Proudman Oceanographic Laboratory
NATURAL ENVIRONMENT RESEARCH COUNCIL

Modelling the carbon fluxes and budgets on the northwest European continental shelf…and beyond

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CASIX

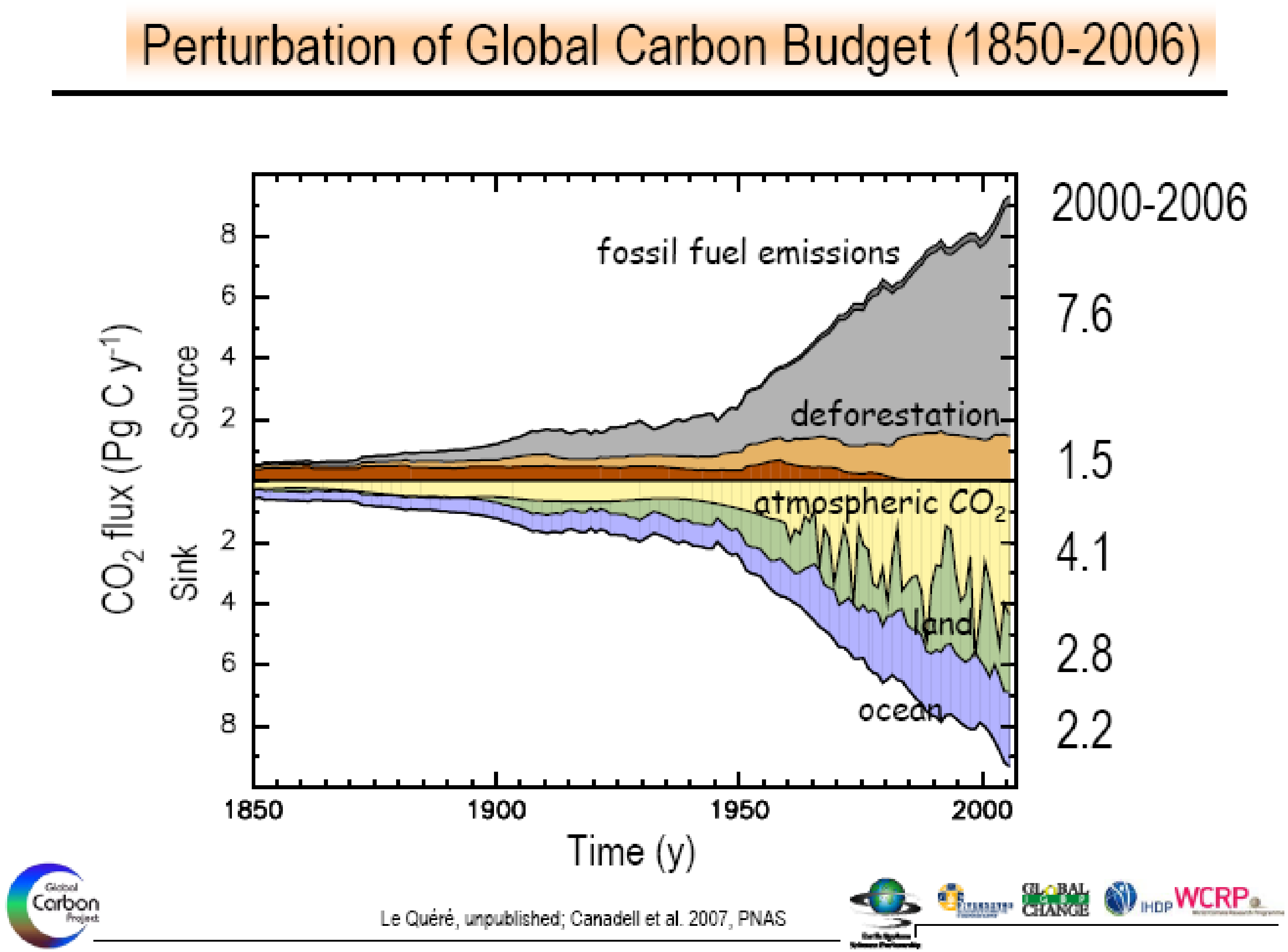
GCOMS

QUEST Quantifying and Understanding the Earth System

www.pol.ac.uk

- The global carbon budget
- The NW European shelf carbon budget
- Ocean-Shelf carbon fluxes
- Shelf sea’s contribution to the global budget

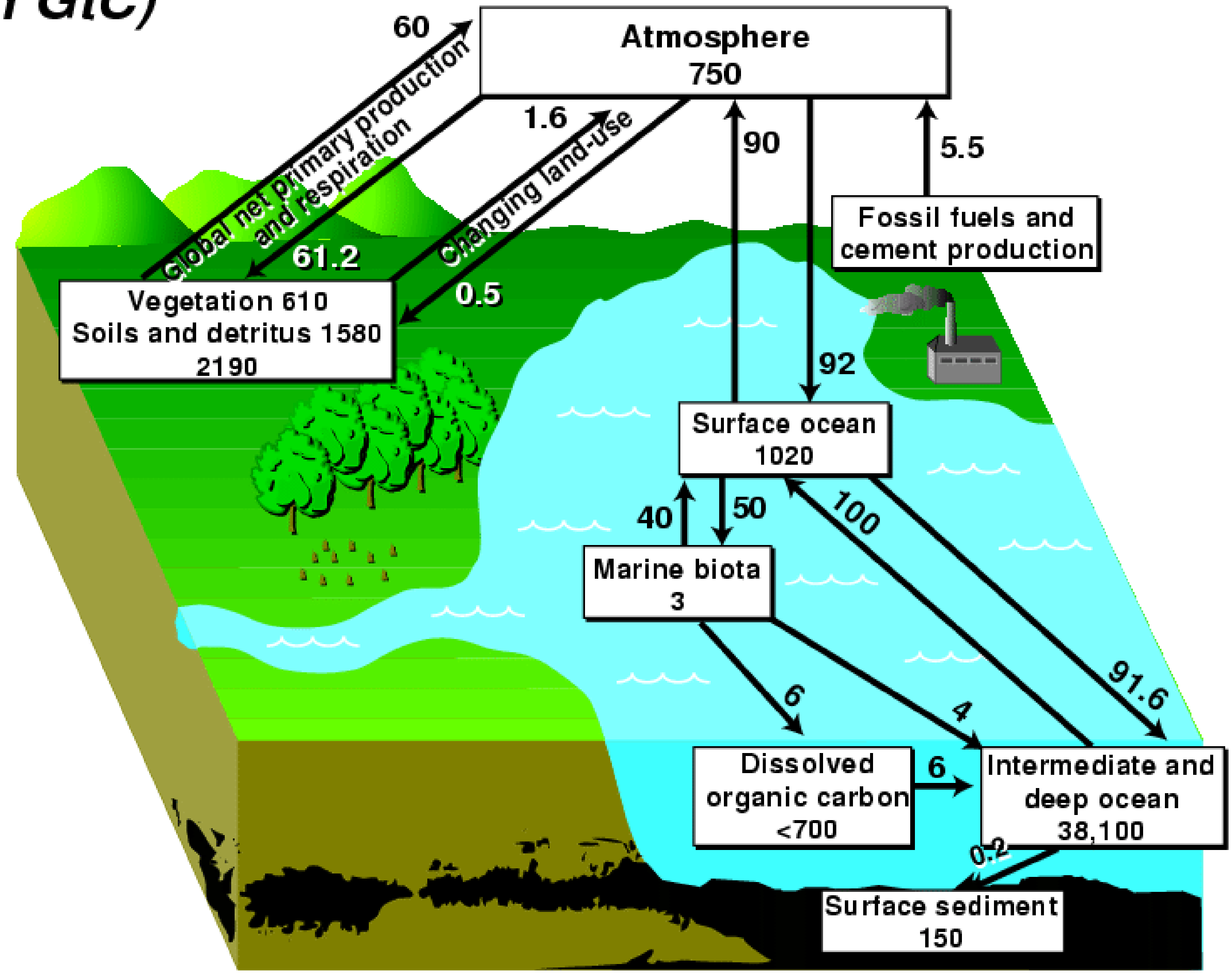
Global Carbon budget



www.**globalcarbon**project.org

Global Carbon Cycle

(in GtC)

