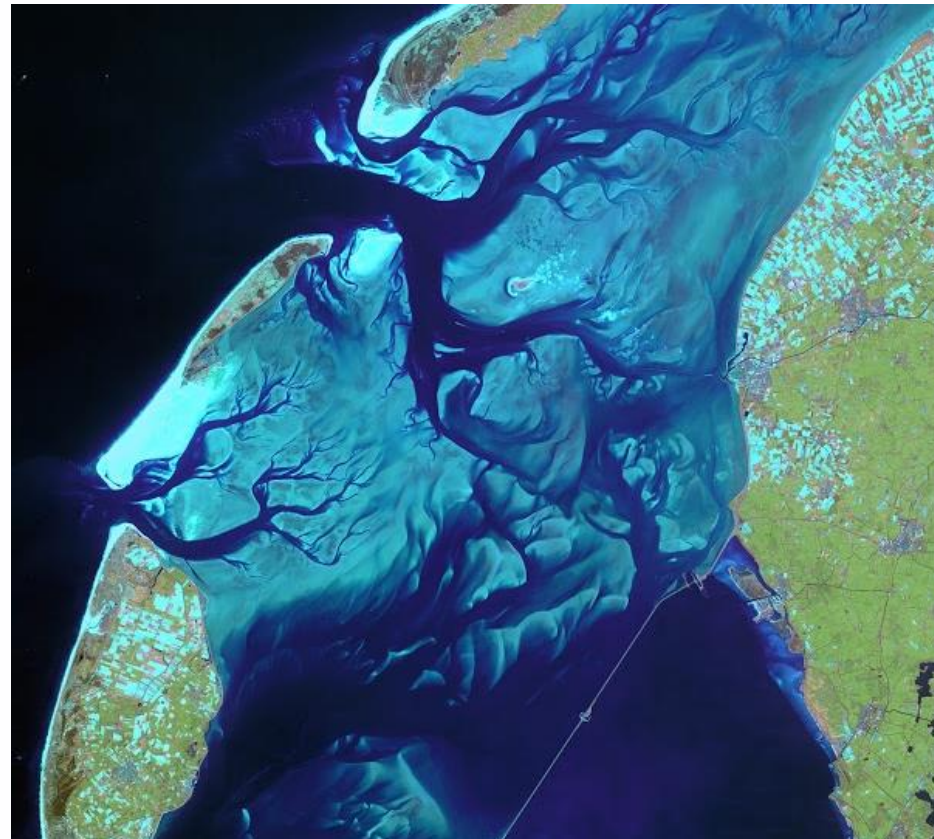
Unexploded ordnance





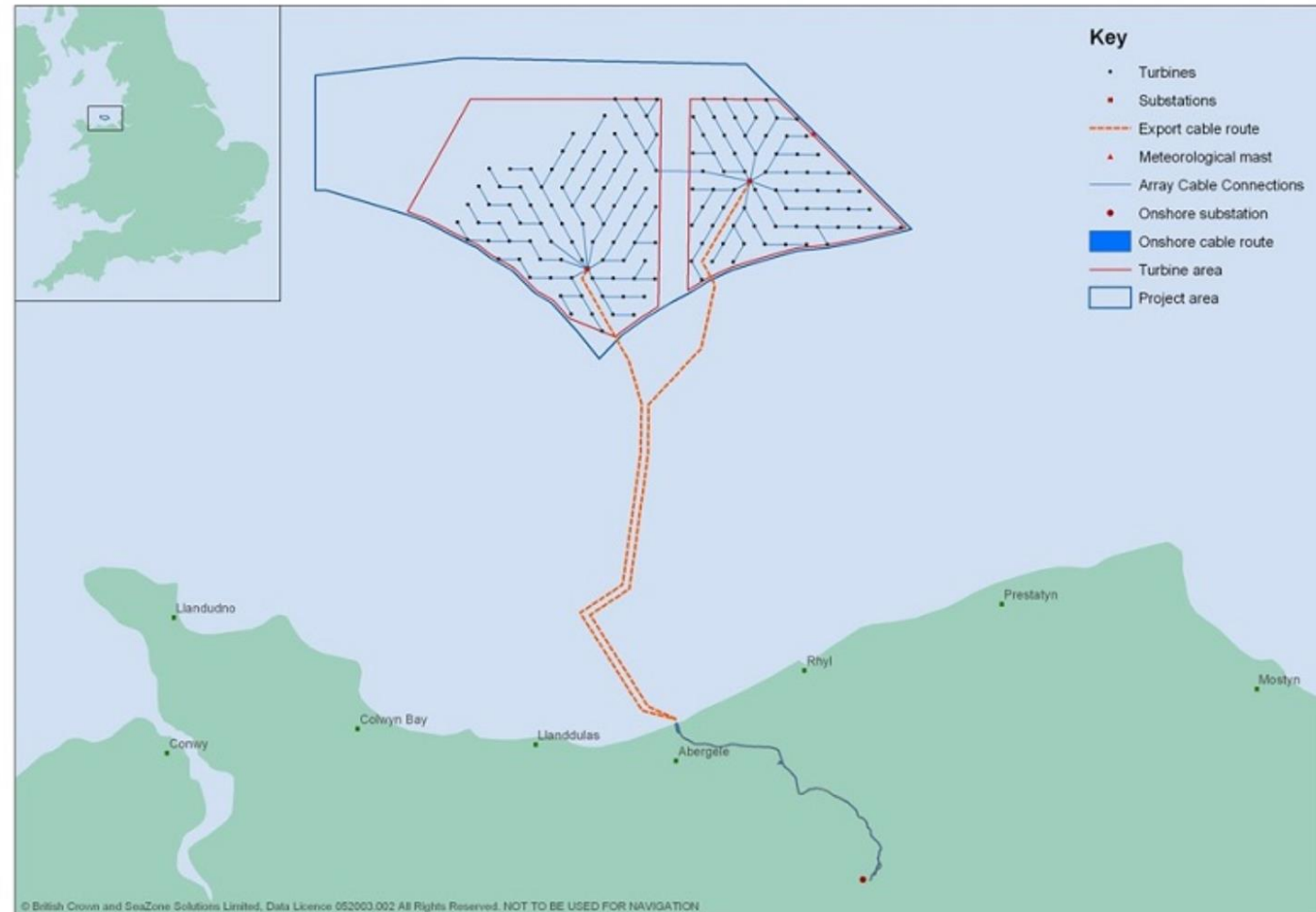
