Modelling nearshore sediment fluxes in embayed settings over a multi-annual timescale

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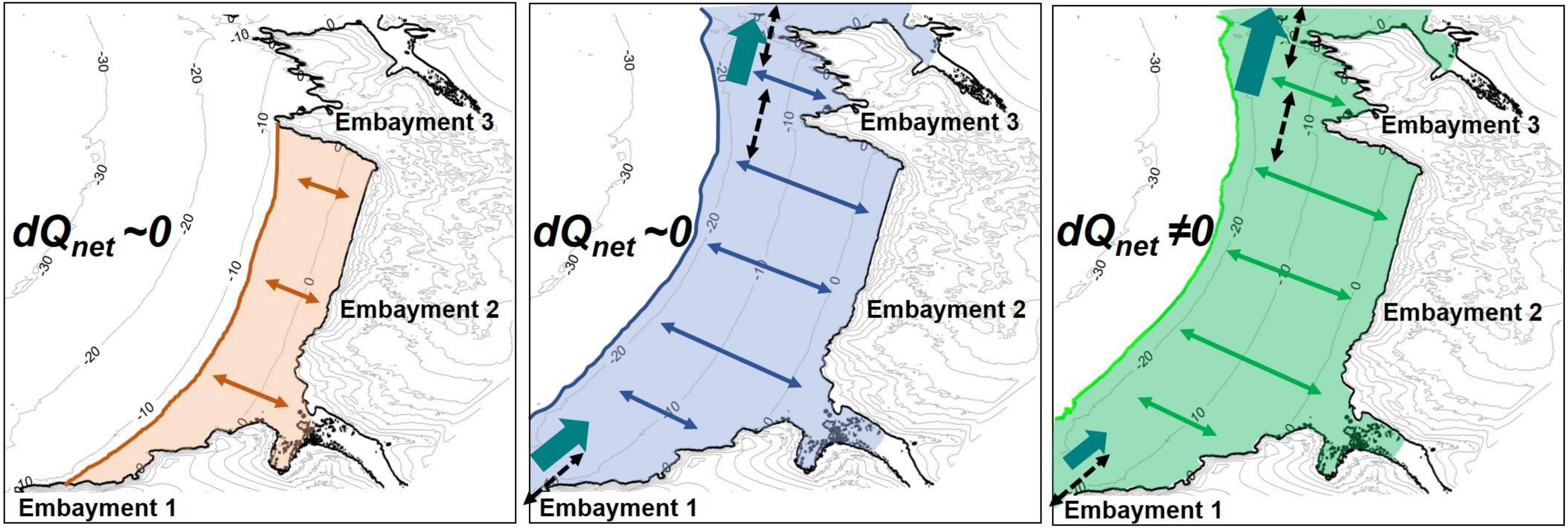
Fundamental question concerning embayed coastlines: closed systems?



Combination of field observations and numerical modelling to address this question

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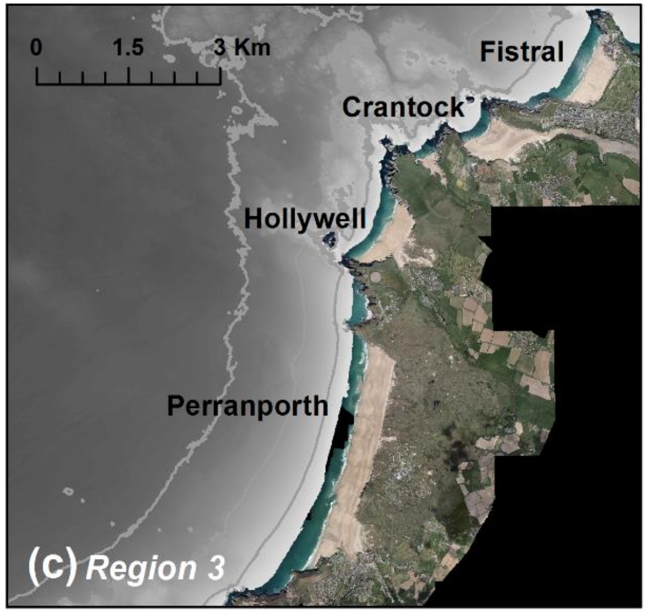
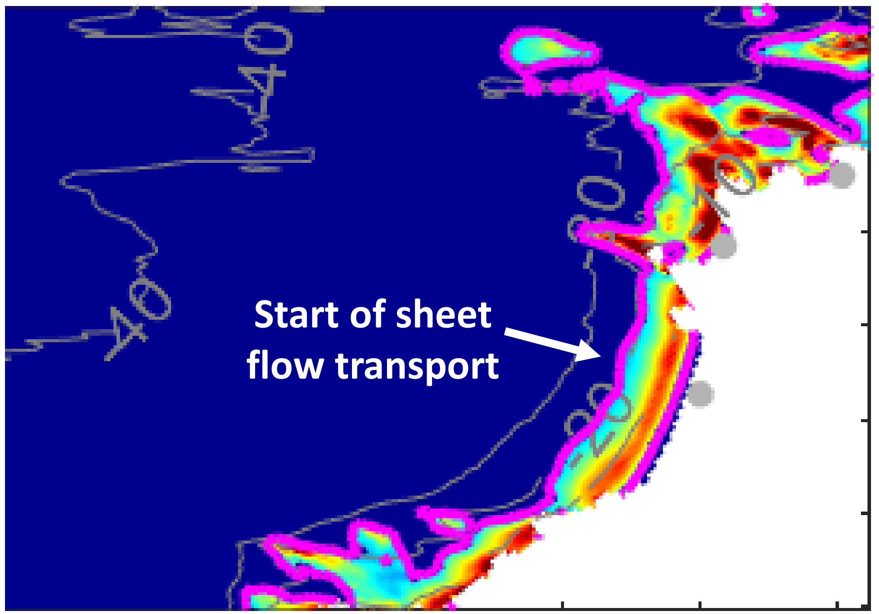
Potential for sediment exchange between the beach and adjacent bays?

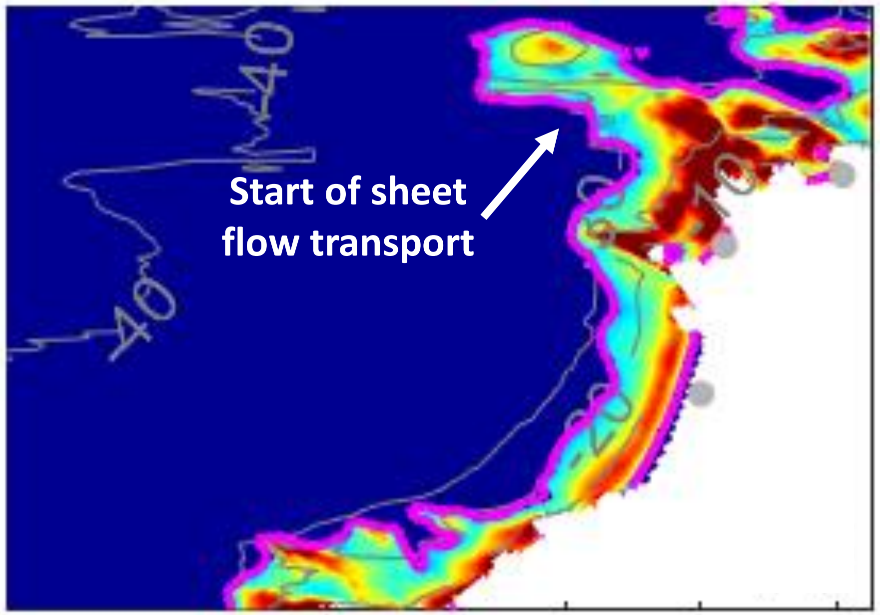
➢ Simulation of conditions inducing maximum bed shear stress (exceedance of critical values)



Extreme storm waves, but no tide



Extreme storm waves + spring tide



Significant sediment transport beyond the morphological depth of closure, possibly up to 30 m water depth

Valiente et al. (2019a)