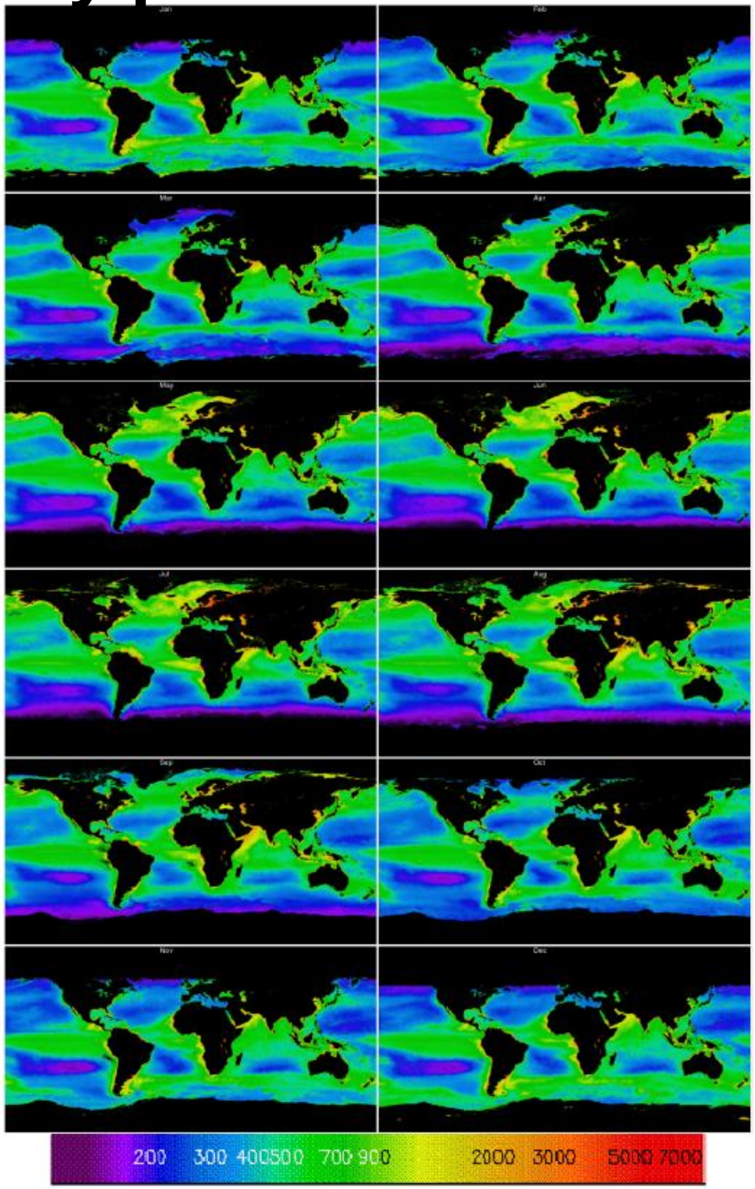


www.metoffice.gov.uk/research/hadleycentre/models/carbon_cycle/intro_global.html

Satellite estimates of Primary production

Jan

- All the PP hot-spots are coastal
- Bio-optical takes into account class II waters
- Not straightforwardly related to carbon drawdown

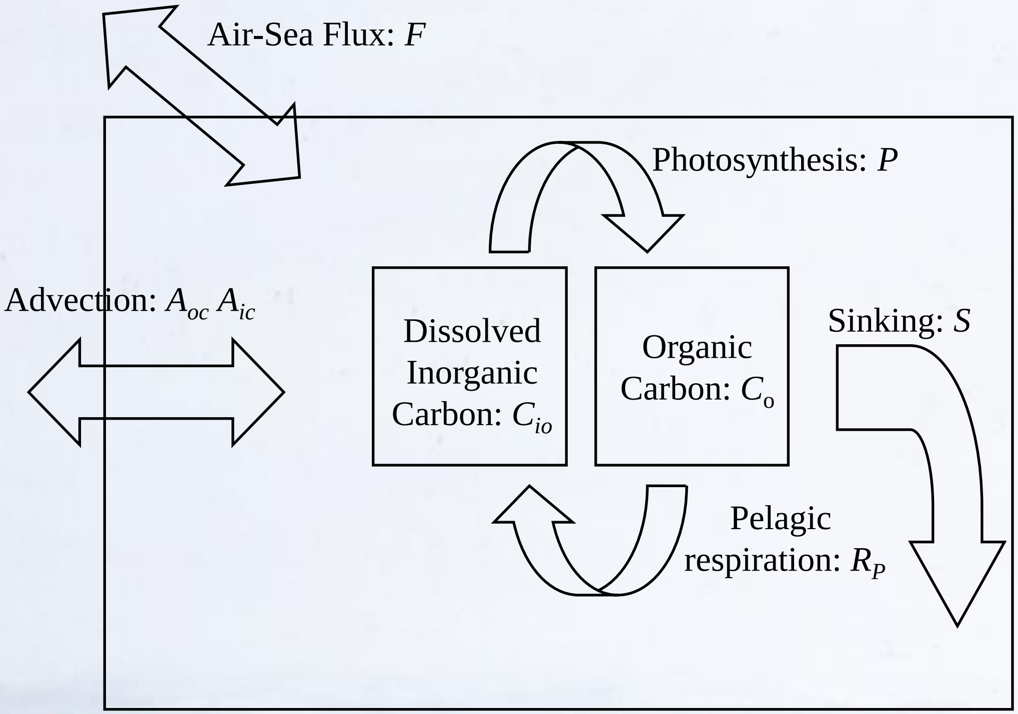


Dec

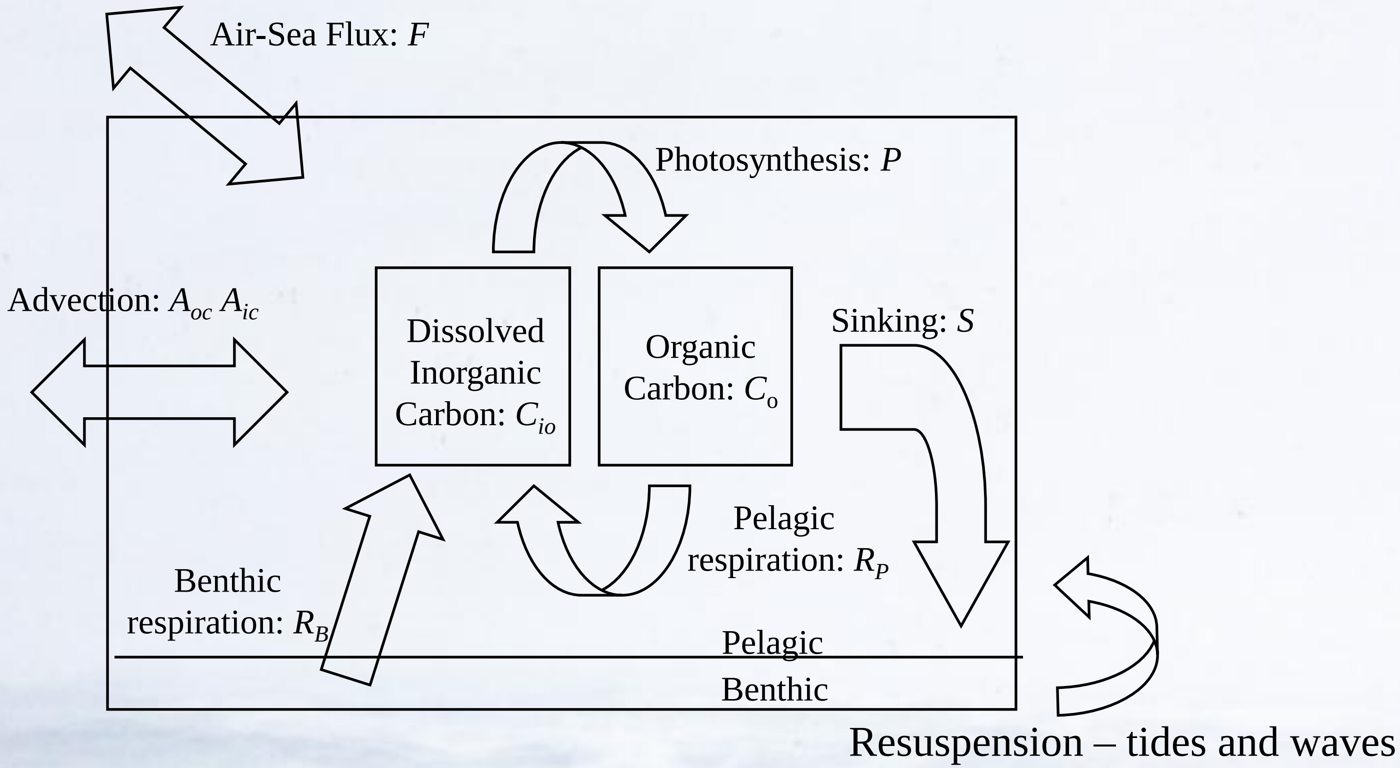
Figure 1. Global monthly climatologies (Jan to Dec left to right, top to bottom) of primary production obtained from the Smyth et al. (2005) look-up-table. Units are mgC m-2 d-1.

