Boundary fluxes to and from the shelf

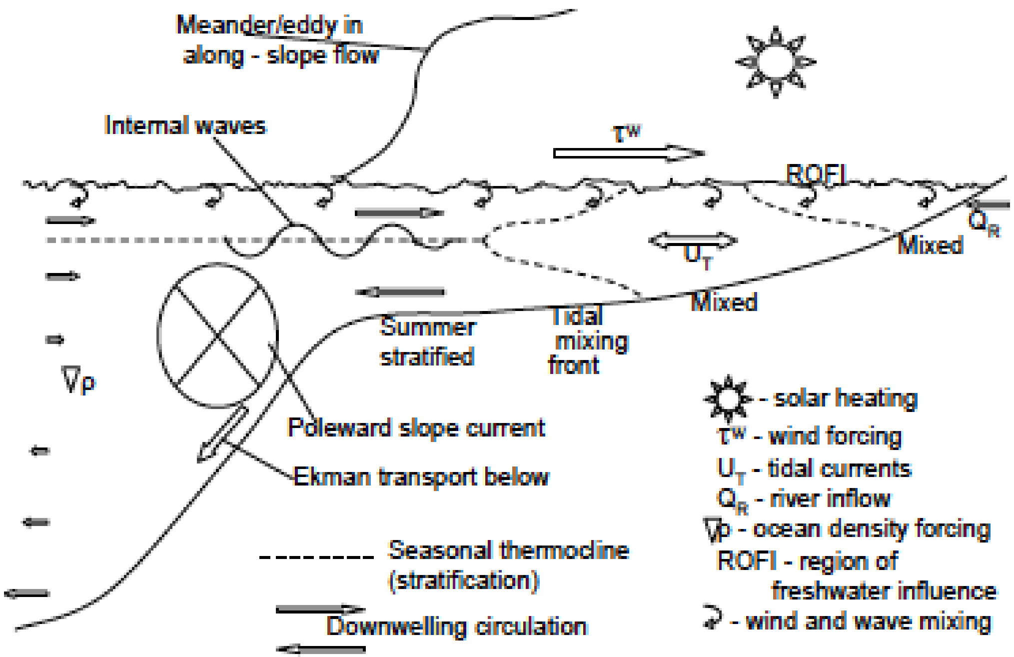
Vertical and cross-shelf perspectives

Matthew Palmer and Jo Hopkins

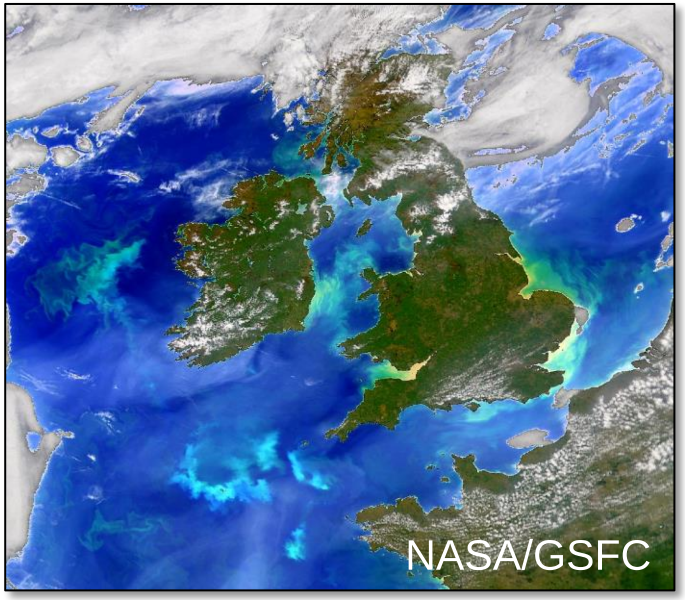
On behalf of WP1 team

Vertical and horizontal fluxes in a shelf sea

Ocean-atmosphere exchange
Cross pycnocline fluxes
Shelf-wide circulation and transport
Localised shelf-edge exchanges



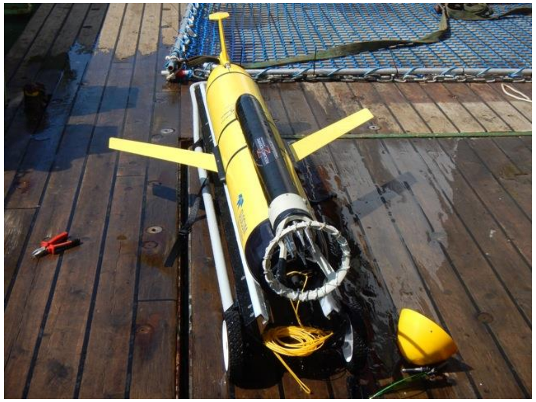
Huthnance (2009)

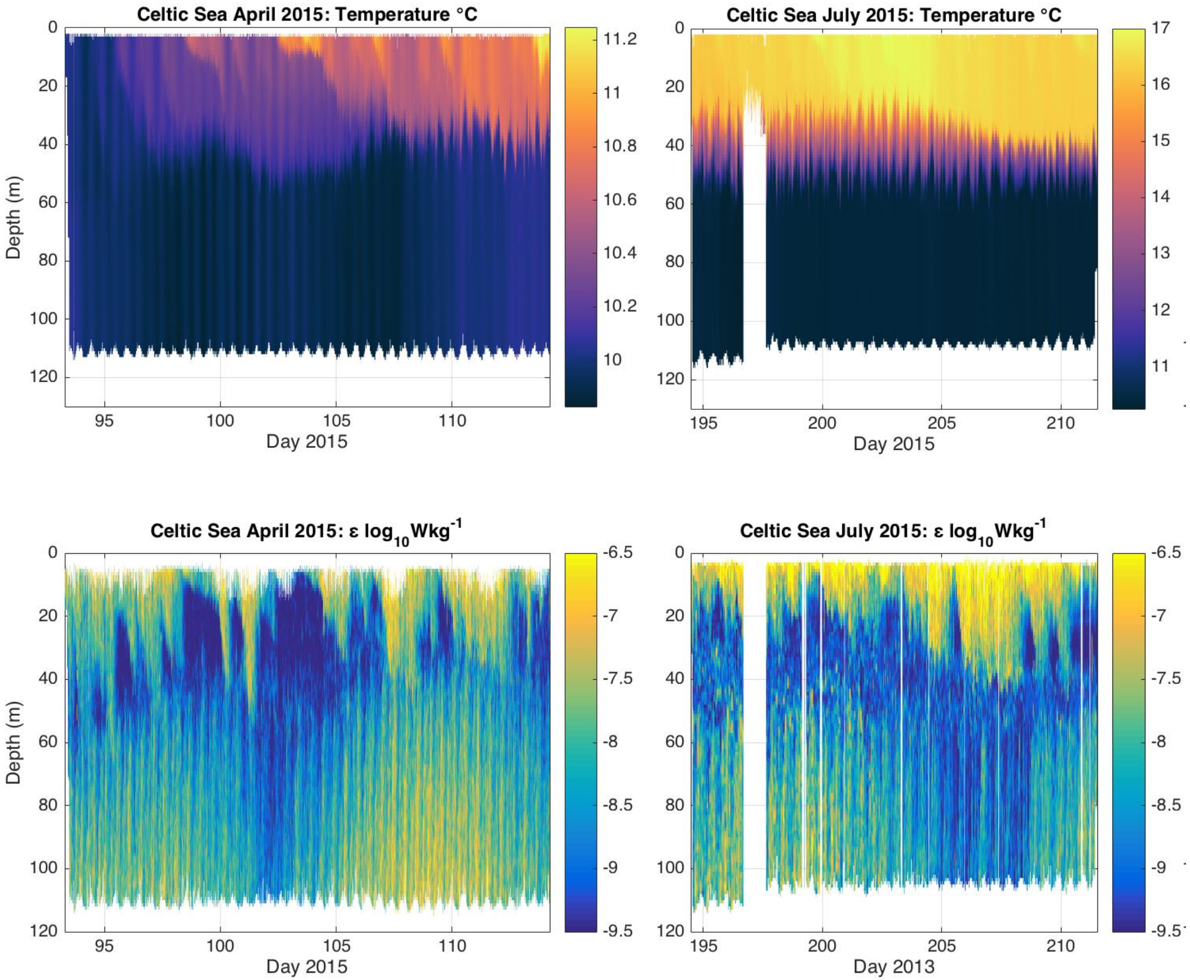


mm to 10s km
Seconds to months
Vertical vs. horizontal

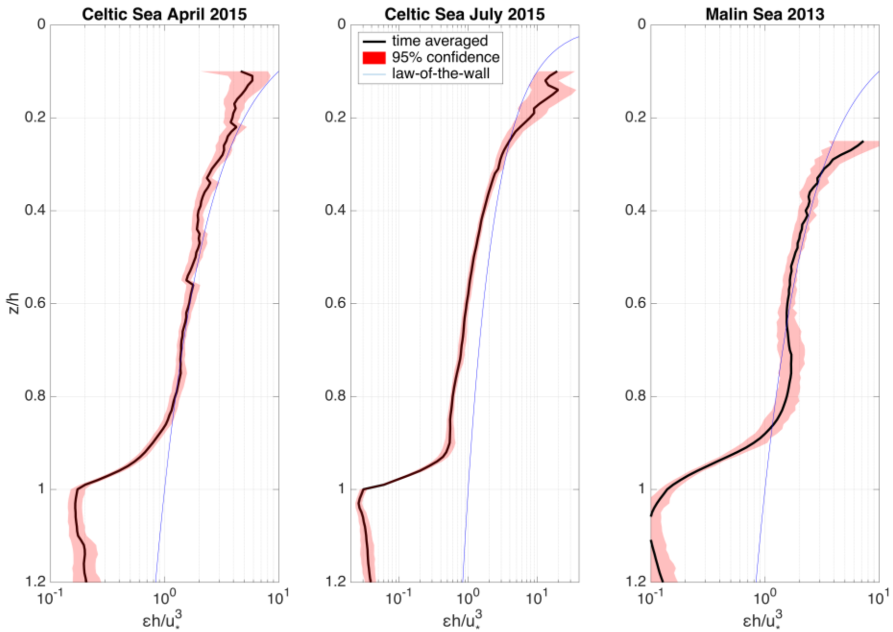
Fine-scale measurements of ocean structure and turbulent mixing from the Ocean Microstructure Glider:

- 37 days of turbulence profiling
- 3163 individual profiles or T, S, ε and O_2 during spring and summer periods





Improving our understanding of air-sea interactions:

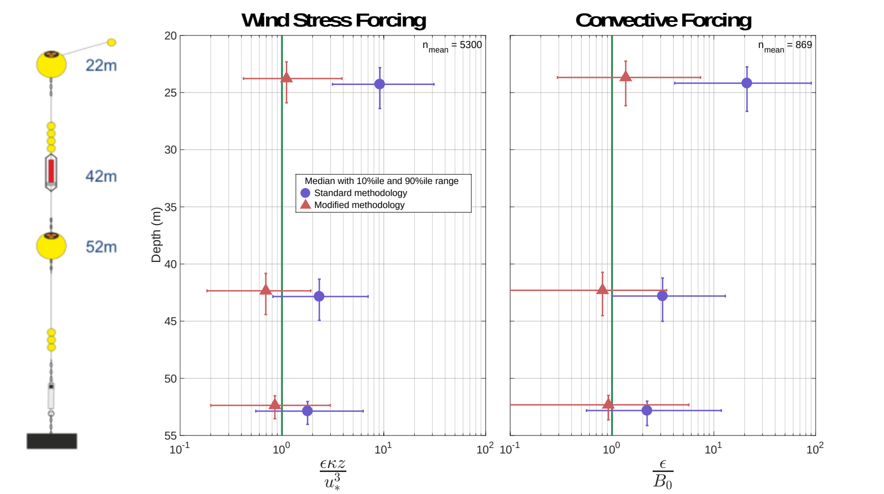


- Combined OMG data from FASTNEt and SSB shows the upper ocean mixing to be largely controlled by a balance between wind and buoyancy.
- OMG data confirms that over the region of active mixing, a law-of-the-wall scaling is effective for over 90% of the time.
- ADCPs provide potential for seasonal coverage of turbulent forcing

Ocean surface boundary layer turbulence is therefore predictable

length scale: $L_{Ob} = {}^{U_*}/_{kB_S}$

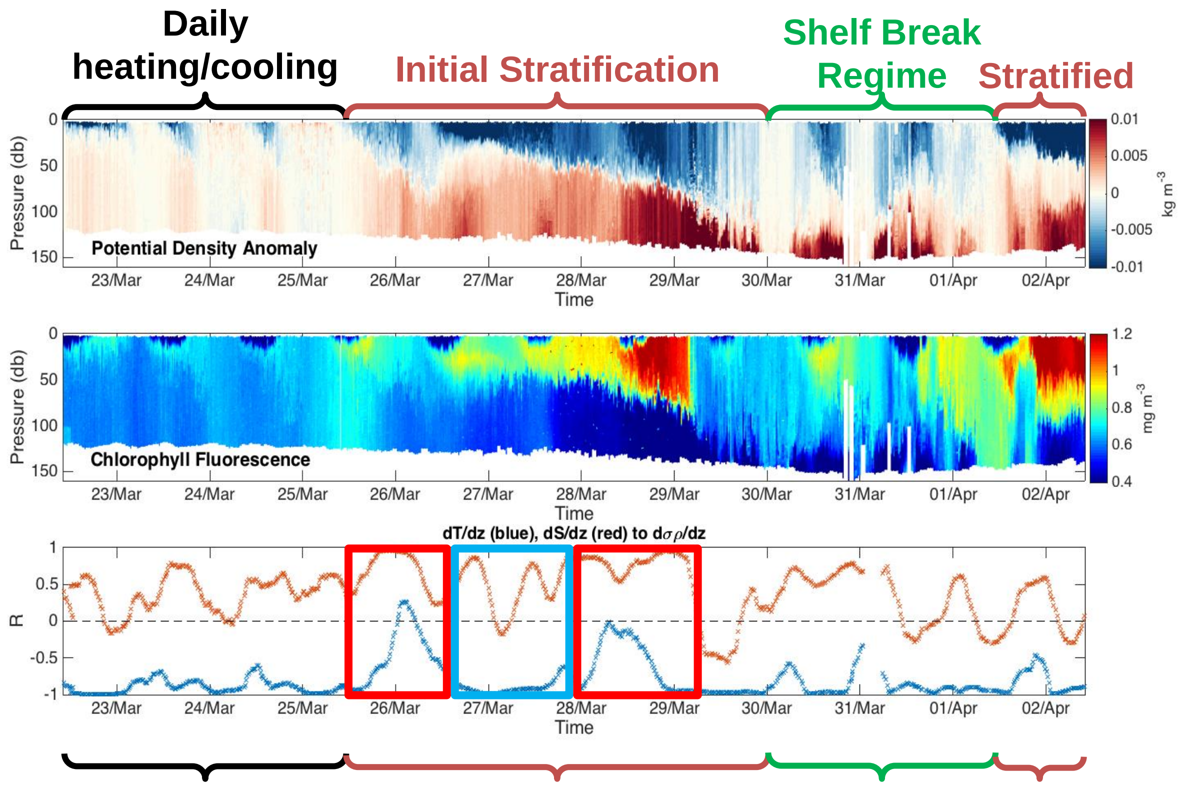
and energy levels: $\varepsilon_{OSBL} = {}^{U_*^3}/_{k*L_{OB}}$

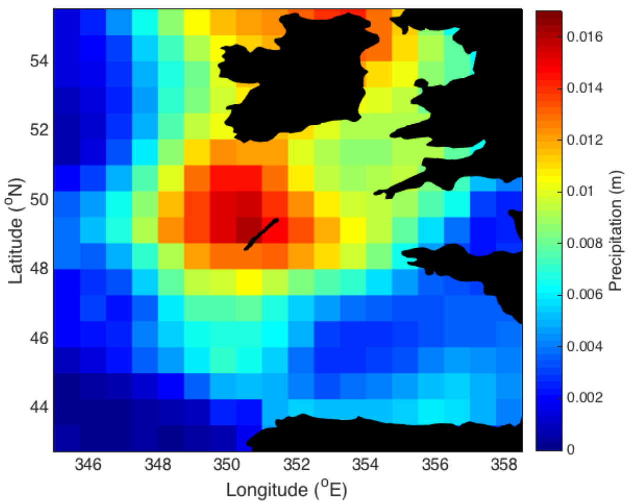


Brian Scannell

The role of precipitation in initiation of seasonal stratification?

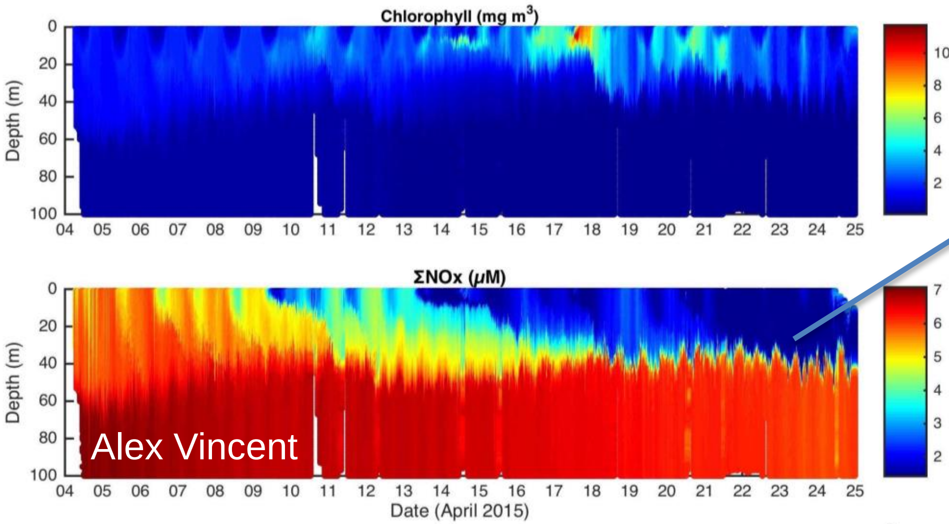
There is a noticeable switch between dominant **salinity** and **temperature** controls on stratification but the initial sustained stratification period is mostly controlled by **salinity**





Jenny Jardine j.jardine@liv.ac.uk

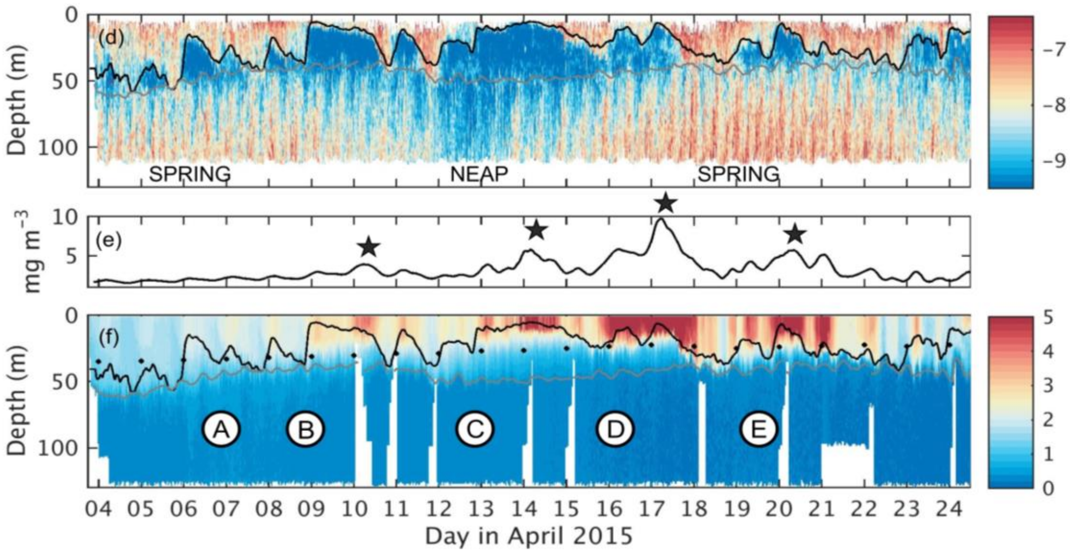
Calculating vertical internal fluxes to understand biogeochemical cycles



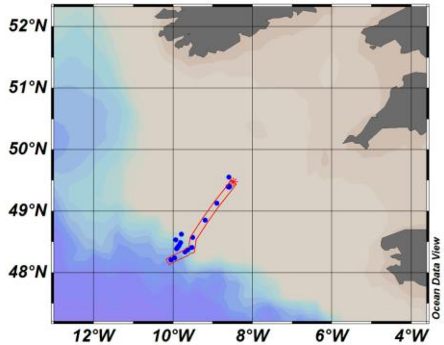
Turbulent mixing estimates from the OMG enable calculation of fluxes across the stratified interior to constrain physical and biogeochemical budgets

Top-to-bottom observations of turbulence also enable direct forcing of a bio-physical model to investigate triggers for the spring bloom.