Sandbanks

- Move over time

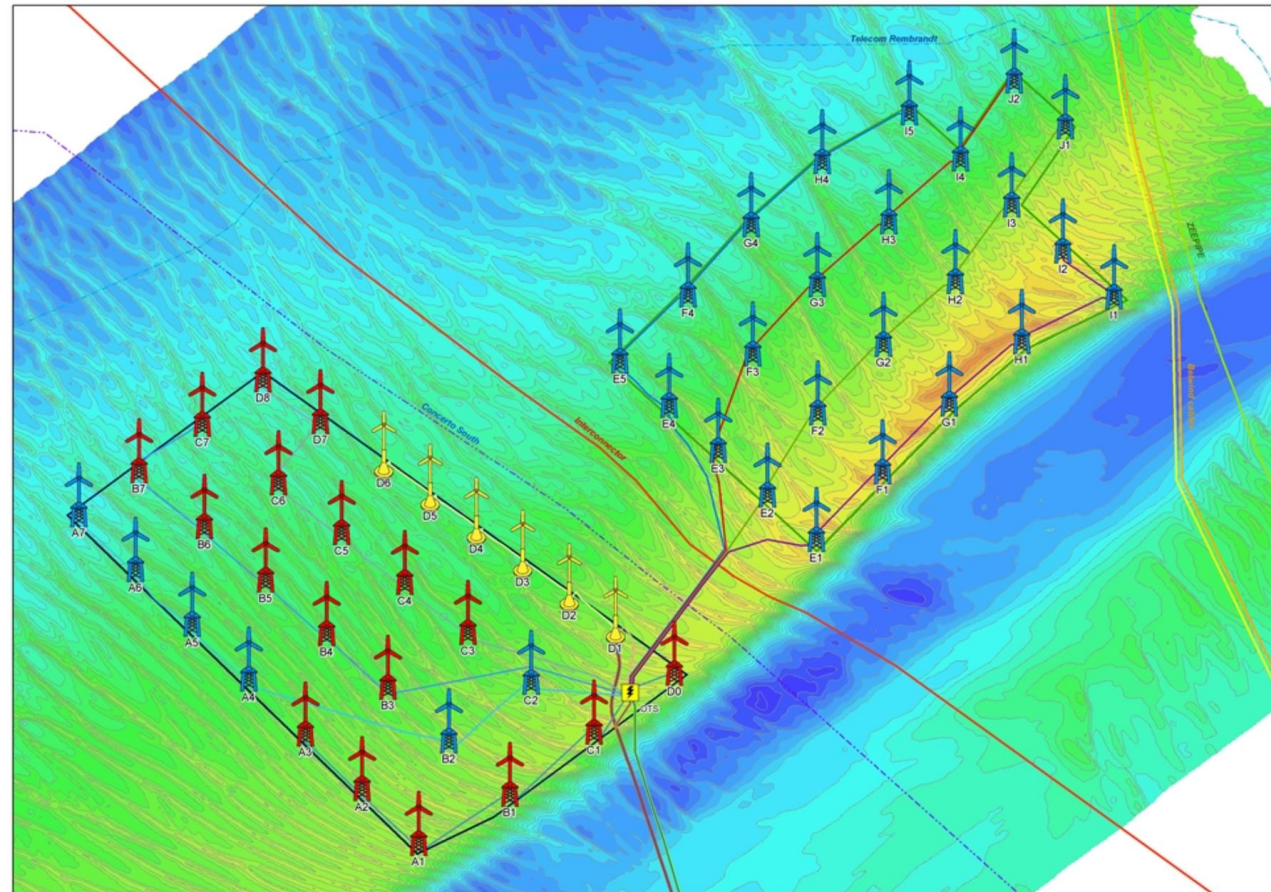