Smyth 2007

Ocean Carbon Cycle



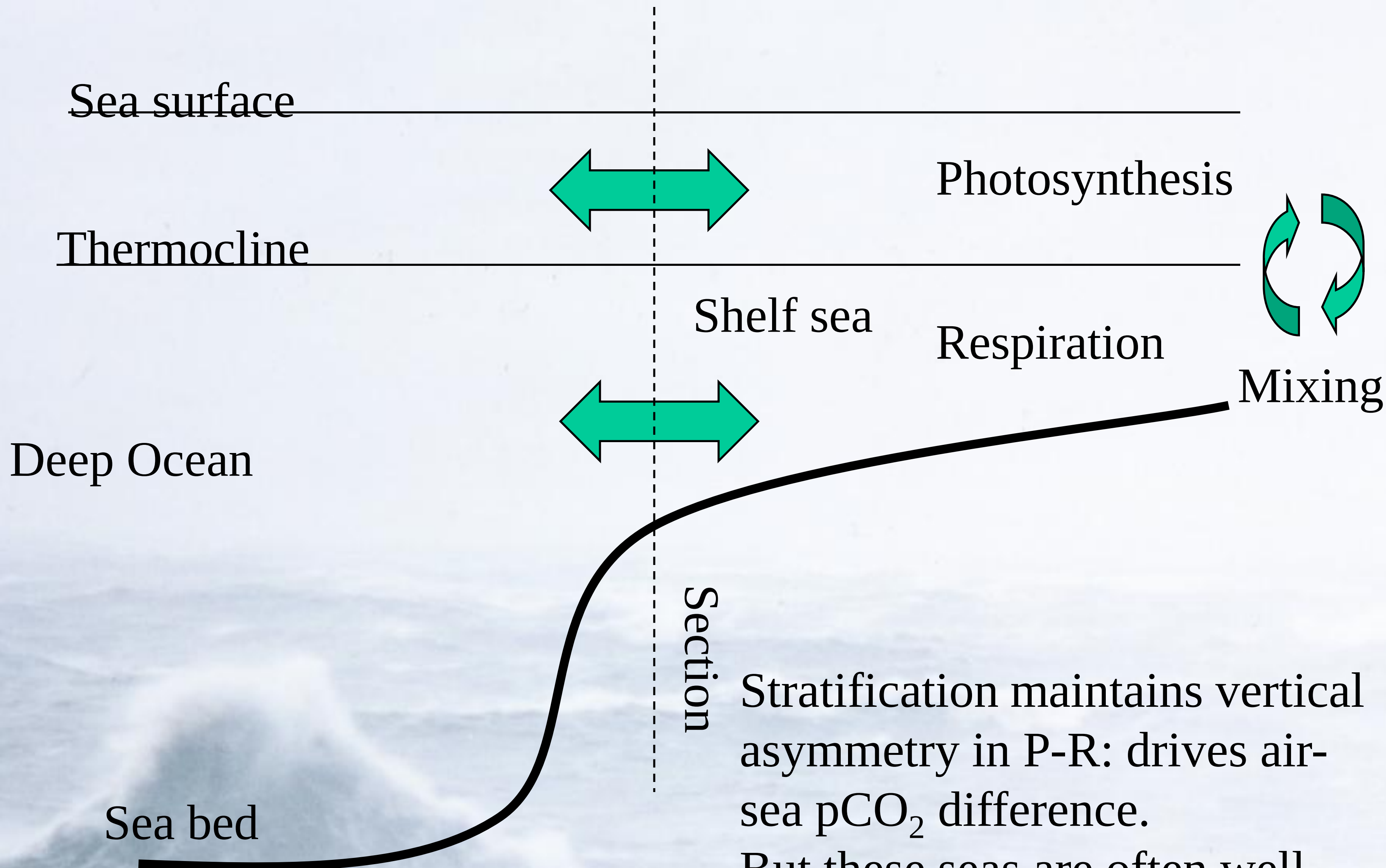
Coastal-Ocean Carbon Cycle



- Nutrient re-cycling
- Benthic coupling
- Terrestrial coupling (rivers/coast)

Units: $x10^{12}$molCyr $^{-1}$= 0.012Pg Cyr^{-1}

The shelf-sea carbon pump

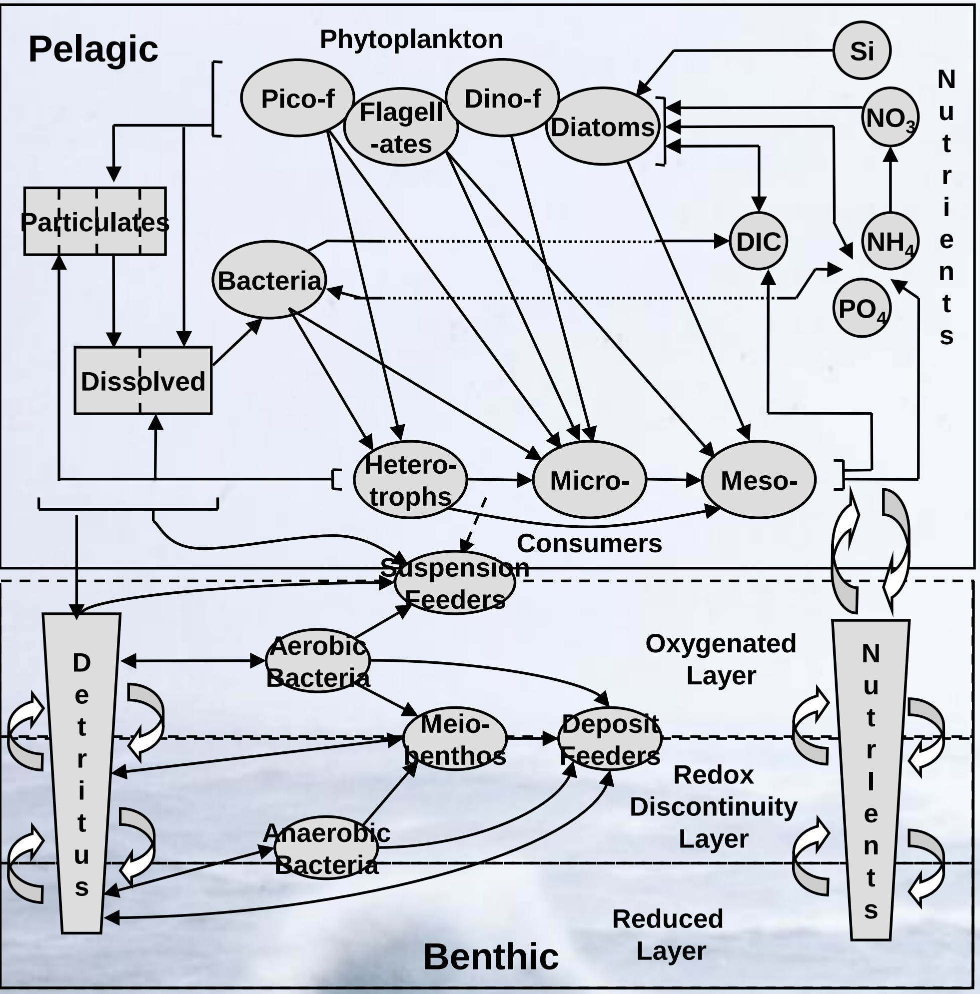


Stratification maintains vertical asymmetry in P-R: drives air-sea pCO_2 difference.
But these seas are often well mixed in winter….

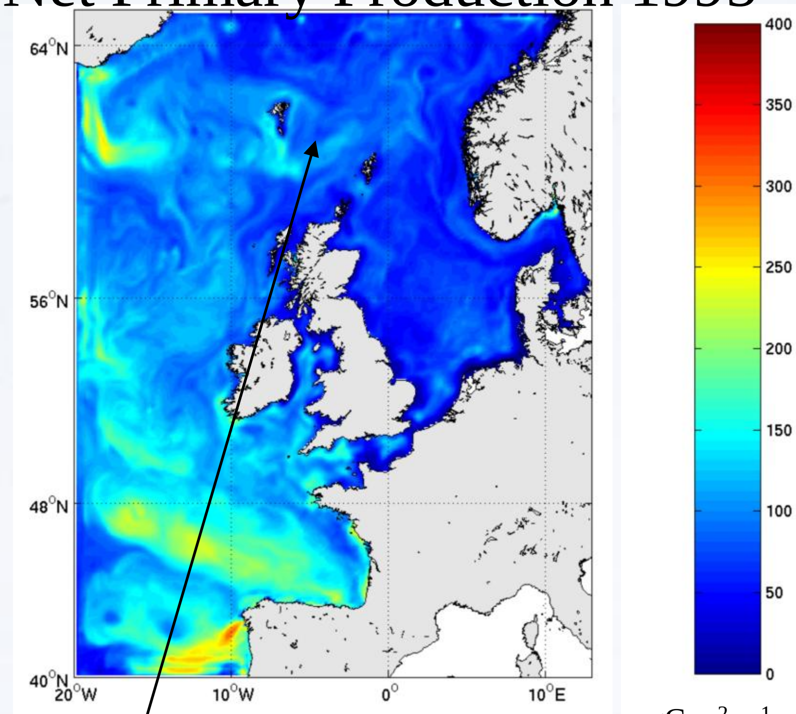
Does the shelf-sea pump work?

- How much of the carbon (drawn-down during the growing seasons) is ‘permanently’ isolated from the atmosphere?
  - Transport to deep ocean
  - Burial
- or does it just re-equilibrate with the atmosphere after winter mixing ?