Hopkins et al, in prep for GRL (see poster)



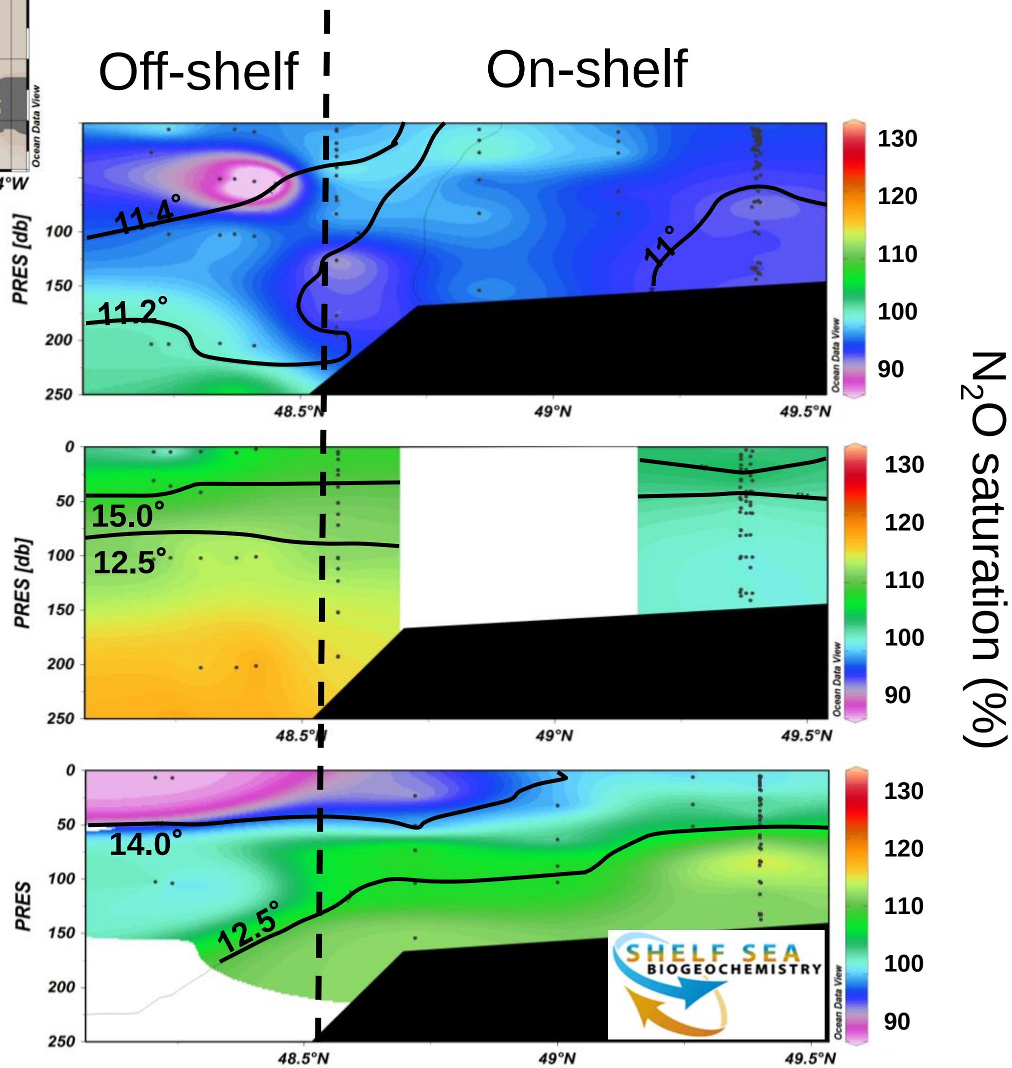
N_2O -Temporal & spatial variability



April-May

Jul-Aug

Nov-Dec



Fluxes (μmol $m^{-2}d^{-1}$)	
off-shelf	on-shelf
0.0	-0.5
+0.6	+1.2
-4.5	+0.3

Andy Rees

A simple model for predicting the active mixing layer depth?

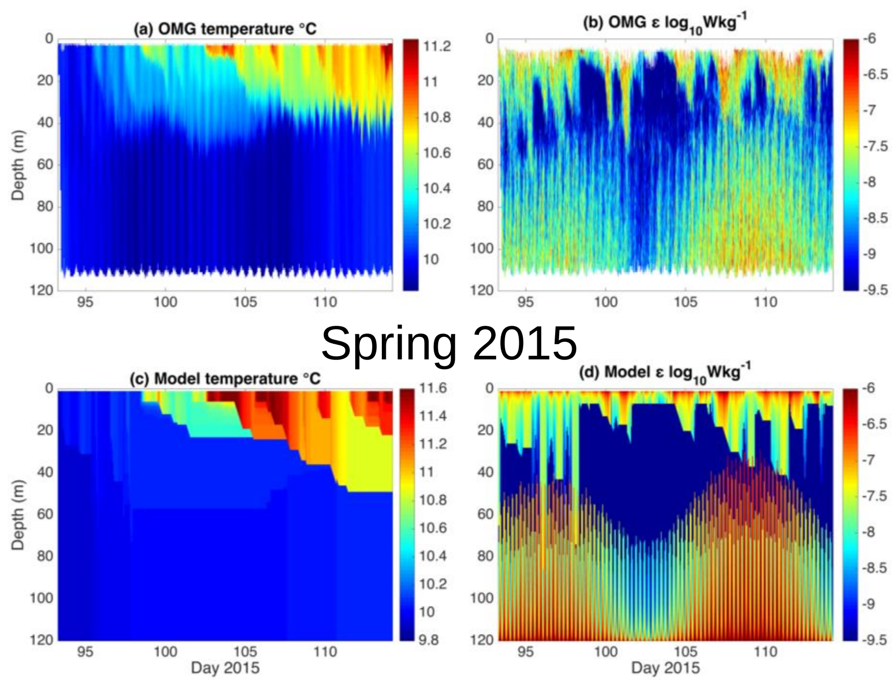
Ocean surface boundary layer turbulence

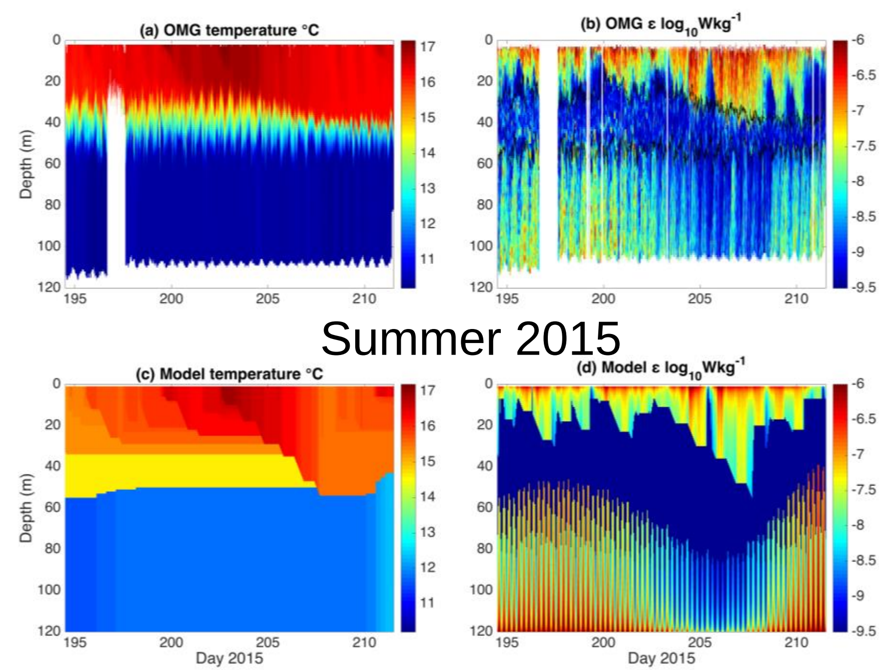
length scale: $L_{Ob} = {U_*}/{kB_S}$

and energy levels: $\varepsilon_{OSBL} = {U_*^3}/{k_* L_{OB}}$

Bottom boundary layer turbulence

$\varepsilon_{BBL} = {U^3}/{BBL}$





Summary

- We have developed new insights into atmospheric controls of winter and spring stratification and associated biogeochemical responses.

- Turbulent controls on the inner-shelf are shown to be largely 1-dimensional, controlled at the bed by tidal mixing and wind-buoyancy forcing at the surface, with only a small impact attributable to surface waves.

- Upper ocean turbulence in seasonally stratifying shelf seas is shown to be largely predictable from atmospheric inputs alone, enabling accurate estimates to be made of the active mixing layer depth (see poster by Matthew Palmer).

- Internal mixing is weak, but does play a critical role on diapycnal heat and nutrient fluxes, providing a critical control on N_20 supply to the atmosphere (see Andy Rees) and bottom layer oxygen concentration (see poster by Charlotte Williams).