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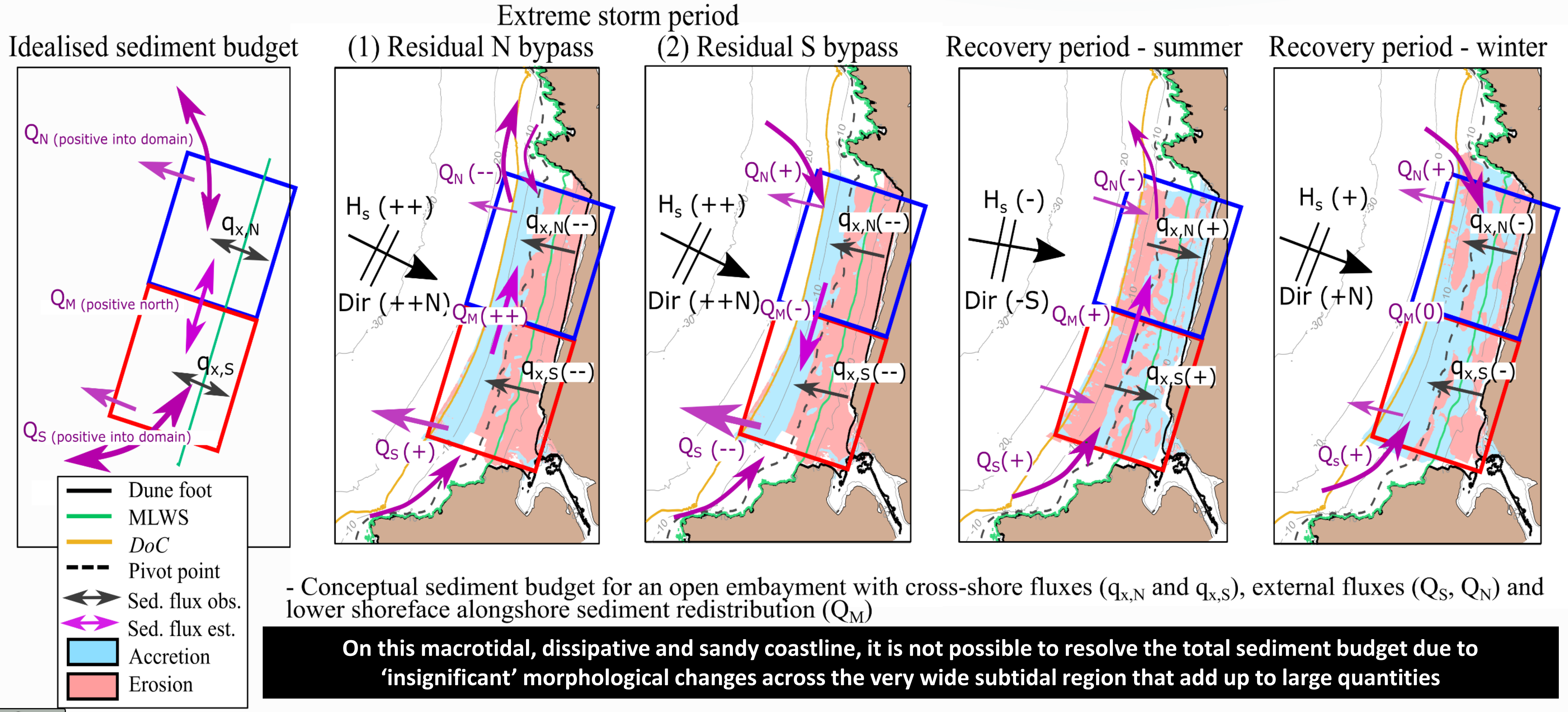
Total sediment budget based on morphological observations

➢ **Computation of DoDs and propagated uncertainty (2011-2018): system is neither closed, nor balanced**



- Conceptual sediment budget for an open embayment with cross-shore fluxes ($q_{x,N}$ and $q_{x,S}$), external fluxes (Q_S, Q_N) and lower shoreface alongshore sediment redistribution (Q_M)

On this macrotidal, dissipative and sandy coastline, it is not possible to resolve the total sediment budget due to 'insignificant' morphological changes across the very wide subtidal region that add up to large quantities

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Valiente et al. (2019b)

Research aims

Provide a more robust and comprehensive understanding of the complex sediment dynamics driving coastal evolution along embayed coastlines across event to multi-annual timescales:

(1) main processes inducing sediment exchange in/out the embayment;

(2) sediment transport rates: headland bypassing and sediment ejection outside the offshore morphological limit of the embayments;

(3) and sediment exchanges within Perranporth and adjacent embayments over multi-annual time scales.

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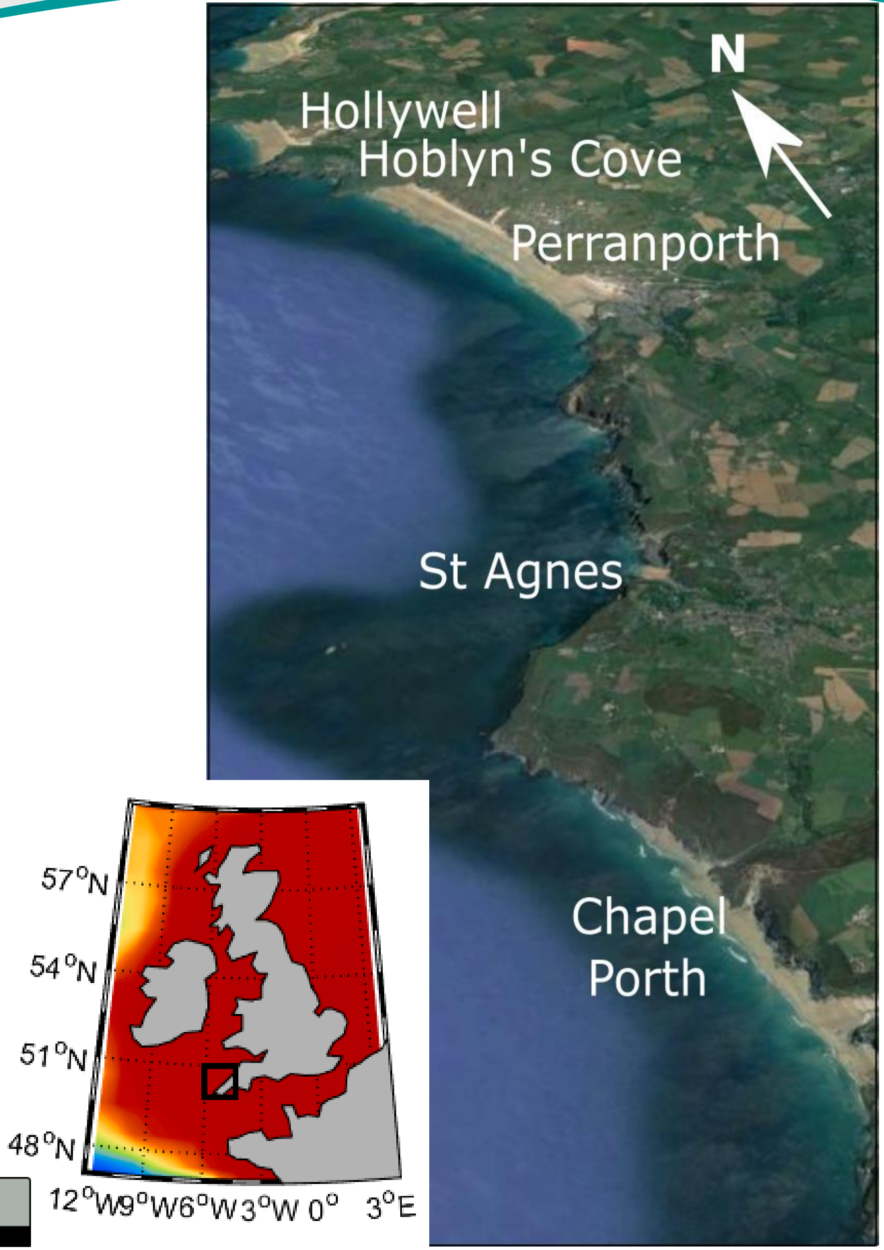
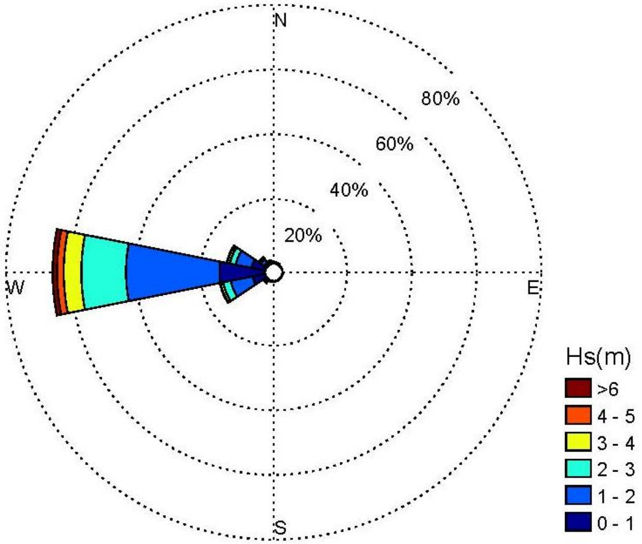
A macrotidal and embayed sandy coastline: the N coast of Cornwall