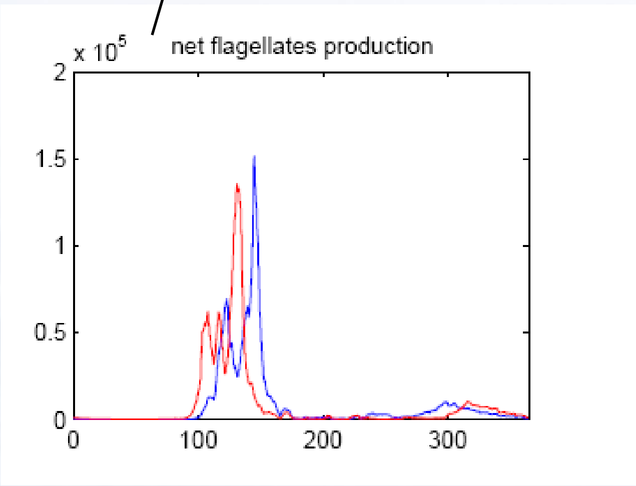
POLCOMS-ERSEM



Net Primary Production 1995



$gCm^{-2}yr^{-1}$



$mgCm^{-2}$

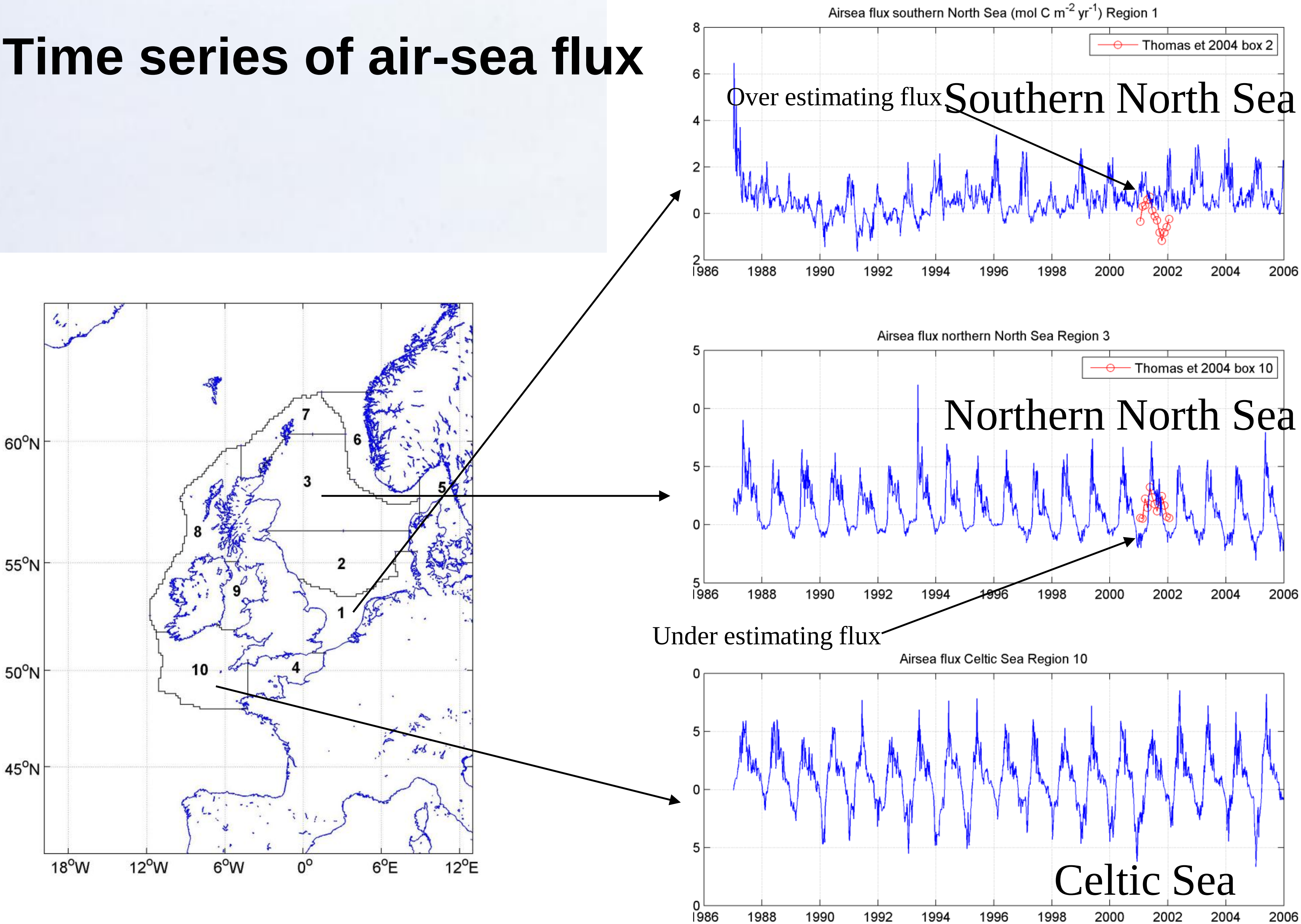
(red = x2 PAR)

Decouples nutrient and carbon cycles

The AMM simulation

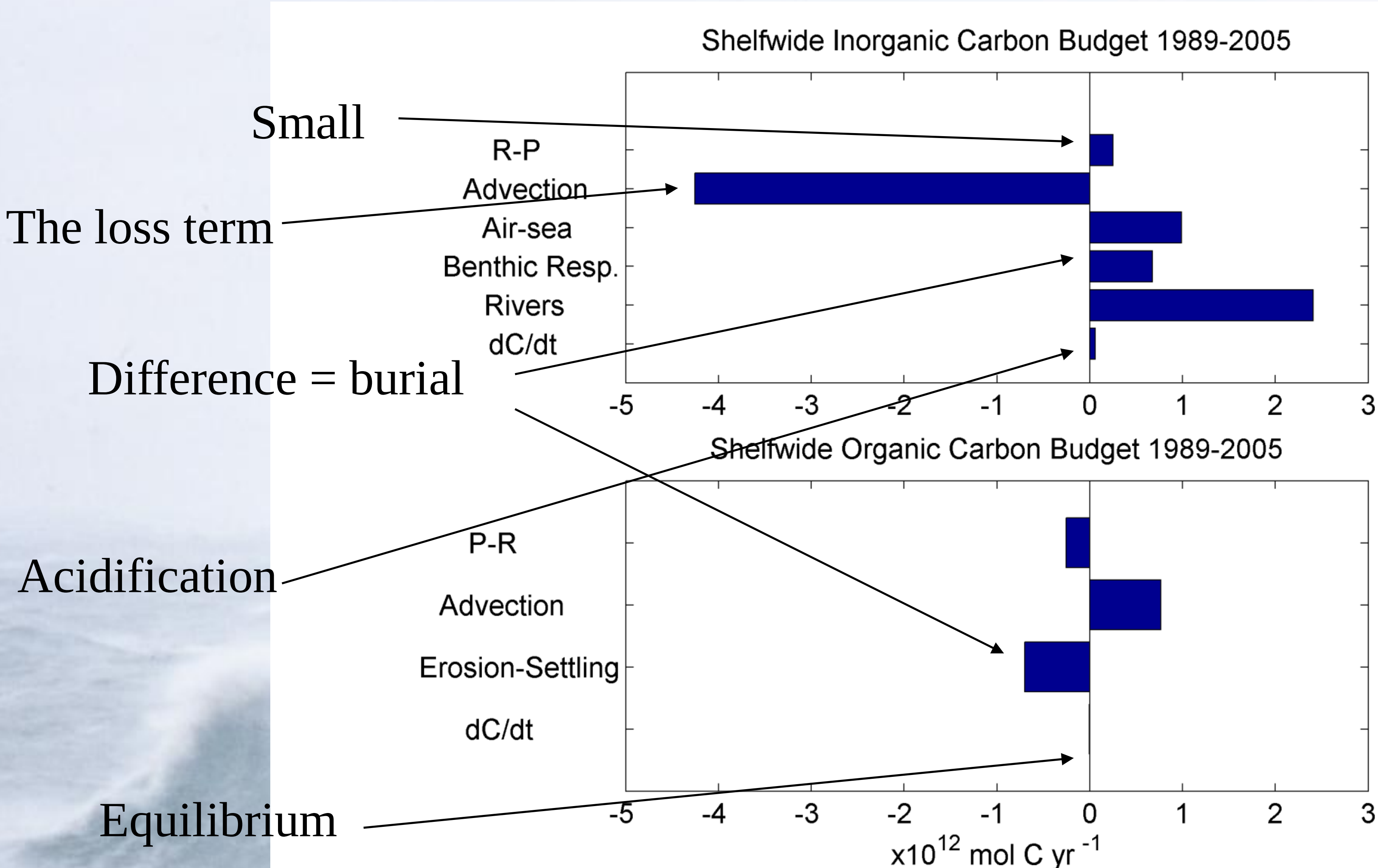
- ~12 km resolution, 34 s-leves
- 1987 spinup, 1988 to 2005 – 18 years
- POLCOM-ERSEM
- ERA40 + Operational ECMWF Surface forcing
- ~300 river flows
- 15 tidal constituents
- Time varying (spatially constant) atmos pCO_2
- Mean annual cycle for
  - Ocean boundaries
  - EO SPM/CDOM Attenuation
  - River nutrient and DIC
- Validation v's ICES data: ~50% rms error for winter nutrients