- While vertical processes dominate on the shelf, horizontal process are seen to play an important role in turbulent control of physical and biogeochemical structure.

Seasonality in cross-shelf hydrography and the implications for nutrient supply

E. Ruiz, J. Sharples, J. Hopkins

The problem

- Ocean typically viewed as the primary source of nutrients to the shelf
- Mechanisms that weaken geostrophic control at the shelf break and enable local exchange are 'easy' to list, but……
- The processes that subsequently transport nutrients to the interior of a wide shelf are less well defined

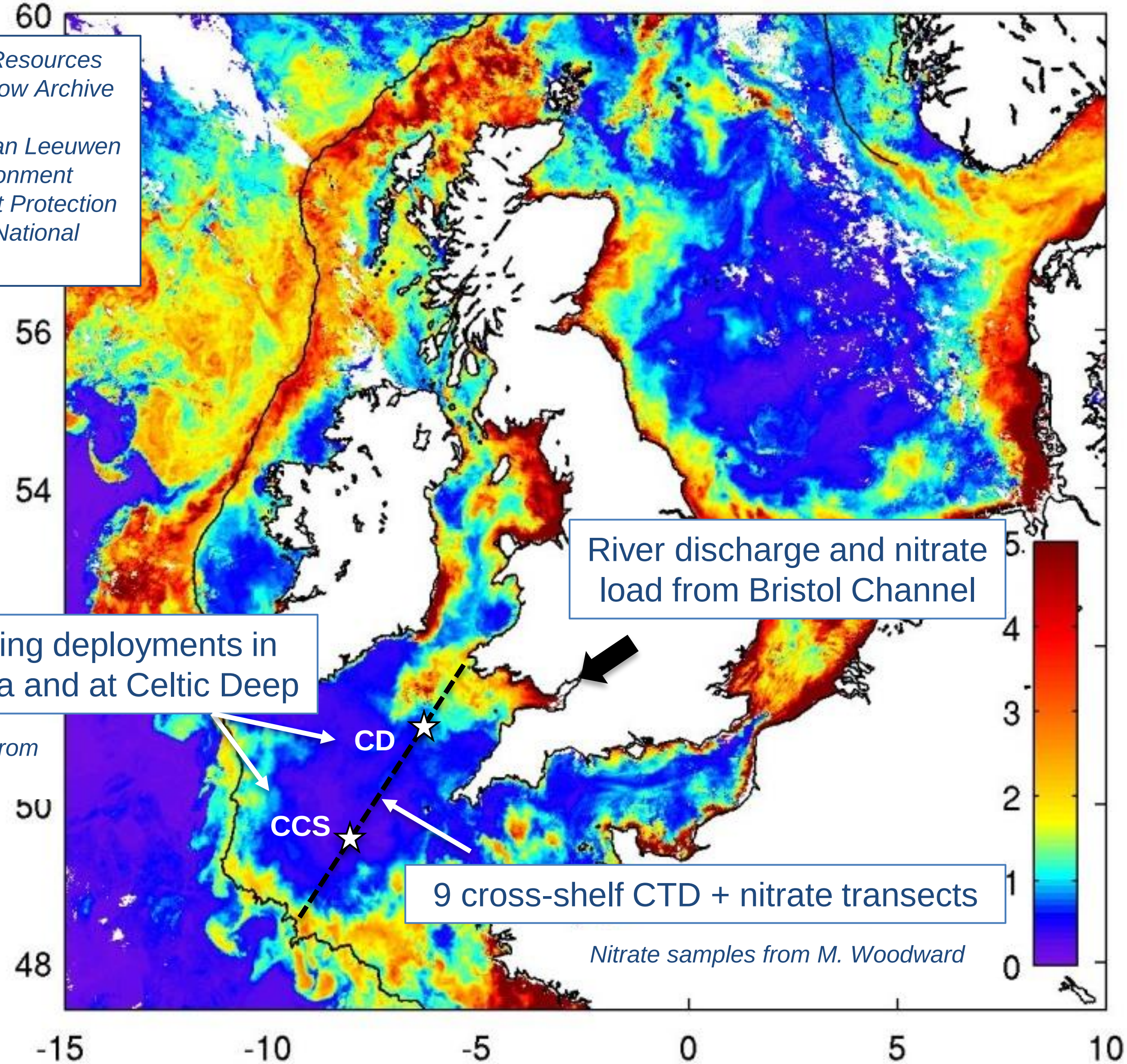
The question

How do nutrients supplied at the coastal and ocean boundaries penetrate onto the shelf to support primary production?

Data sets used

River flow data from Natural Resources Wales & the National River Flow Archive

Nitrate input provided by S. van Leeuwen (Cefas). Raw data from Environment Agency, Scottish Environment Protection Agency, Rivers Agency (NI), National River Flow Archive



17 month mooring deployments in central Celtic Sea and at Celtic Deep

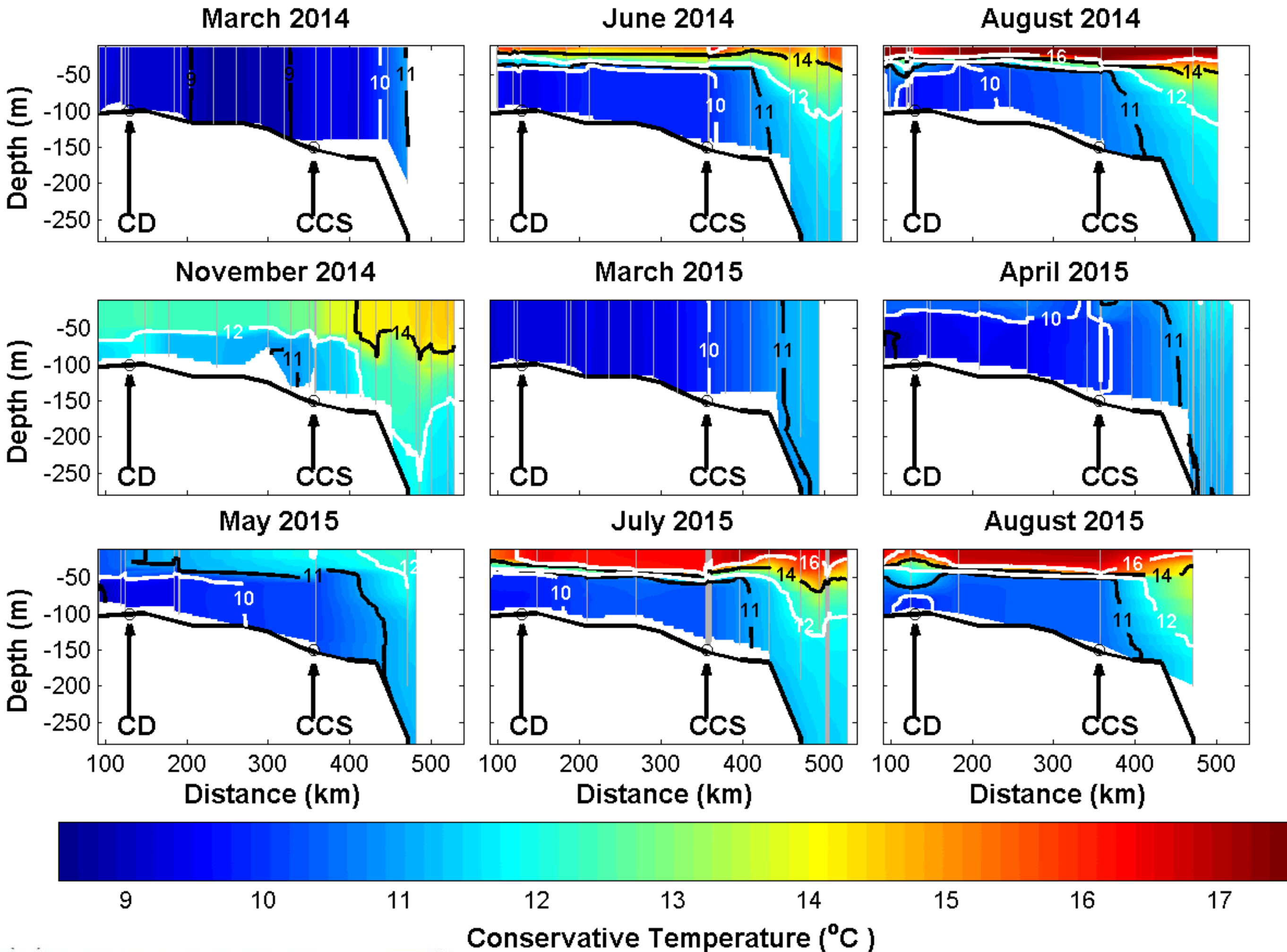
CD & CCS time series from T. Hull & J. Wihsgott