- 0.02 average gradient
- Low-tide bar-rip intertidal
- Outer bar (z ~ -6 – -12 m)
- Unimodal wave conditions
- MSTR = 6.3 m
- $H_{s50\%}$ = 1.5, $T_{p50\%}$ = 10 s

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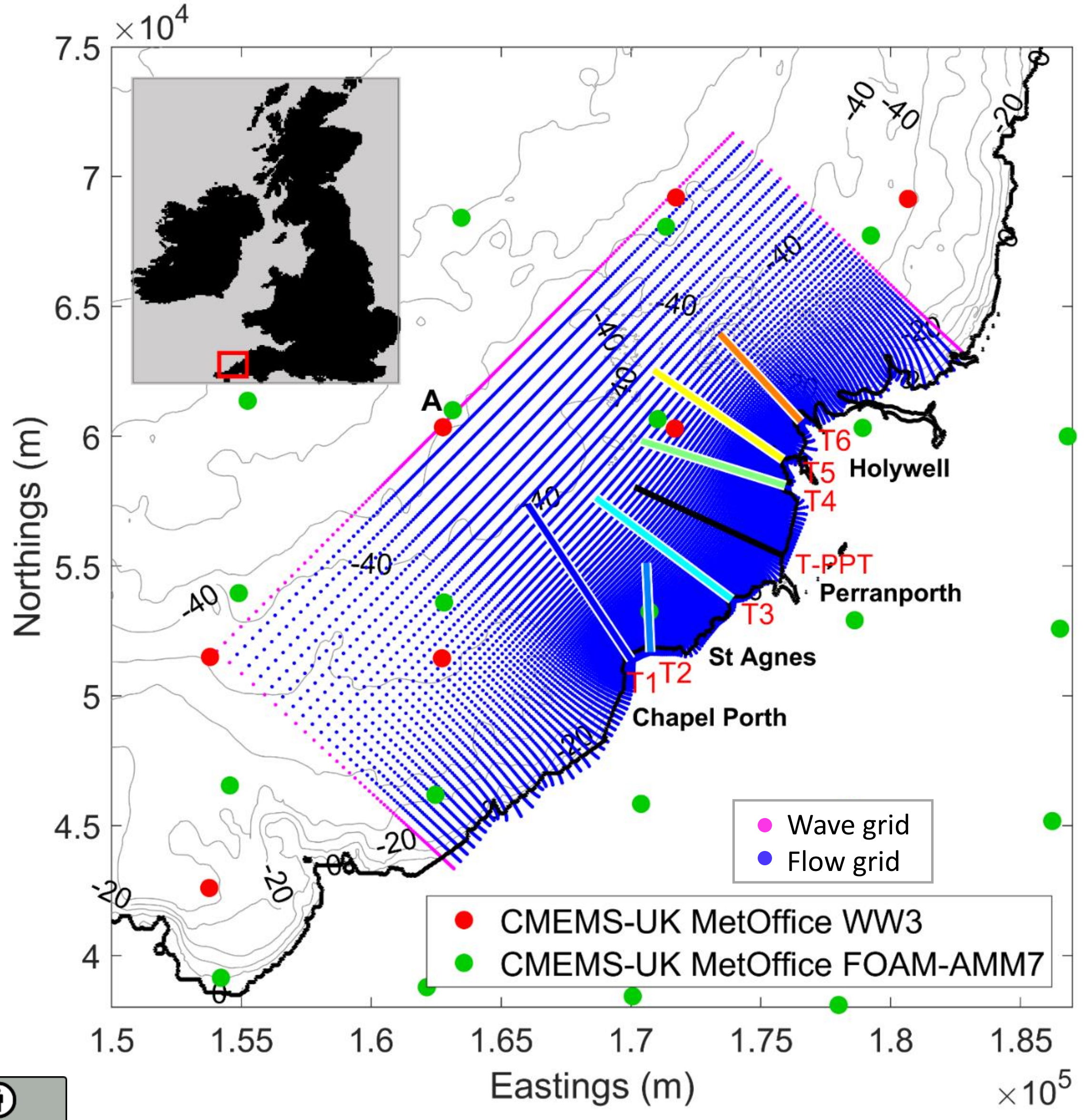
Numerical model setup



- Delft3D (WAVE and FLOW) run in 2D and online-coupled mode (i.e. two way wave-current interaction).
- Forcing datasets: (i) waves from WW3 8 km, (ii) currents and WL from FOAM-AMM7, (iii) pressure from 0.5^o NOAA Climate Forecast System Version 2 (CFSv2), and (iv) wind from 0.25^o CERSAT Global ocean blended wind.
- Bathymetry: UKHO+LiDAR.
- Two orthogonal curvilinear grids designed to follow the primary morphological features along the study coastline as per Bruciaferri et al. (2020). Variable resolution from 300 m to < 20 m.
- Boundaries: WL for offshore NW and cross-shore NE, current for cross-shore SW (inflow).

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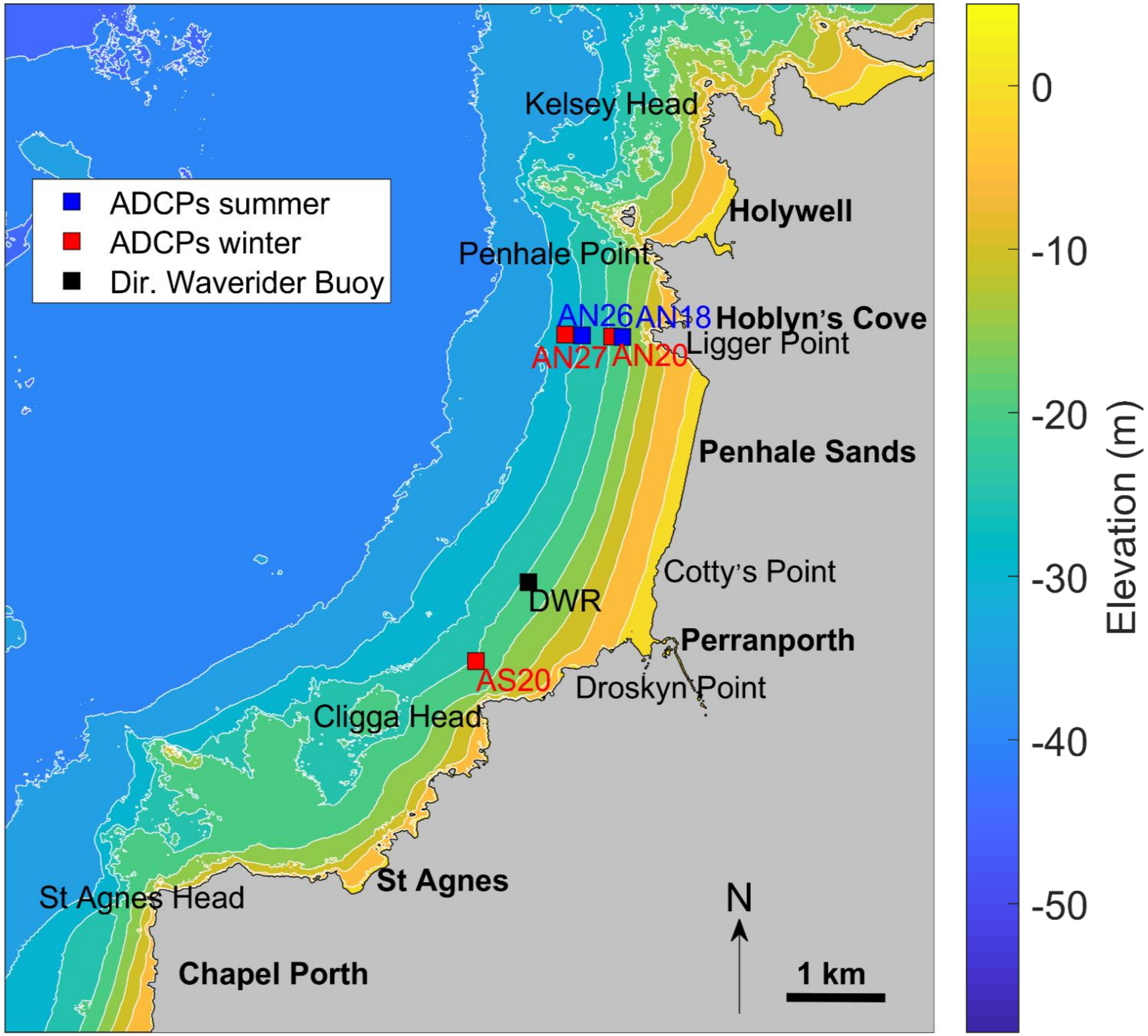
Hydrodynamic observations