Example: Gwynt y Mor

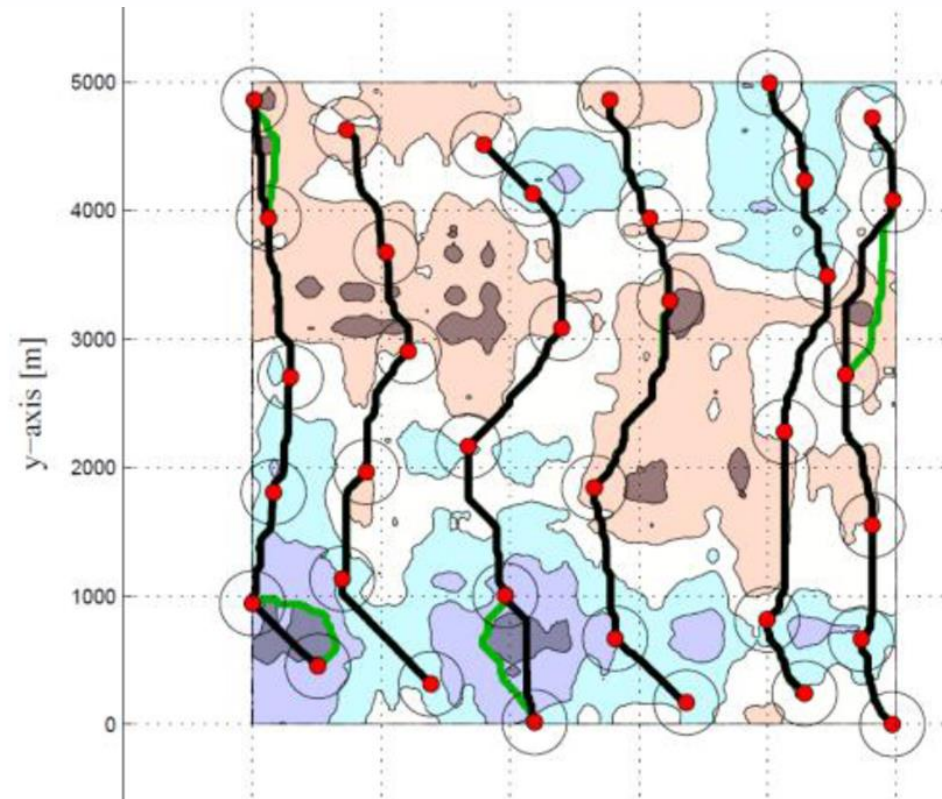
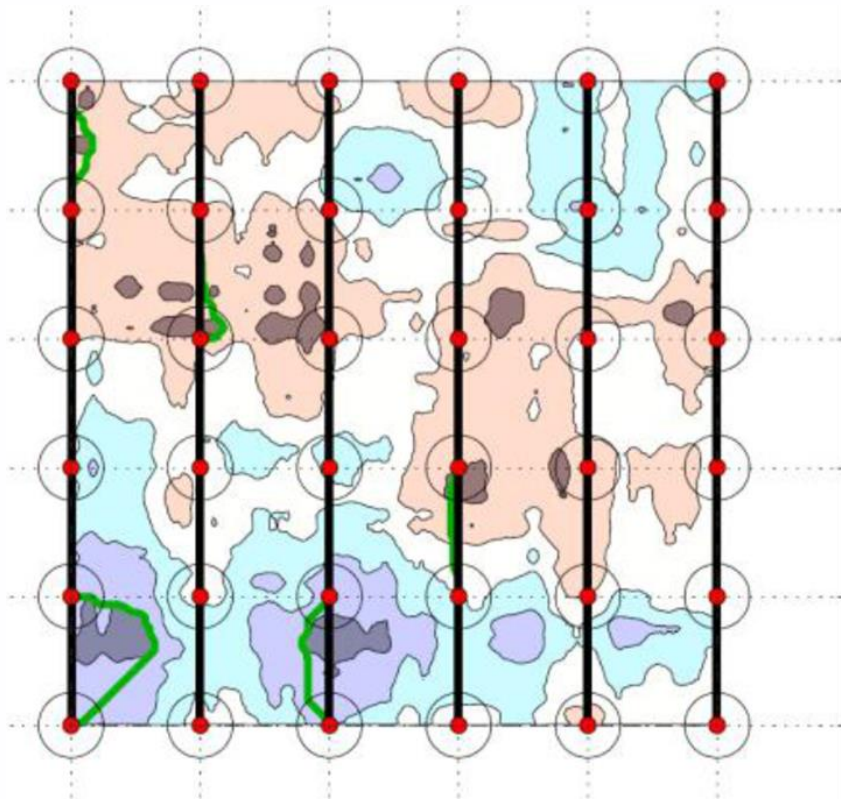