River discharge and nitrate load from Bristol Channel

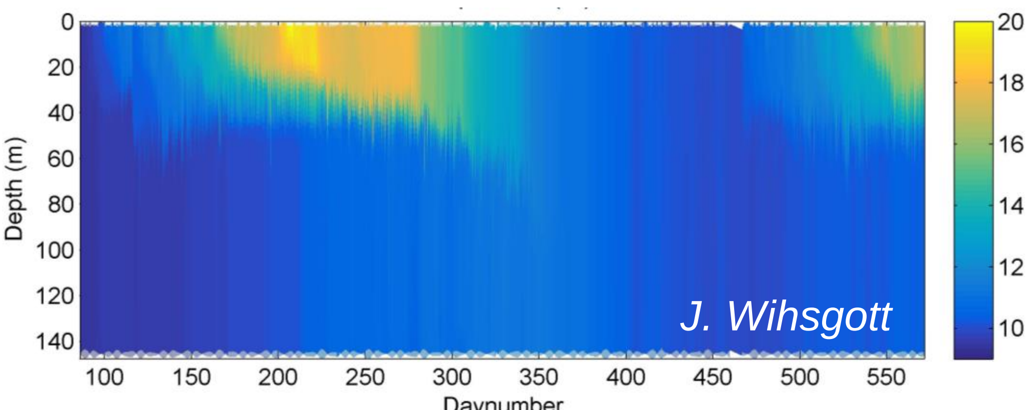
9 cross-shelf CTD + nitrate transects

Nitrate samples from M. Woodward

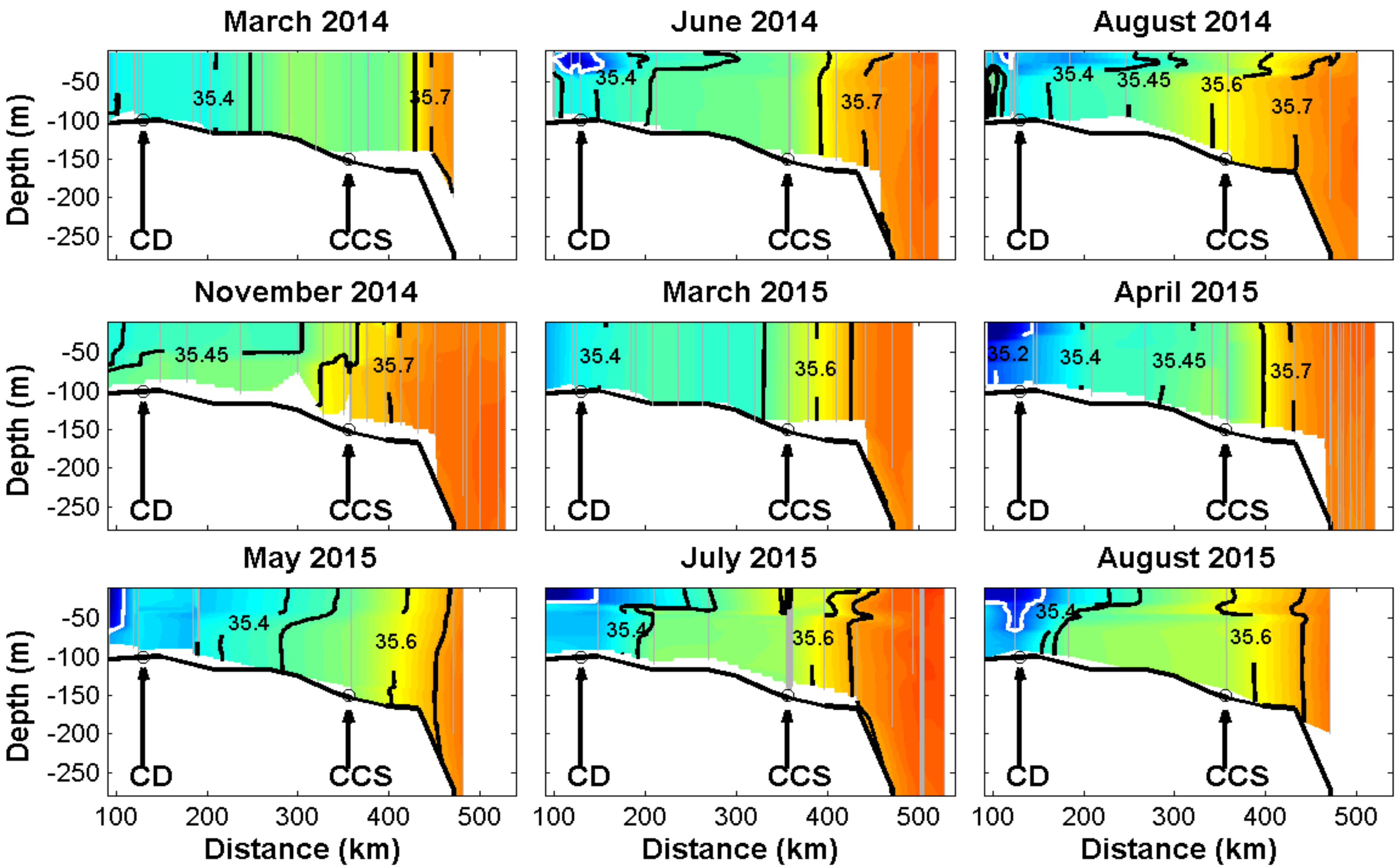
Conventional thermal perspective



Temperature at CCS



Salinity structure

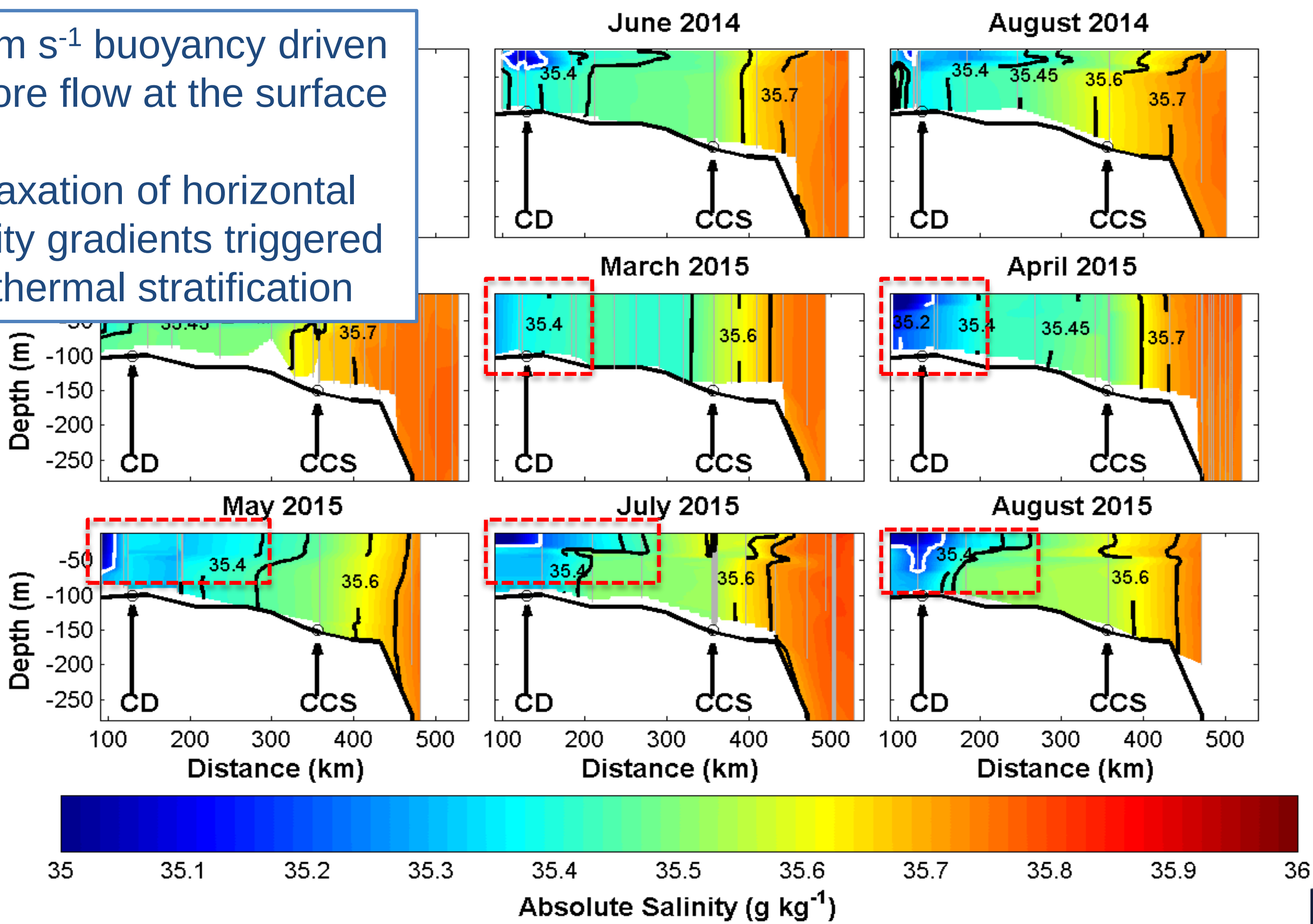


(1) Low salinity surface plume
(2) On-shelf intrusion of saline bottom water

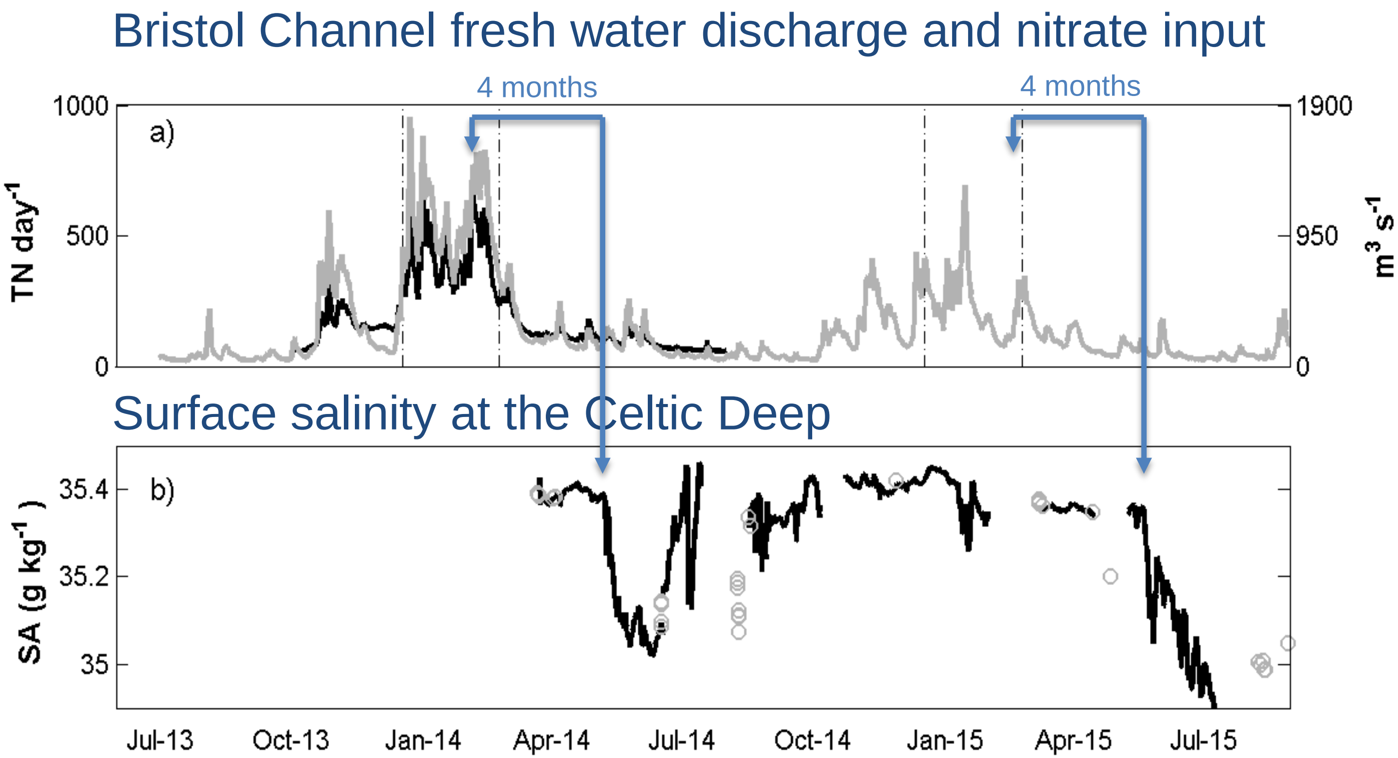
(1) Low salinity plume in the northern Celtic Sea