- Measurements of waves, currents and water levels
- 600 kHz RDI WorkHorse Monitor Acoustic Doppler Current Profilers (ADCPs)
- Directional wave buoy (DWR)

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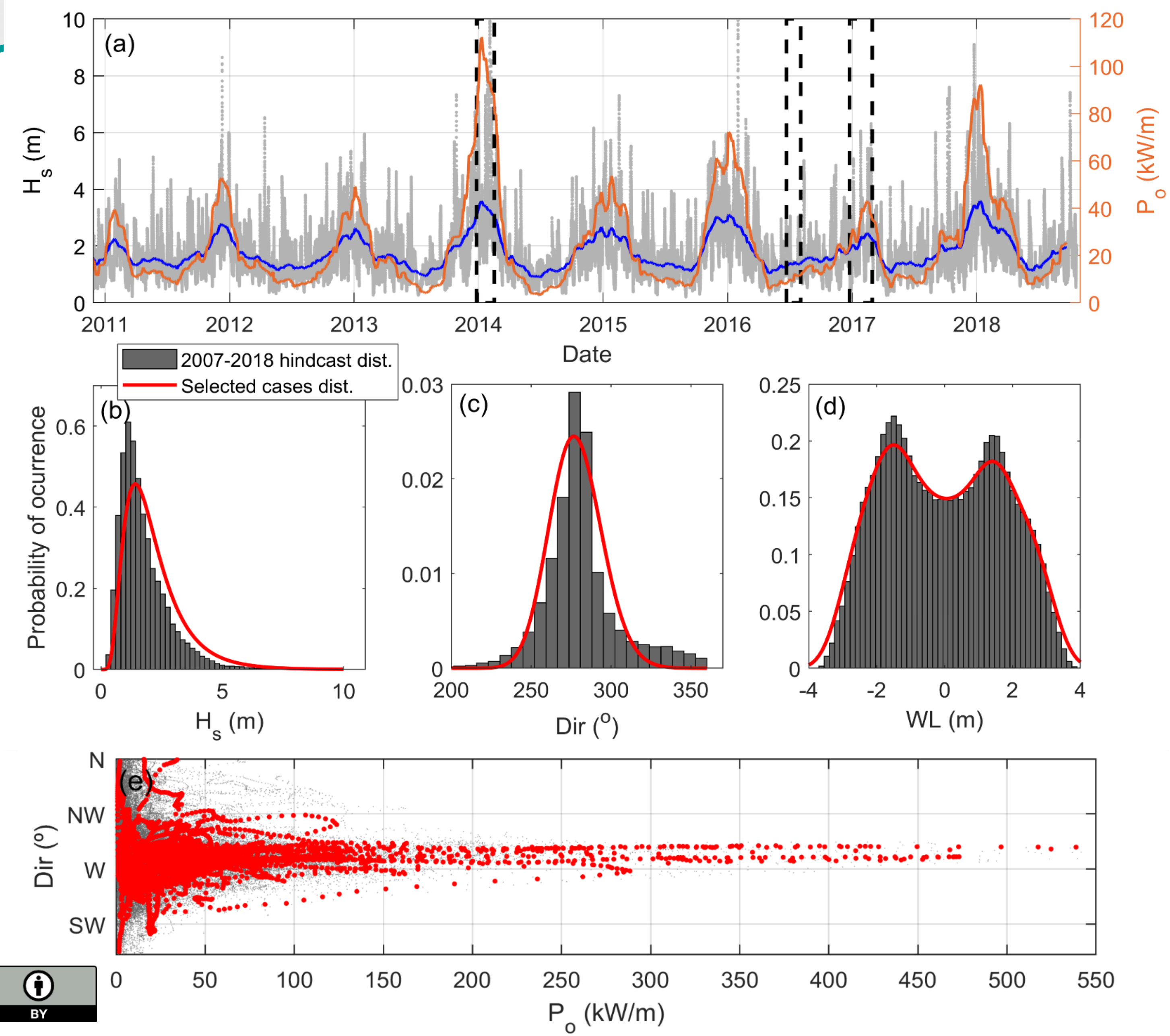
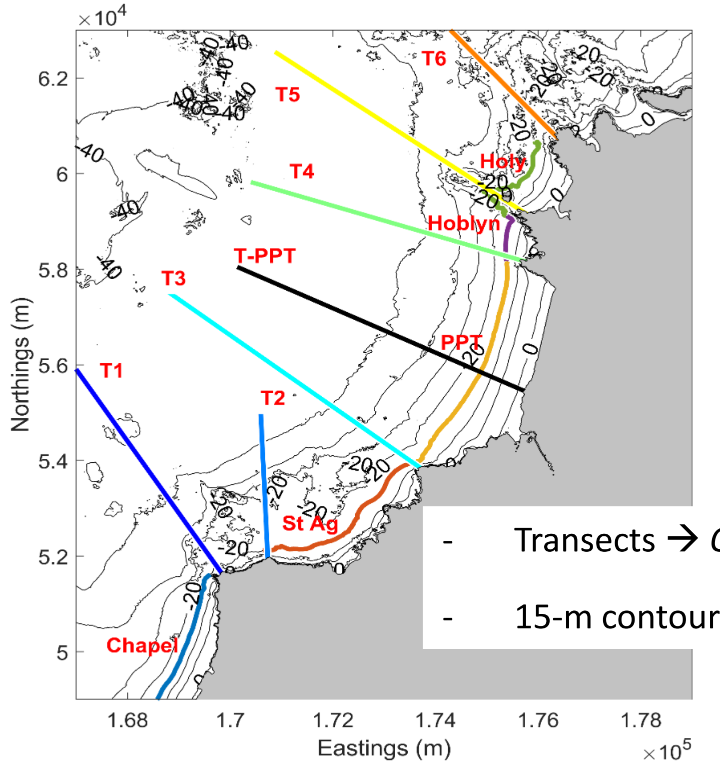
Methodology: modelled scenarios and transport rates integration



- Period 2011-2018, including the severe 2013/14 winter (Masselink et al., 2016)
- Range of representative wave conditions:
  - H_s = 0.1 – 8 m;
  - T_p = 4 – 20 s;
  - Dir = 260 – 360^o