Example: Thornton Bank



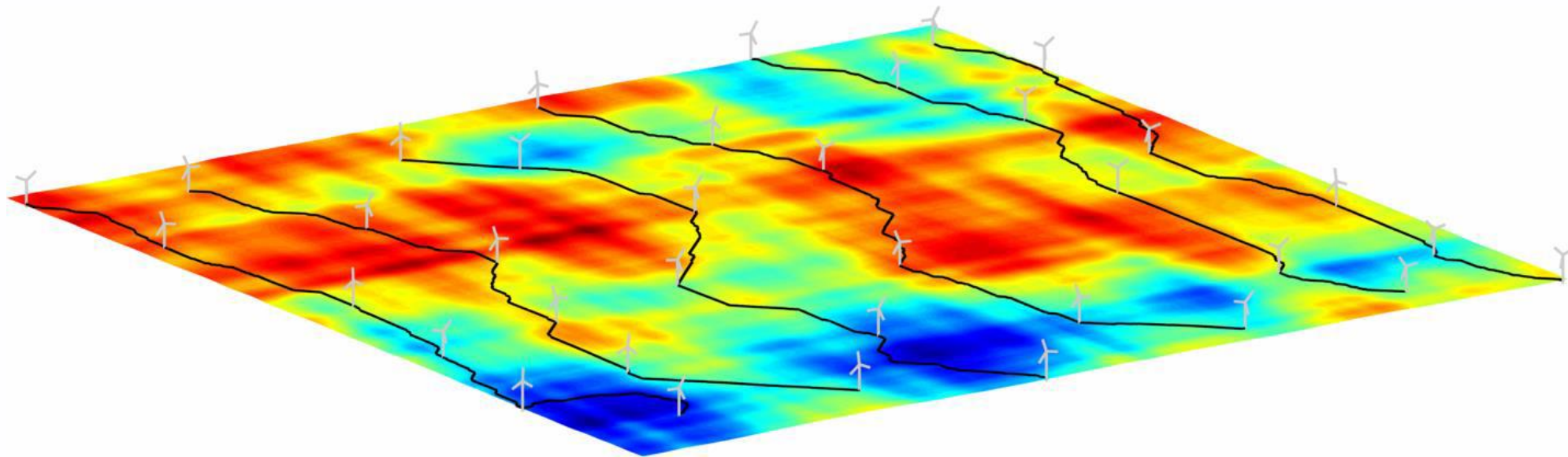


Wake, depth and cable length optimisation





Wake, depth and cable length optimisation

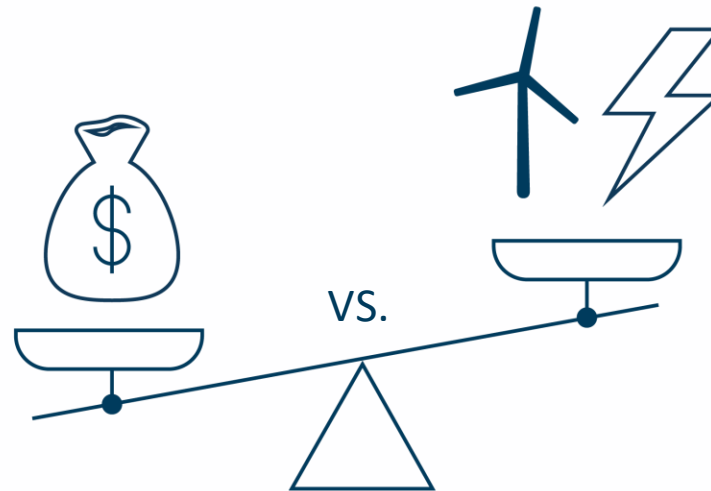




Summary

Trade off:

Infrastructure costs
(and electrical losses)



Power production
revenue



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