1-4 cm s^{-1} buoyancy driven offshore flow at the surface

Relaxation of horizontal density gradients triggered by thermal stratification



(1) Low salinity plume in the northern Celtic Sea

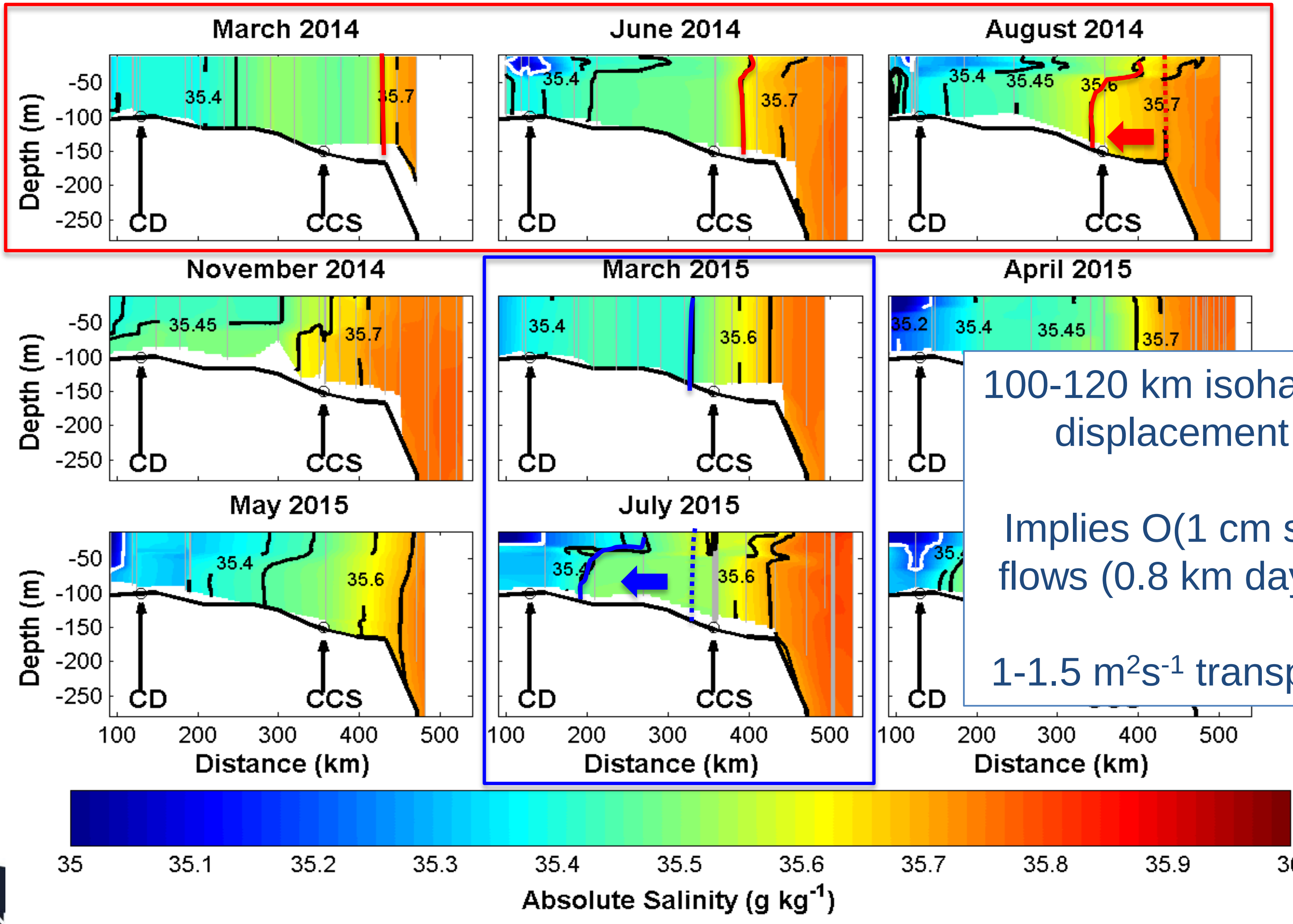


- Winter fresh water nitrate concentration of 500 mmol m^{-3}
- 4 months for peak fresh water discharge to reach CD
- 30 % nitrogen removal in 4 months
- Fresh water fraction of 0.8 % at the Celtic Deep

40% of the nitrate observed in spring at the Celtic Deep is from the river

(10 % at CCS)

(2) On-shelf bottom water flows



100-120 km isohaline displacement

Implies O(1 cm s^{-1}) flows (0.8 km day^{-1})

1-1.5 $m^2 s^{-1}$ transport

(2) On-shelf bottom water flows

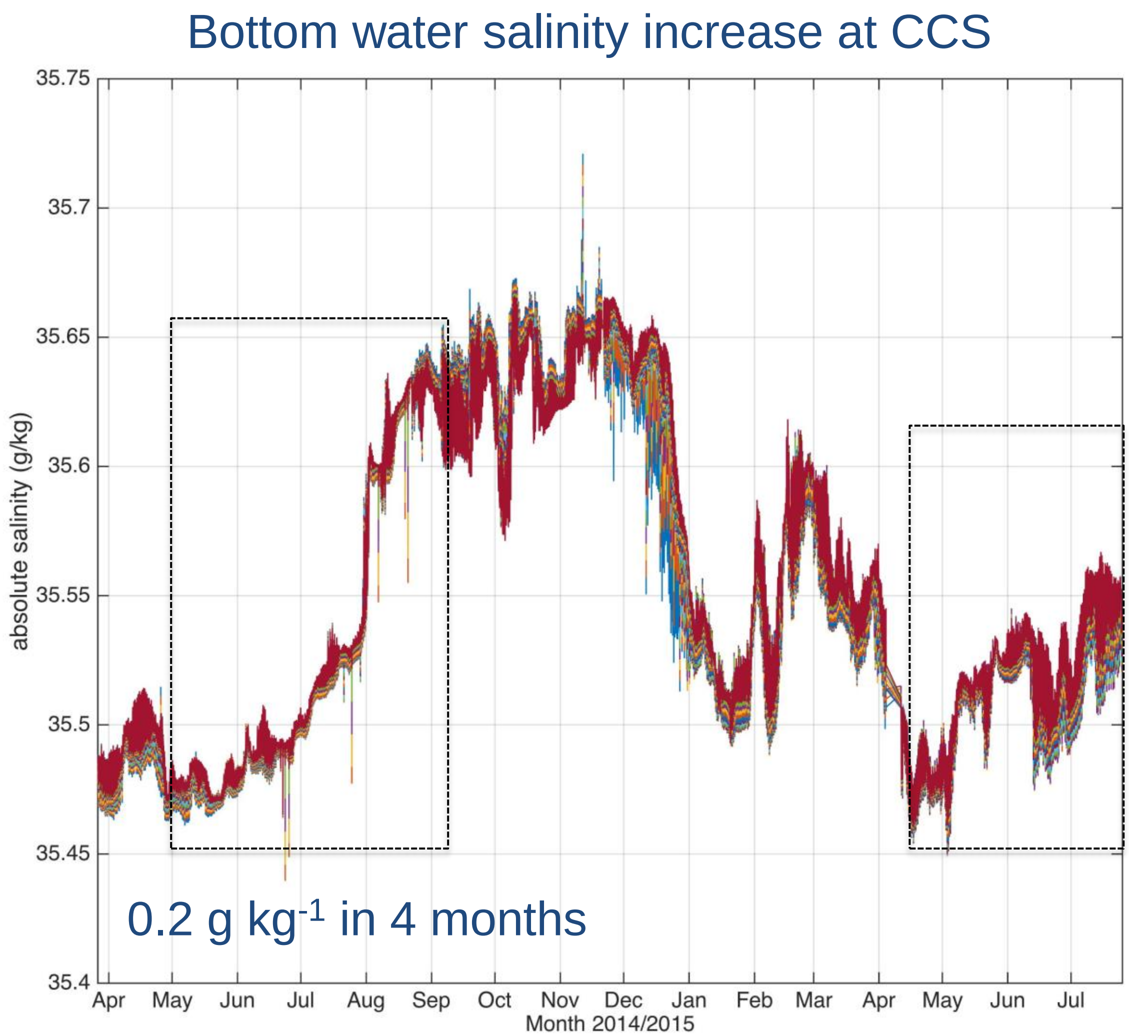
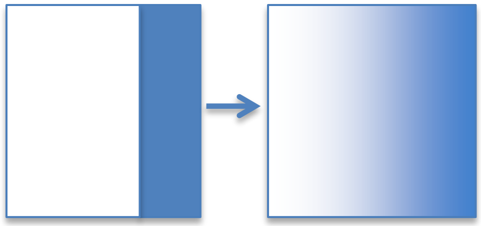


Figure from J. Wihsgott

(2) On-shelf bottom water flows

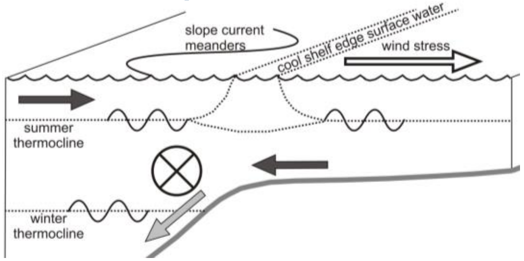
How to maintain a persistent 1-1.5 m^2s^{-1} transport across 100 km of shelf?