Time series of air-sea flux



0.6-1.2 v's 1.7-2.8 mol C m^{-2} yr^{-1} Frankignoulle & Borges (2001)

The shelf wide Carbon budget

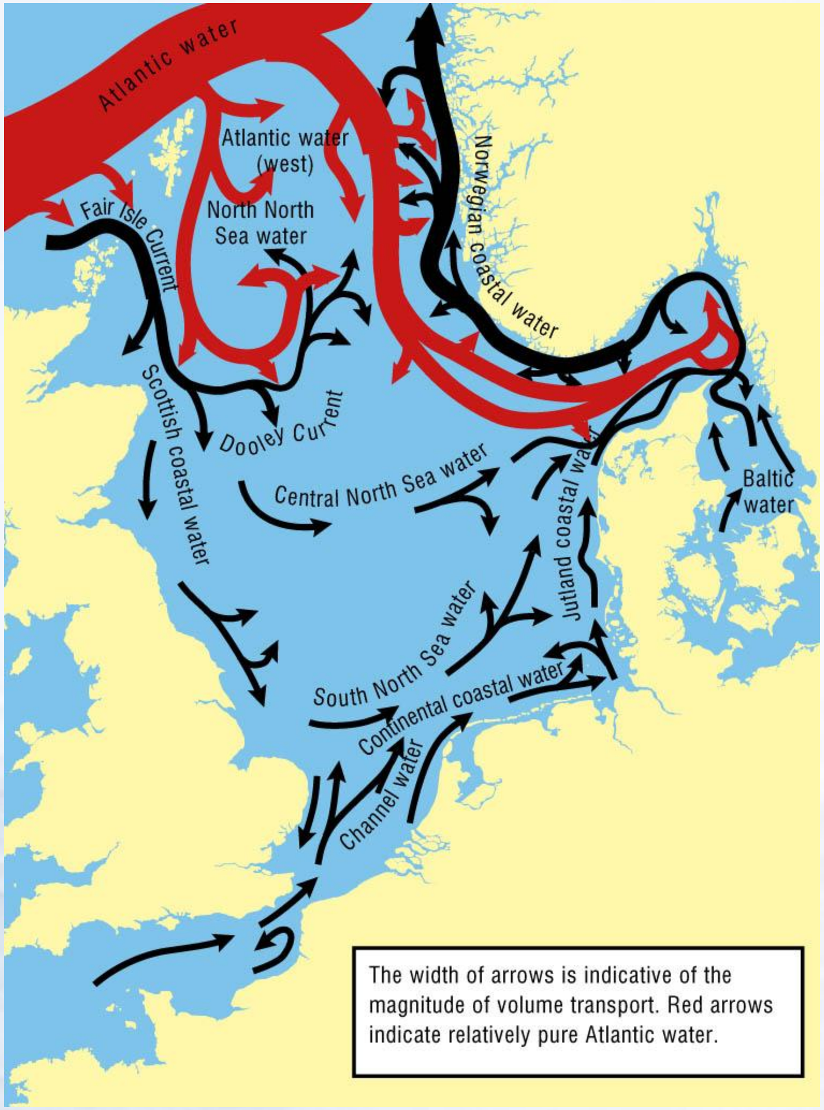


Carbon export

- Horizontal advection is the dominant loss term
- Net advective loss of carbon (subtracting rivers): $1x10^{12}$mol C yr^{-1}
- Net burial: $0.02x10^{12}$mol C yr^{-1}
- But to be an effective sink C must leave the shelf to DEEP water
- Otherwise may re-equilibrate with atmosphere.

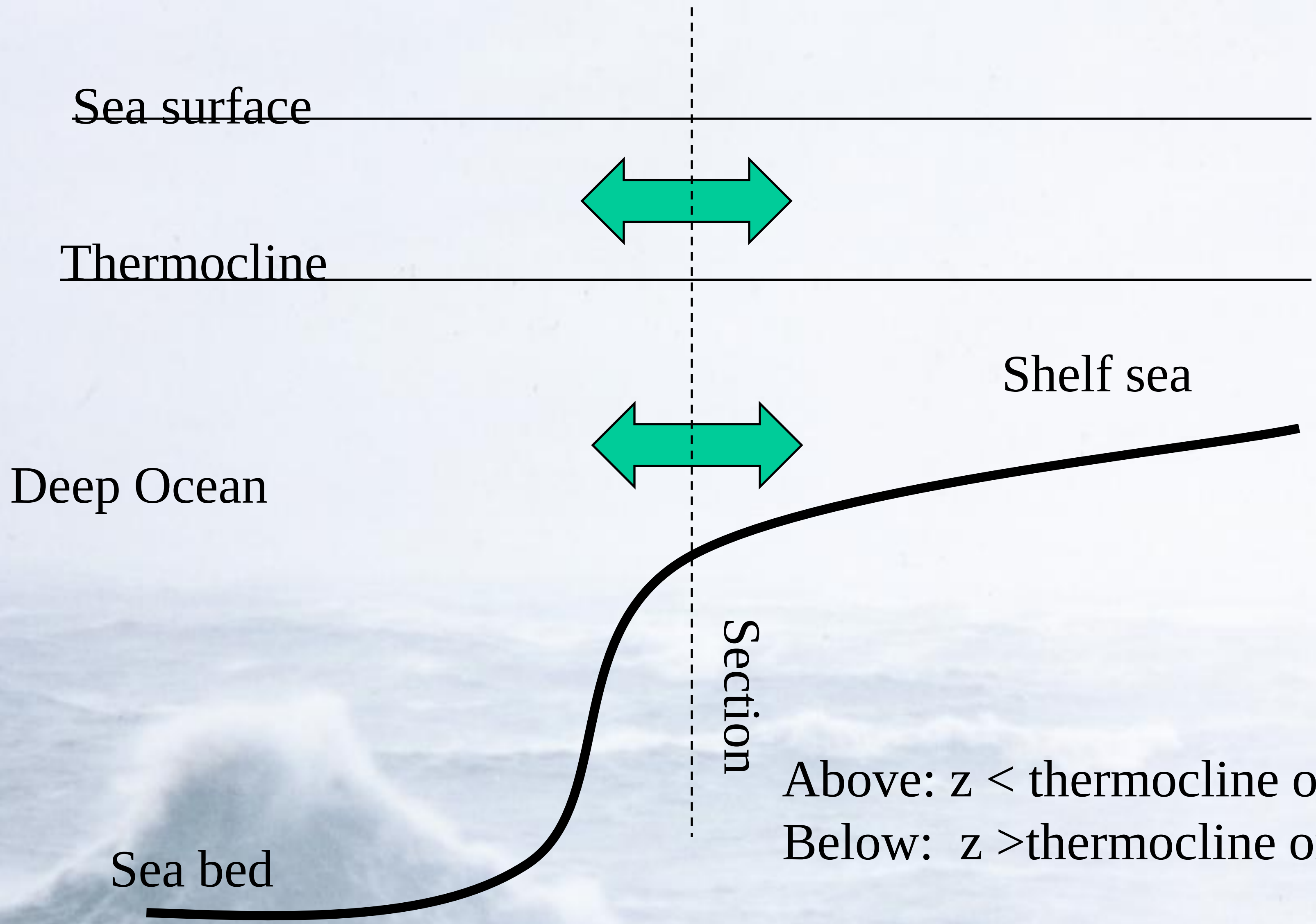
North Sea Circulation

- The main current out of the North Sea is a surface current
- Shelf-edge: ‘frictional’ processes: e.g. Ekman draining; coastal downwelling