- Transects → Q_{bypass}
- 15-m contour → Q_{cross}

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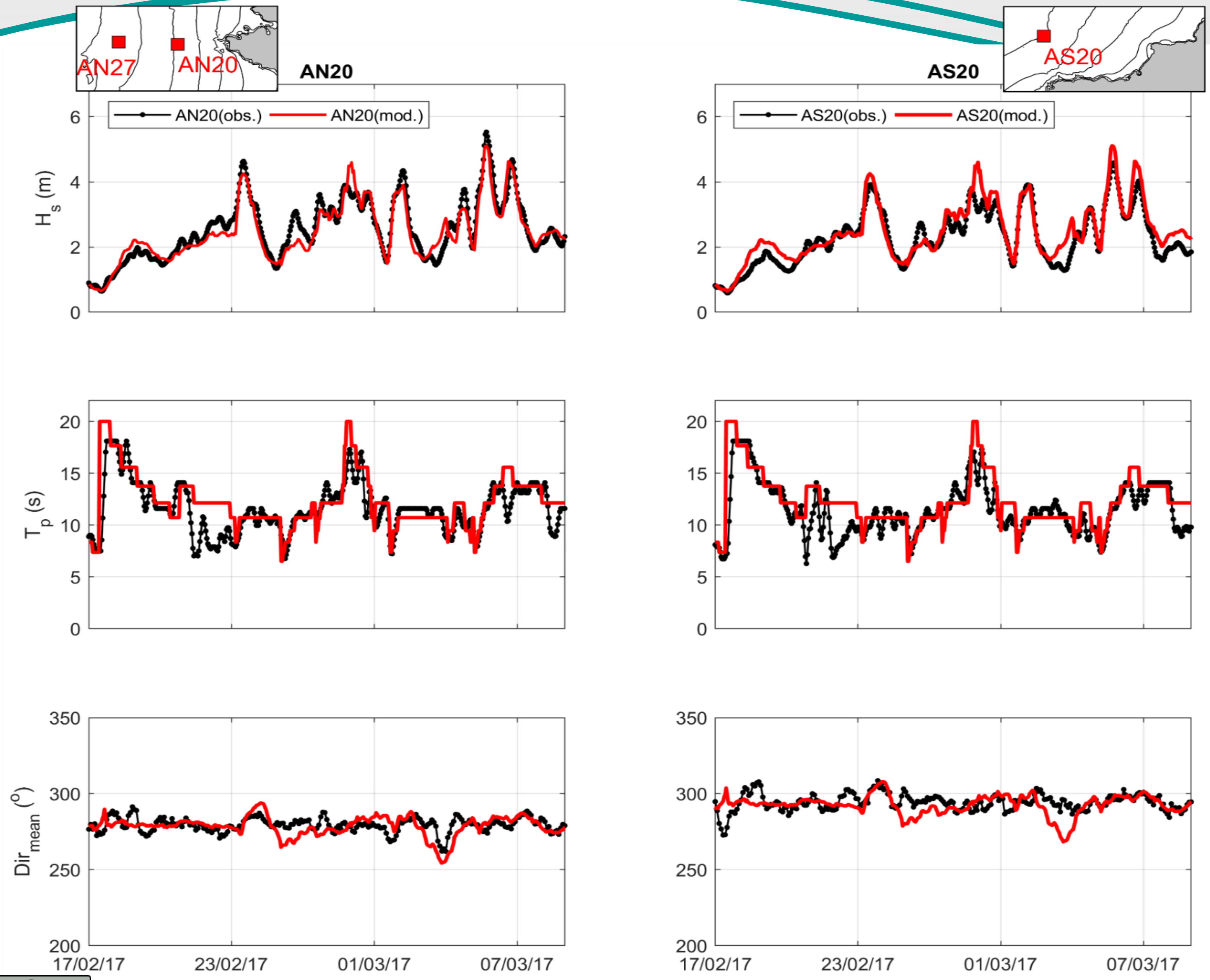
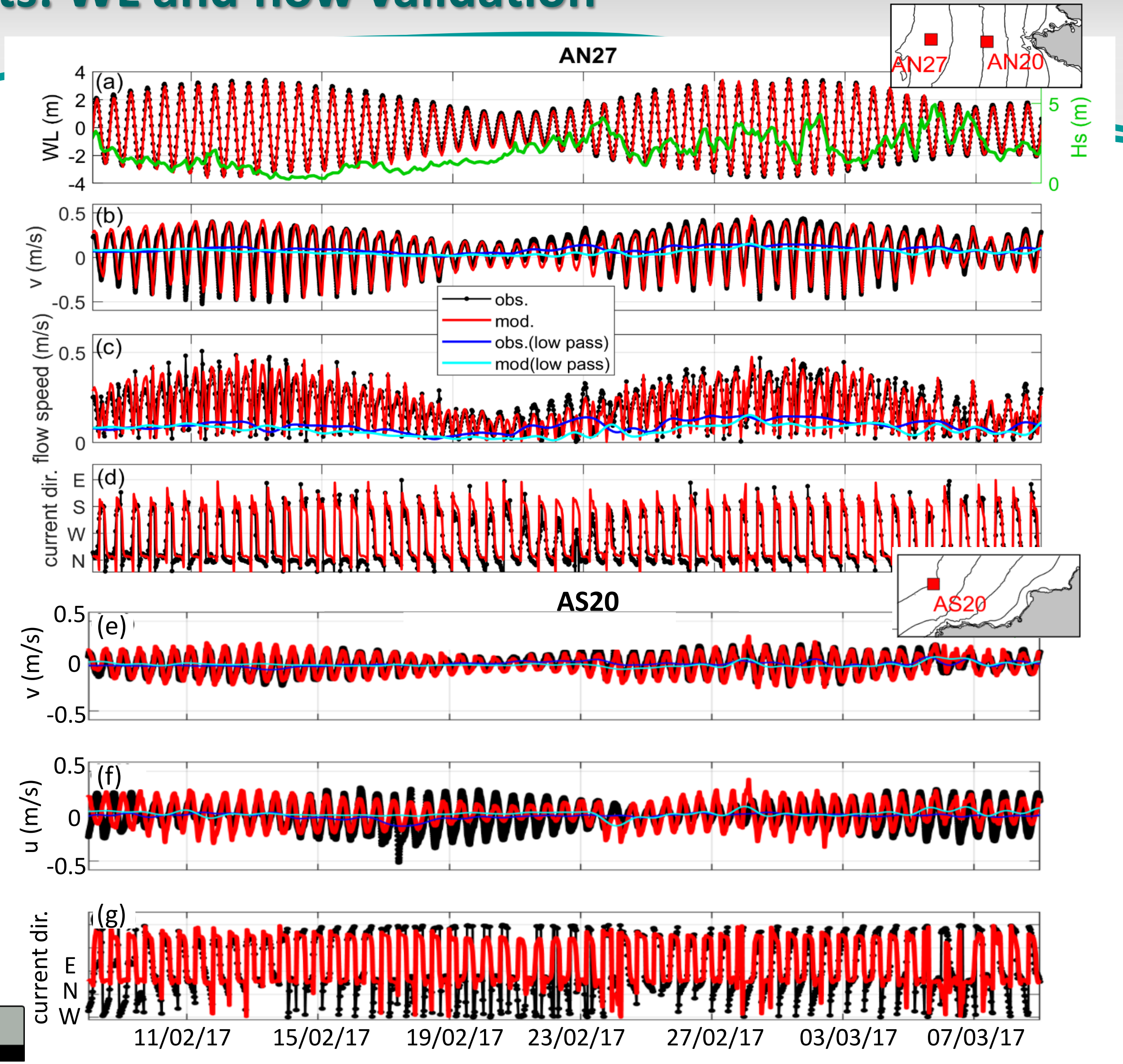
Results: waves validation