Horizontal dispersion?



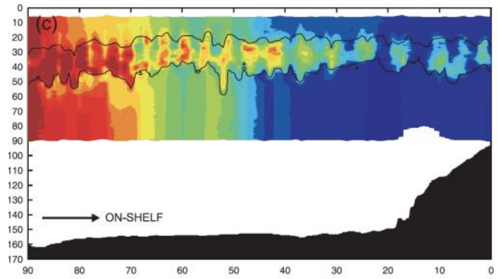
Too slow
100 km in > 1 year

Compensation for surface Ekman transport?



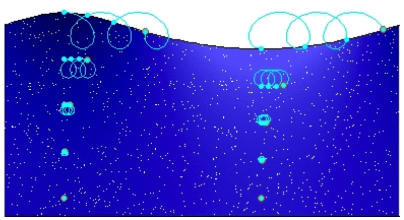
Wrong direction, off-shelf

Non-linear internal waves?



~0.6 m^2s^{-1}
Patchy, upper limit

Internal tide stokes drift?



~1 m^2s^{-1}
Upper limit

(2) On-shelf bottom water flows

How to maintain a persistent 1-1.5 $m^2 s^{-1}$ transport across 100 km of shelf?

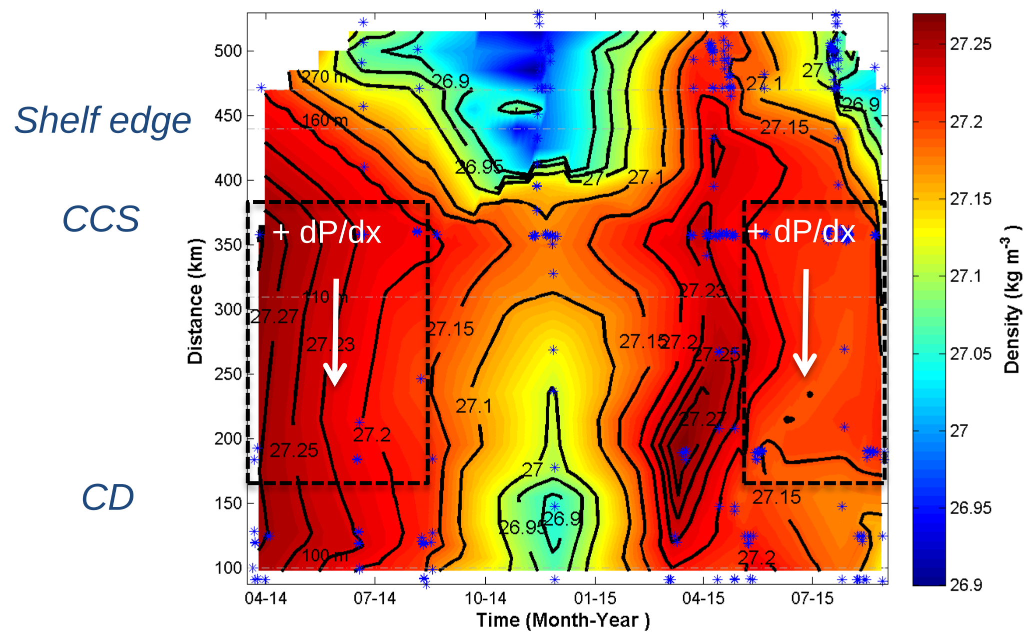
Pressure gradient flow ?

Cross-shelf density gradient set up by salinity and modified by seasonal temperature structure

Spring-Summer positive (on-shelf) pressure gradient over central shelf

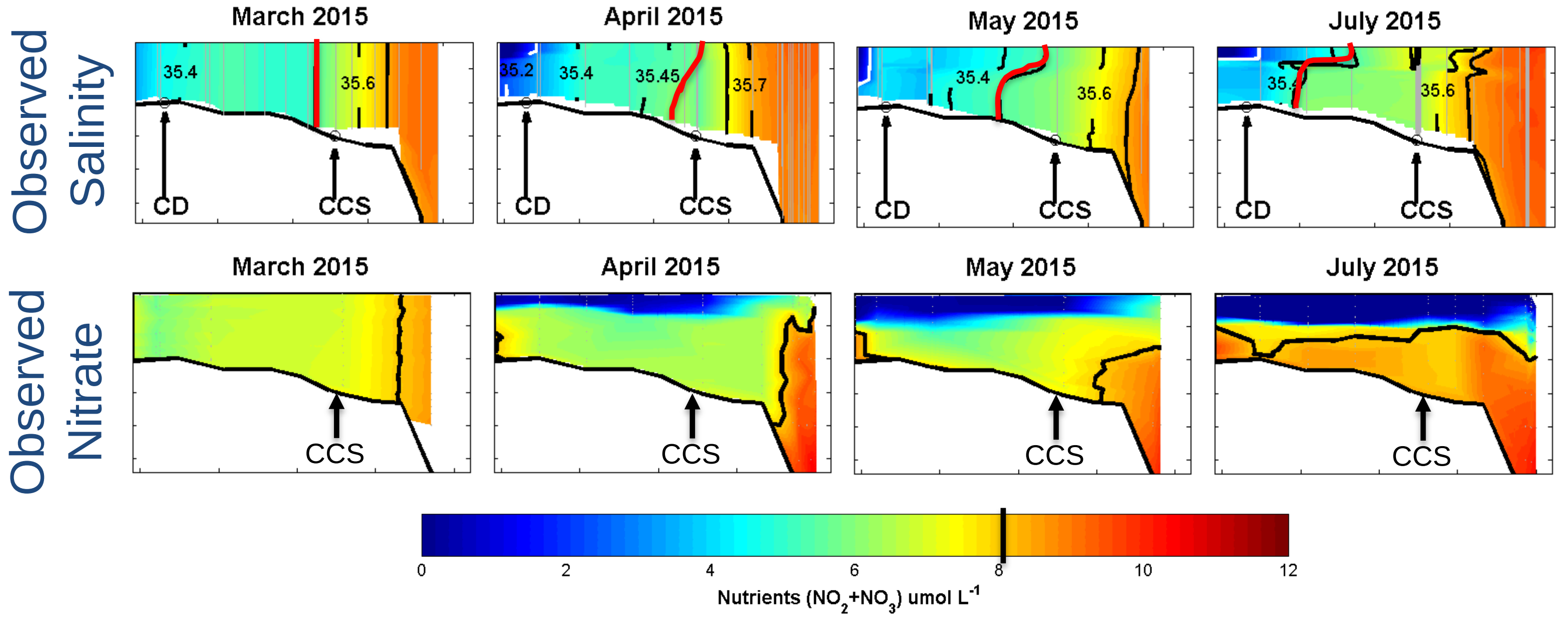
On-shelf bottom boundary layer transport of 1.6 $m^2 s^{-1}$

Bottom water density



Persistence, length and timescales fit with the observed isohaline displacements and salinity changes