Model	Variable	Location	RMSE	R^2	Bias
WAVE	Significant wave height (m)	AN27	0.40	0.7	0.04
		AN20	0.46	0.81	0.05
		AS20	0.48	0.74	0.09
		Buoy	0.48	0.79	0.09
	Peak period (s)	AN27	2.83	0.27	0.01
		AN20	2.12	0.51	0.01
		AS20	2.22	0.50	0.02
		Buoy	2.01	0.58	0.02
	Mean direction (deg.)	AN27	17.13	0.44	<0.01
		AN20	10.91	0.76	<0.01
		AS20	17.31	0.76	<0.01
FLOW	Water level (m)	AN27	0.16	0.97	0.04
		AN20	0.13	0.97	<0.01
		AS20	0.13	0.98	<0.01
	Flow speed (m/s)	AN27	0.07	0.59	<0.01
		AN20	0.09	0.52	<0.01
		AS20	0.09	0.17	0.04
	Flow direction (deg.)	AN27	48.49	0.73	0.39
		AN20	69.00	0.66	0.35
		AS20	73.53	0.44	0.82

Results: WL and flow validation



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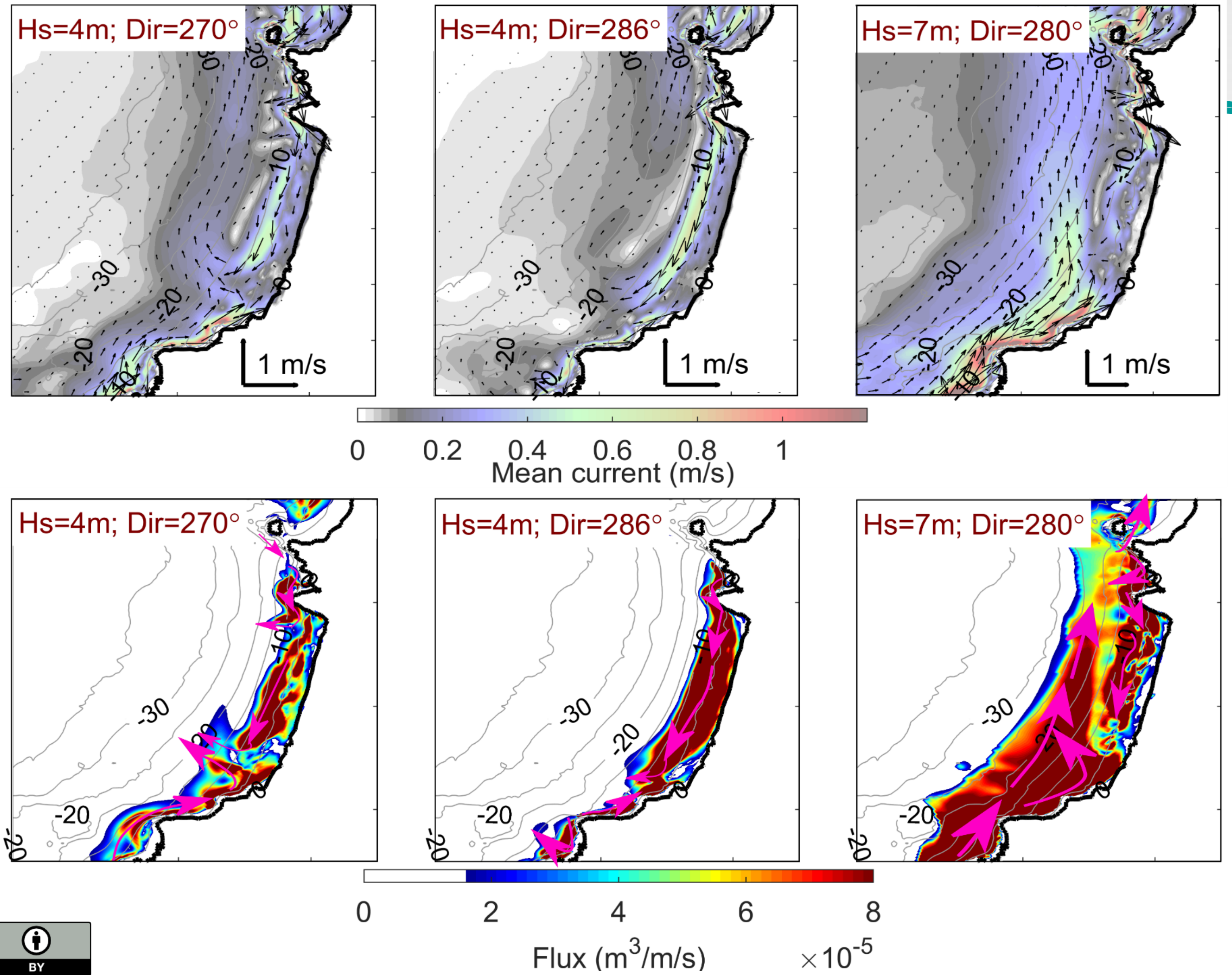
Brier Skill Score = 0.77 ('Excellent')

Results: circulation and sediment fluxes during major modes



(H_s = 4m; Dir = 270°)

- Clockwise embayment-scale circulation.
- Along-coast N current diverted offshore by S flow from up-wave headland.

(H_s = 4m; Dir = 286°)

- Clockwise embayment- scale circulation.
- Intra-embayment southward current.
- Weak N residual bypass fluxes to north.

(H_s = 7m; Dir = 280°)

- Multi-embayment circulation.
- Large N down-wave headland flow (> 1 m s^{-1}) to mega-rip: cross-embayment bypass up to >20 m depth.

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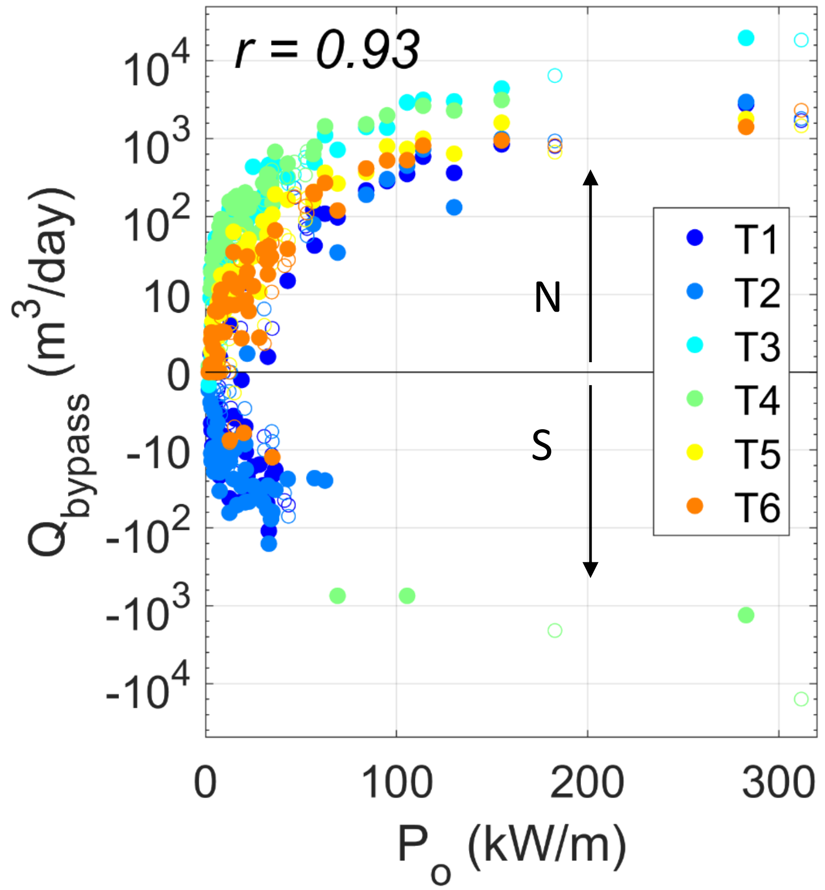
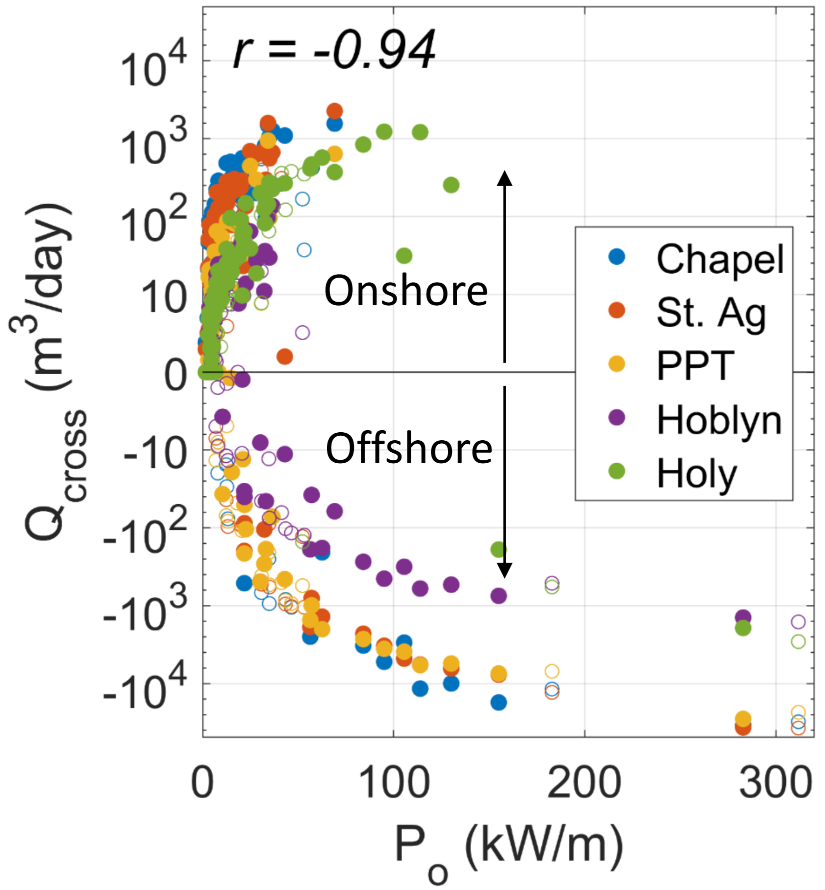
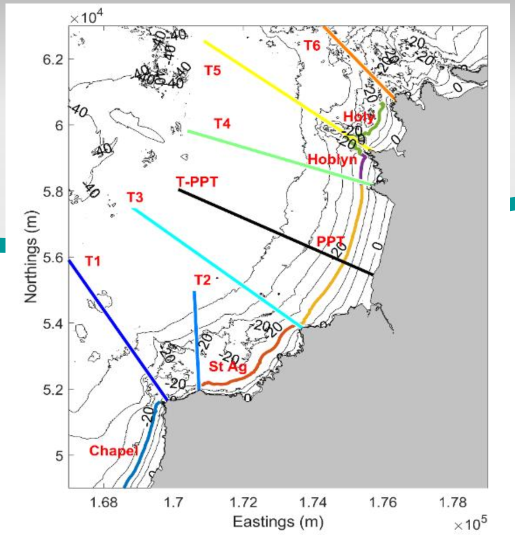
Results: daily bypassing rates







- Minor tidal control when integrated daily.
- Episodic, significant for large events
- Max. longshore O.10^4 m^3/day
- Longshore tte mostly northward except P_0<70-80 kW/m
- Cross-shore tte always offshore for P_0>120 kW/m
- Q_{bypass} correlated to offshore wave power, P_0 ($r > 0.92$).
- Q_{bypass} adjusted to second order linear polynomial model.

$$\boxed{Q_{bypass}(m^3/day) = aP_o^2 + bP_o + c}$$

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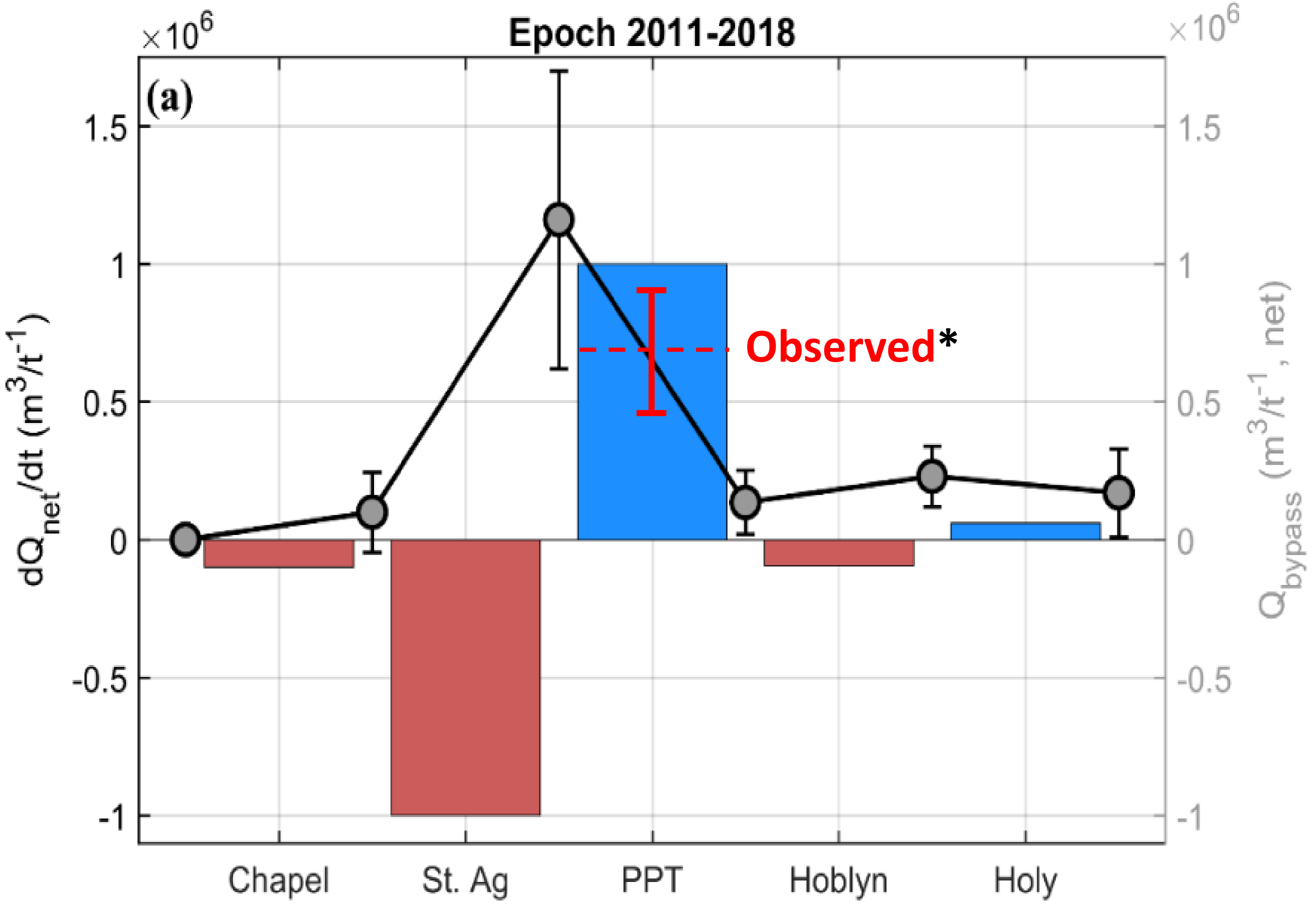
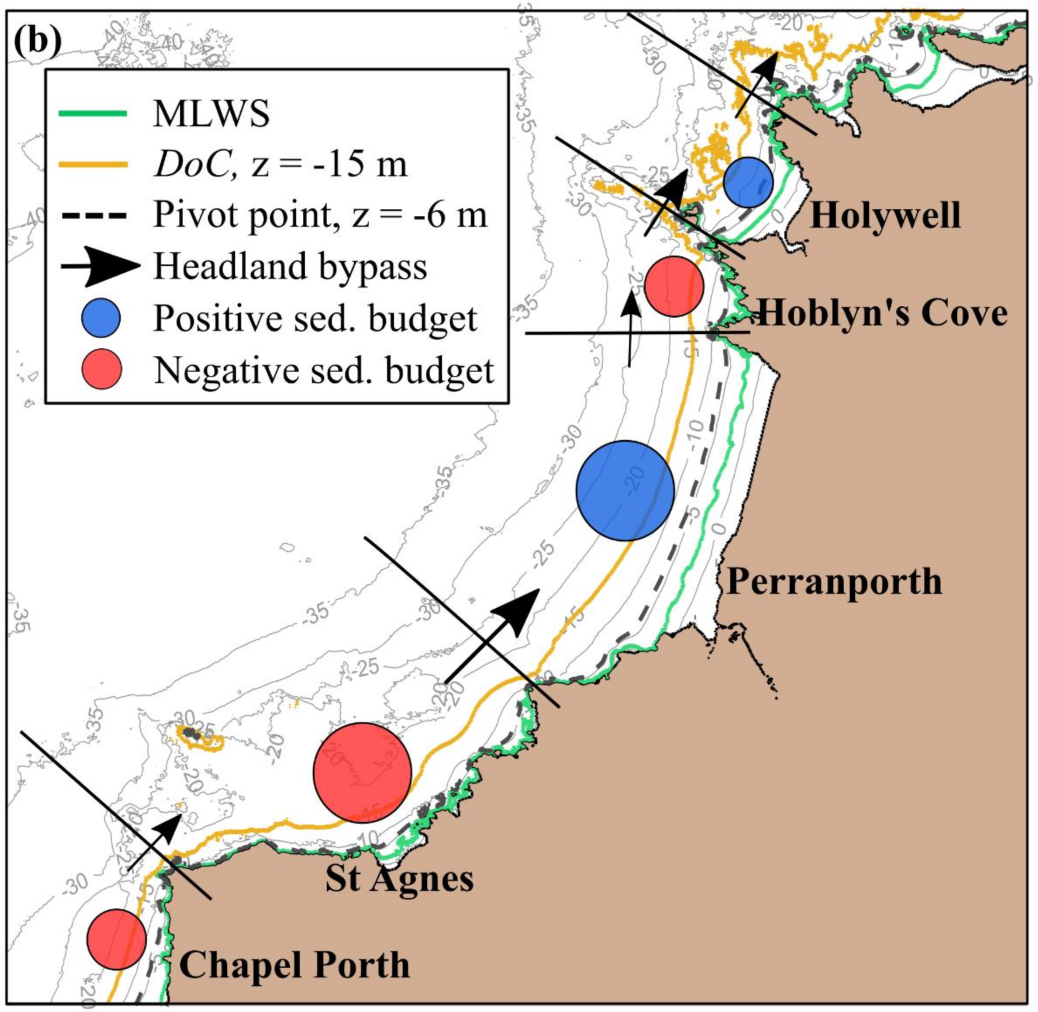
Prediction of bypassing rates and potential sediment budgets