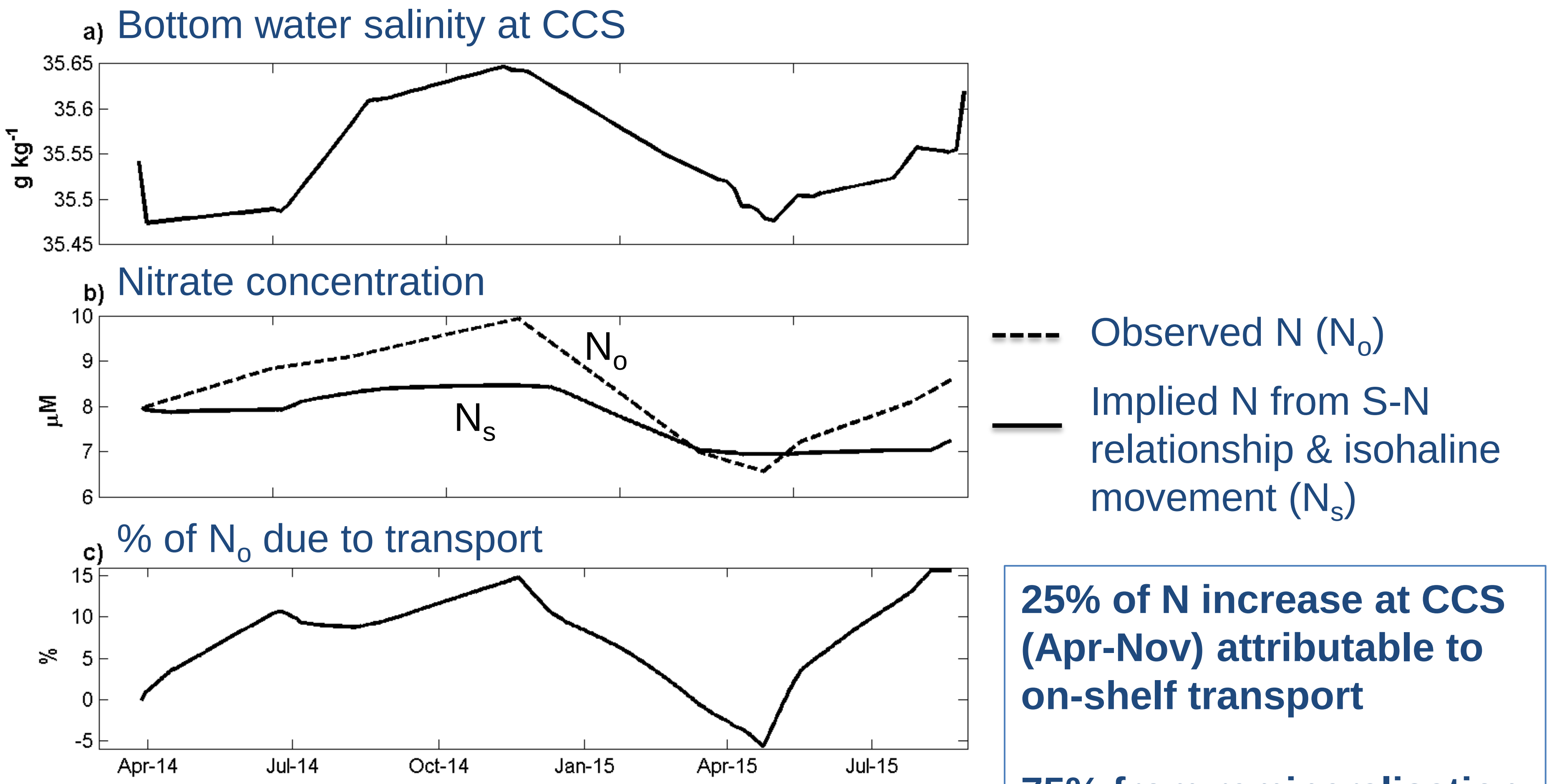
(2) On-shelf bottom water flows



Nutrient supply to the inner shelf?

- Assume conservative nitrate-salinity relationship in March
- Predict transport of nitrate on-shelf in bottom waters based on isohaline displacement
- Differences between this prediction and observed values attributed to remineralisation

(2) On-shelf bottom water flows



25% of N increase at CCS (Apr-Nov) attributable to on-shelf transport

75% from remineralisation

Summary

Salinity gradients matter

Riverine supply of nutrients to inner shelf minimal (10% at CCS)

Northern Celtic Sea benefits more (40% Celtic Deep)

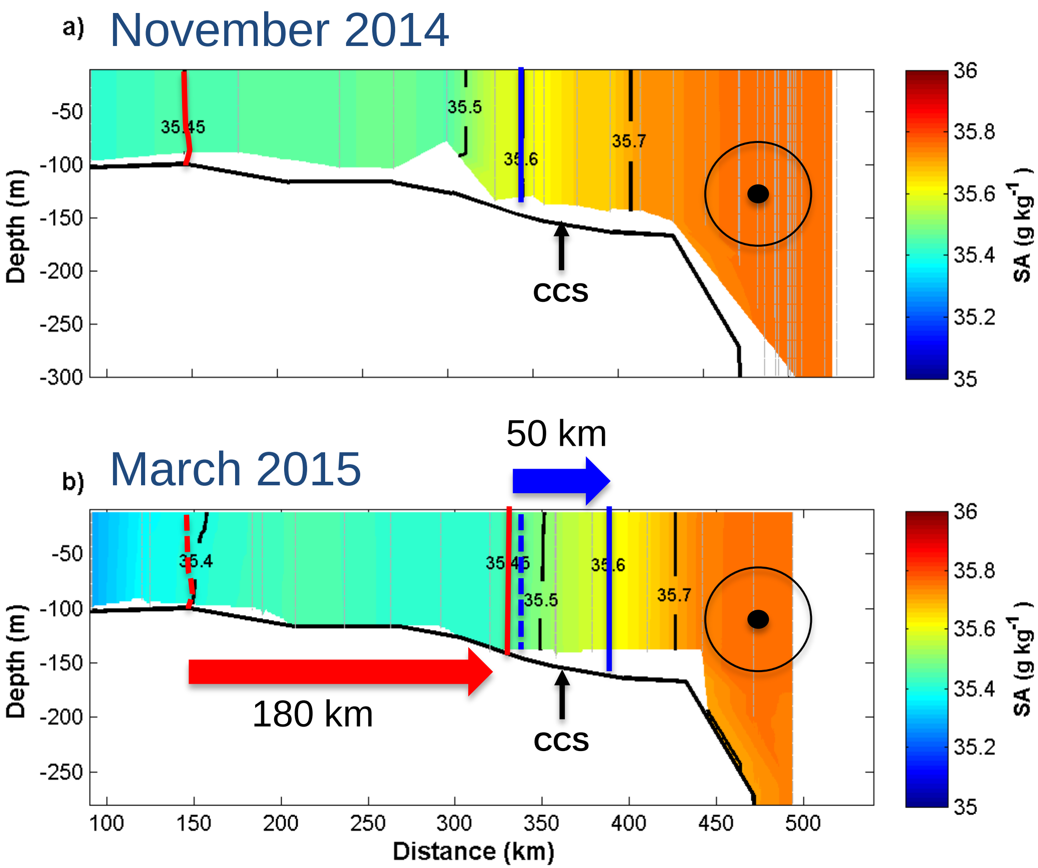
Density driven shelf-wide circulation supplies nutrients to the inner shelf

Nutrients available to each years spring bloom in the central shelf are a combination of ocean-supplied (25%) and recycled material (75%) from the previous year

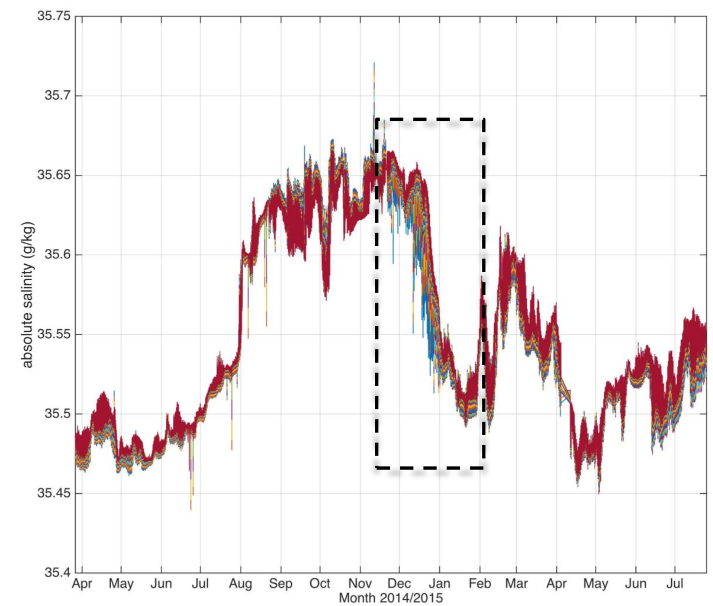
Also…evidence of density gradients to drive off-shelf transport (important for carbon export)..but that's another talk……

See Ruiz et al, in prep for Prog. Oceanog.

Off-shelf transport over winter



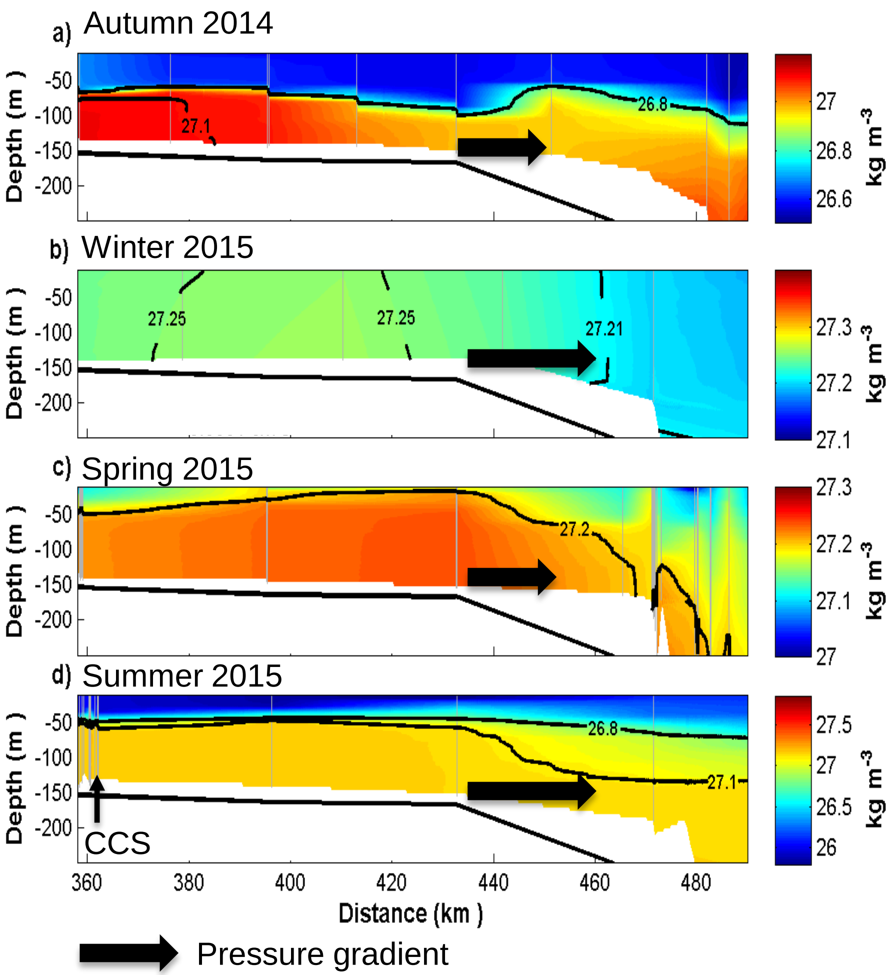
Bottom water salinity decrease at CCS



March pressure gradient towards shelf edge, set up by winter cooling over the shallow shelf, drives off-shelf transport

Off-shelf flow at the shelf edge

Shelf-edge density & pressure gradients



Year round pressure gradient at the shelf-edge conducive to off-shelf flow

Ekman drainage would then help draw water into the deeper ocean

Potential to export carbon from phytoplankton growing at the shelf edge, especially in the summer