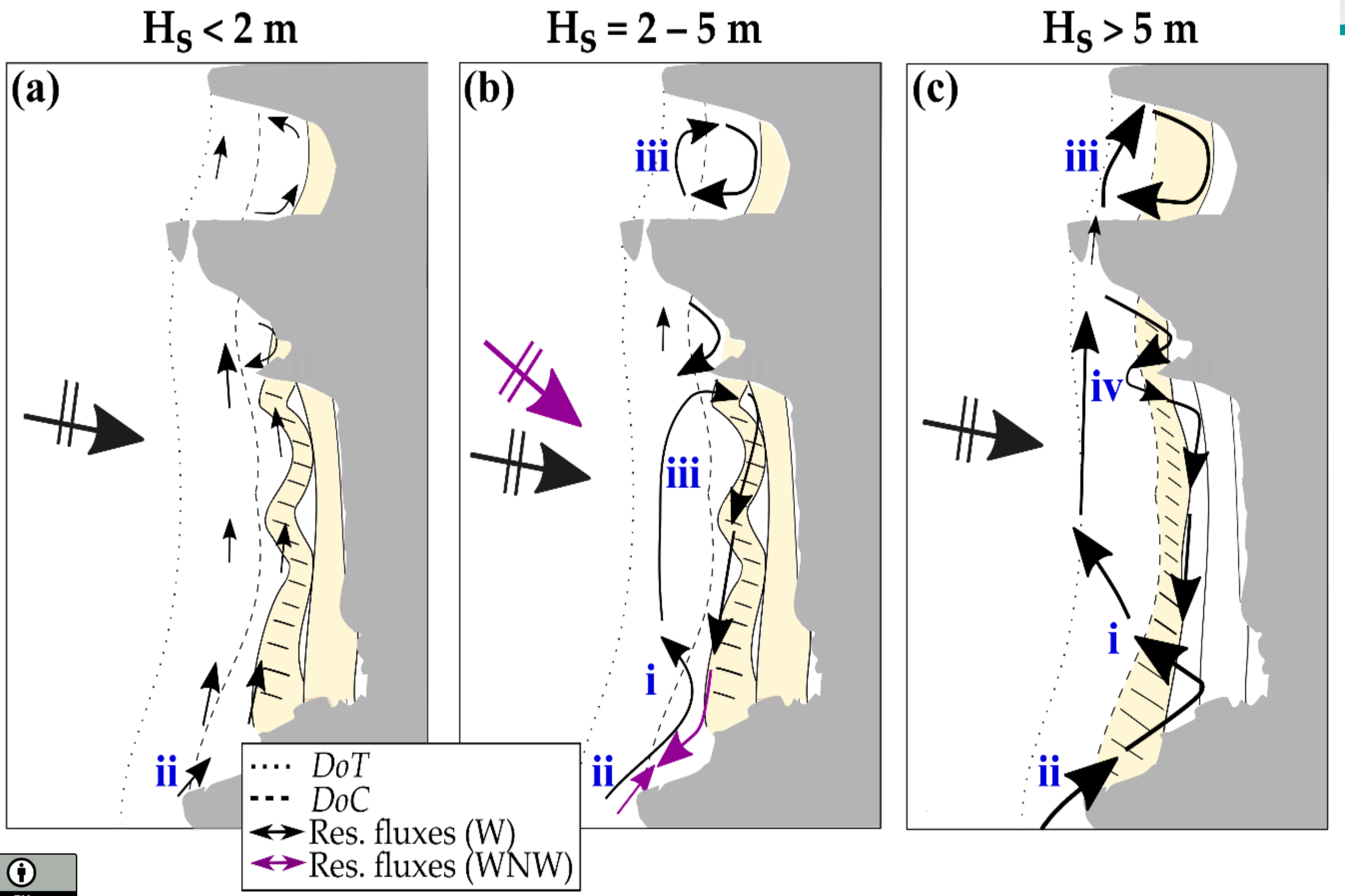
Potential sediment budget under model assumptions of unlimited sediment supply and uniform sediment size.





*Budget based on morphological change and uncertainty analysis

Conceptual model of nearshore sediment transport pathways



*N flow along the lower shoreface during mild conditions

(i) Mega-rip formation

(ii) Headland bypass (northward)

(iii) Clockwise embayment-scale circulation

(iv) Multi-embayment circulation and subsequent headland bypass (southward)

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Conclusions

- Extreme events involve **multi-embayment circulation**, **mega-rip formation** in the down-wave sectors and cross-shore **exchanges extending** to depths that exceed **the base of the headlands** (> $3x10^4$ m^3 day^{-1}) .

- Accretionary phases over moderate-high swell periods are associated with **clockwise intra-embayment circulation** with predicted currents inducing redistribution in the long embayments (> 10^3 m^3 day^{-1}) towards the south. This is **combined with significant bypassing rates** around the shallower and wider headlands (10^2 – 10^3 m^3 day^{-1}) .

- The **magnitude** of the hidcasted bypass (10^3 – 10^5 m^3 y^{-1}) will inevitably **affect coastal evolution** of rocky coastlines over **longer temporal scales** (> 10 years).

- Magnitude of **sub-tidal** bypassing indicates substantial **interconnectivity between cells** previously thought limited to cross-shore oscillations.

- It is possible that this transport **system extends along the whole north coast** of SW England, leading to a shift in understanding of sediment budgets along exposed and macrotidal embayments globally.

N.G. Valiente, G. Masselink, R.J. McCarroll, T. Scott, D. Conley, E. King, 2020. Nearshore sediment pathways and potential sediment budgets in embayed settings over a multi-annual timescale, *Marine Geology* (under review).

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