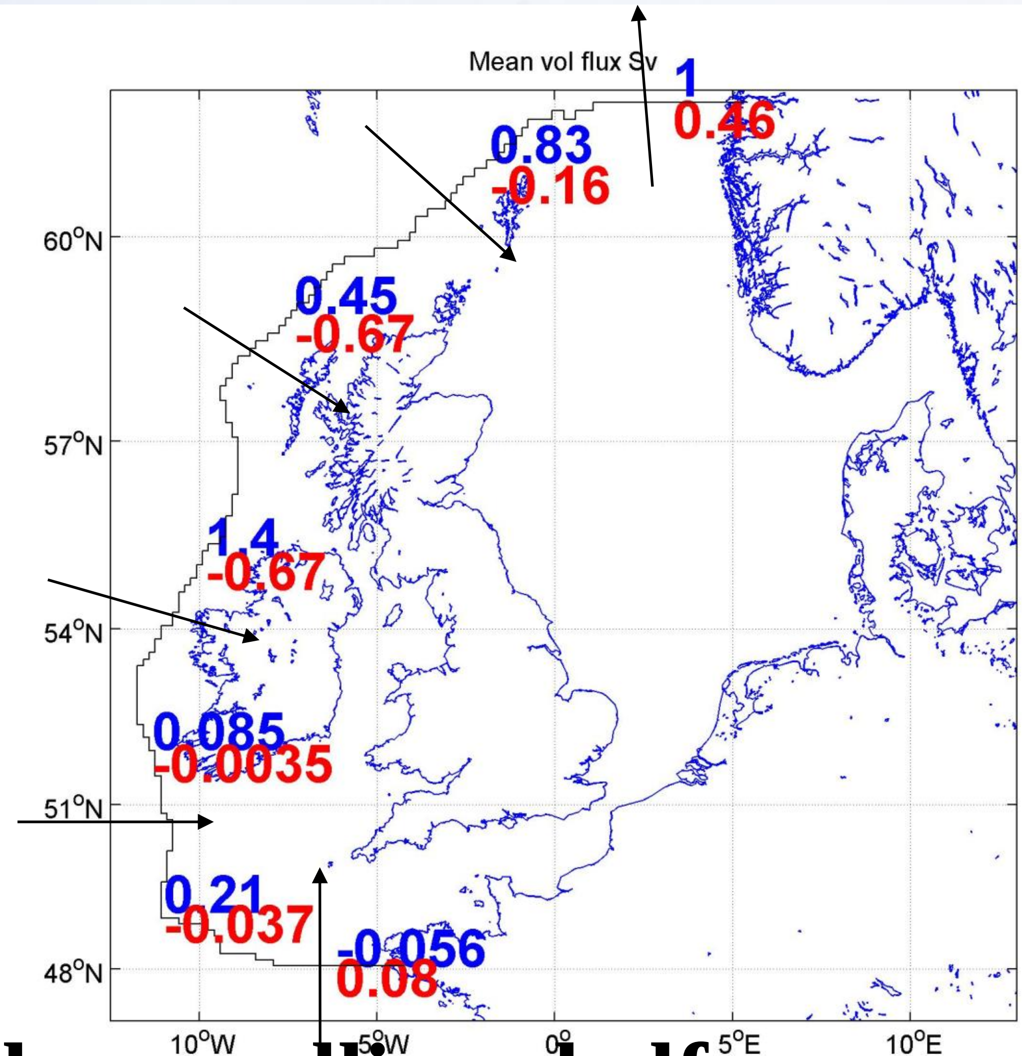
After Turrel et 1992

Dividing fluxes according to vertical structure



Above: z < thermocline or 150m
Below: z >thermocline or 150m

Volume fluxes

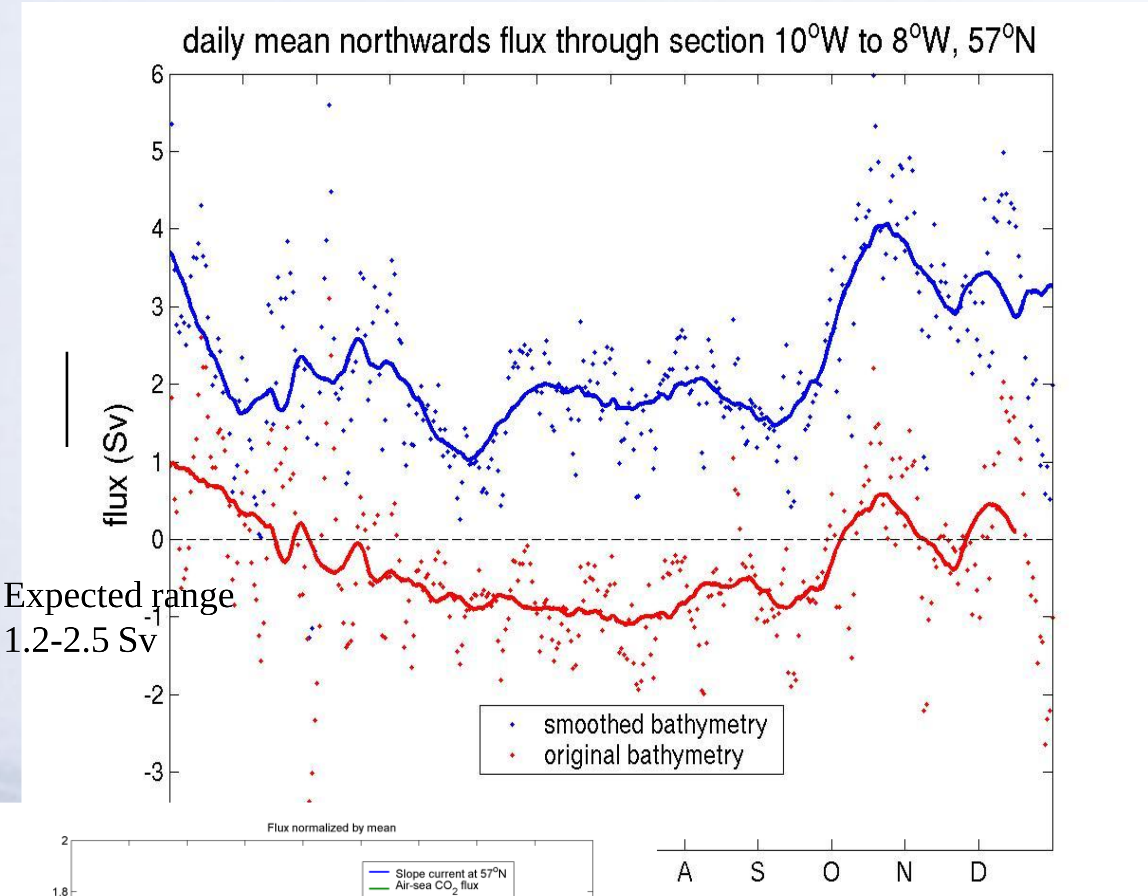


Above: 1.89Sv

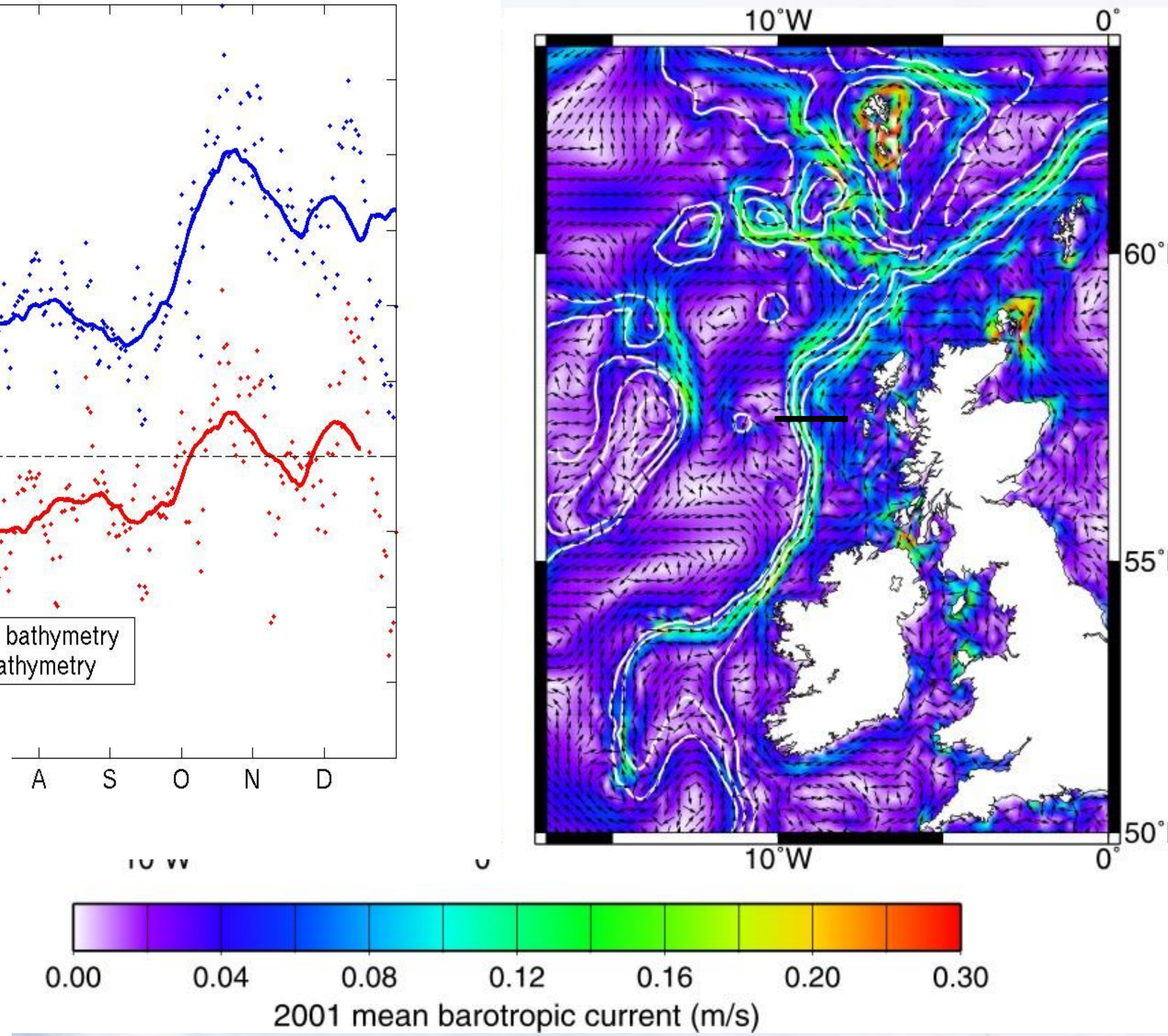
Below:-1.94Sv

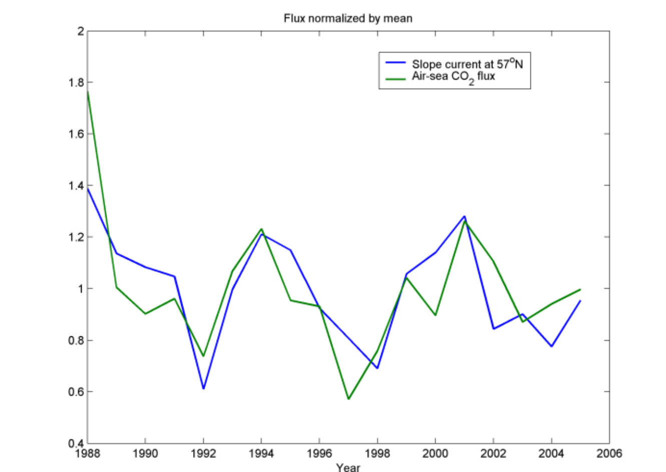
This is a downwelling shelf

The slope current

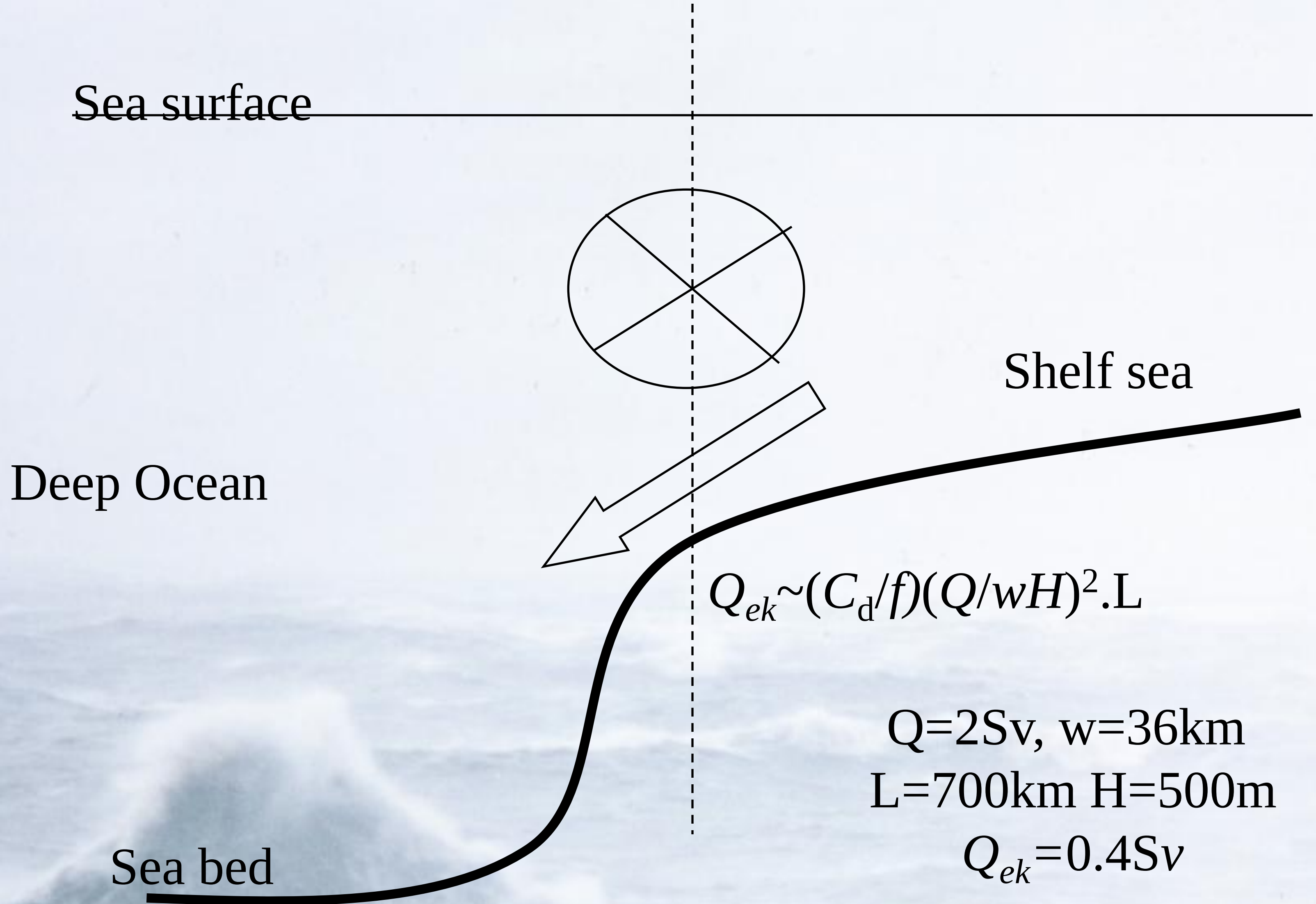


Expected range
1.2-2.5 Sv





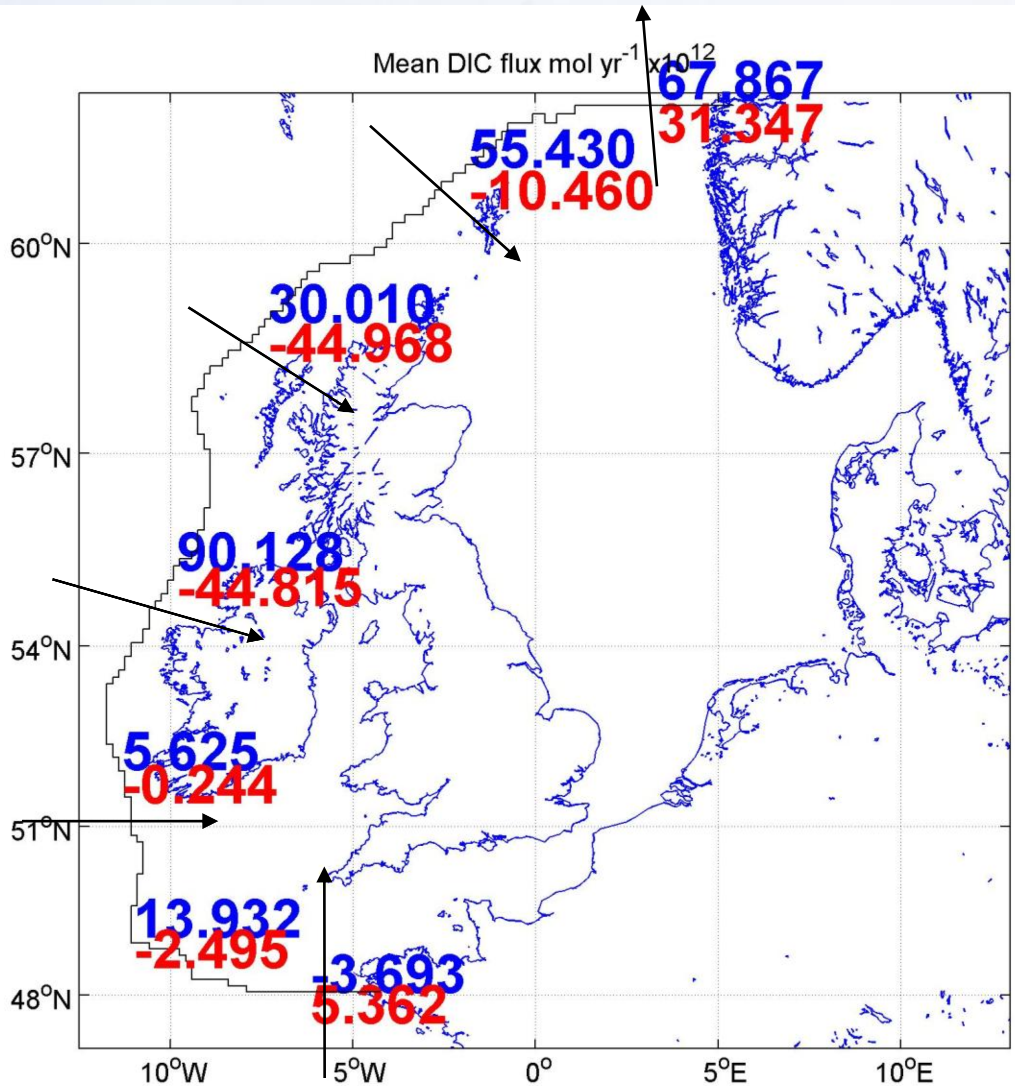
Ekman draining



$Q_{ek} \sim (C_d/f)(Q/wH)^2.\mathrm{L}$

Q=2Sv, w=36km
L=700km H=500m
$Q_{ek}=0.4\mathrm{S}v$

Inorganic Carbon flux



Above: 123.6

Below:-129.0

Net:-5.4

Air-sea flux: 1

Rivers: 2.4

$x10^{12}$molCyr -1

Ocean-shelf anomaly flux

Subtract flux associated with mean concentration: $F_{anom}=F-\bar{C}F_{vol}$

should time/depth average to zero $<F_{vol}+F_{rivs}> \sim 0$

Above thermocline

0.4 0.2×10^{12} mol C yr^{-1} inorganic

-0.8 0.4×10^{12} mol C yr^{-1} organic

Below thermocline

-2.7 1.4×10^{12} mol C yr^{-1} inorganic

1.6 0.7×10^{12} mol C yr^{-1} organic

Errors from winter nitrate values

Total anomaly fluxes

C-fluxes associated with high DIC:

Total loss to deep ocean : -1.1   0.6 x10^{12}mol C yr^{-1}

Total ocean-shelf exchange: -0.7   0.4 x10^{12}mol C yr^{-1}

Air-sea: 1.0   0.5 x10^{12}mol C yr^{-1}

Thomas et al 2004 1.38 mol C $m^{-2}yr^{-1}$ for north sea x area of whole shelf:

1.7x10^{12}mol C yr^{-1}

Efficiency: Loss to deep ocean / Gross PP = 1.1/16.0 ~7%

Role of the slope current

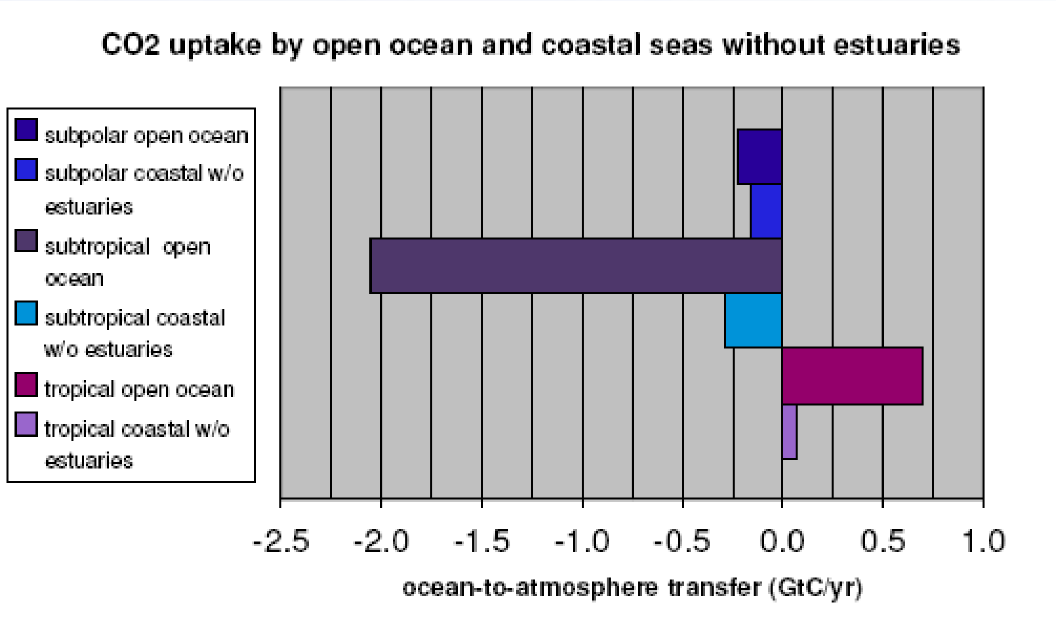
- Acts to replenish on-shelf nutrients (positive correlation with summer organic carbon)
- Acts to remove DIC (negative correlation with summer inorganic carbon)
- Together it helps drive the continental shelf carbon pump.

Global contribution (in perspective)

- 0.01 Pg Cyr^{-1} of ~2 Pg Cyr^{-1} Global biological pump
- 1.5 Pg Cyr^{-1} of ~90 Pg Cyr^{-1} Global downwelling flux
- 7% efficient compared with ~20% Globally (EP/PP)

How does this up-scale to shelf seas globally ?

Importance of Costal Ocean to Global Carbon Budget: extrapolating sparse observations



Borges (2005) "Do we have enough pieces of the jigsaw to integrate CO2 fluxes in the coastal ocean ?" Estuaries, 28, 3-27

Including coastal seas increases oceanic uptake from 1.6 to 1.9 $PgCyr^{-1}$ (increase is largest at high latitudes)

But with estuaries and salt marshes coastal-ocean becomes a source of CO2 and reduces oceanic uptake to 1.4 $PgCyr^{-1}$

i.e. not even certain of the sign!

Importance of Costal Ocean to Global Carbon Budget

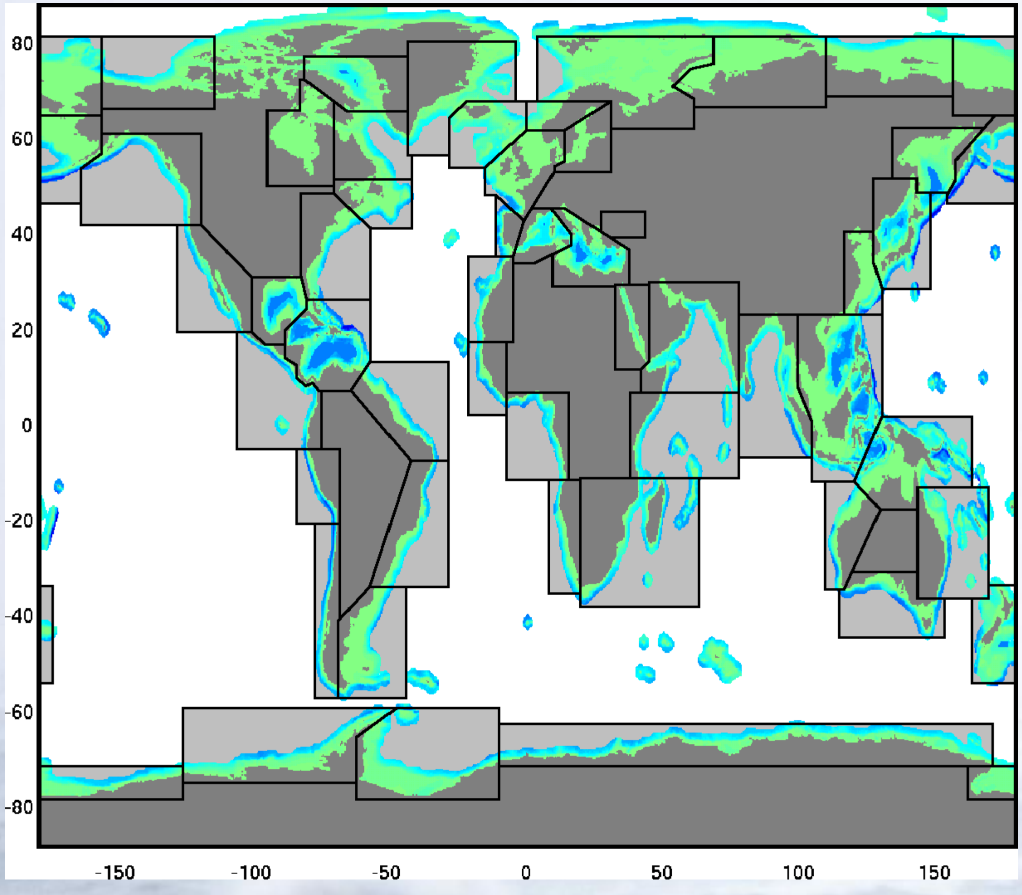
- Important part of marine component of carbon cycles
- Highly susceptible to change
  - Human influence
  - Climate variability
  - Closely balanced between being a source or a sink
- Largely absent from earth system models

Approaches for including shelf seas in Earth System Modelling

- Variable resolution global model
  - ICOM
- Fine resolution global model ($<1/4^o$)
  - Re-focus on vertical co-ordinates/mixing schemes
  - NEMO-shelf
- Nested Coastal-Ocean model
  - The patch work approach: GCOMS
- Parameterised coastal-ocean
  - Use *a-priori* (stationary, high-resolution) information to improve coastal-ocean representation on coarse-grid

If resolution required is x10 v's deep ocean, computer resource required is 10^2x0.07~x 7 (or x70 with time step)

The Global Coastal Ocean Modelling Project



- Run regional shelf-sea models for all of the coastal regions around the world to improve our estimates of their contribution to the global carbon cycle

55 Domains:

- Each fits comfortably on a typical local cluster
- Flexible execution strategies

- Aligned to QUEST
- Forms part of the Carbon-theme in the new NERC centre for Earth Observation

Conclusions

- The NW European shelf has a downwelling circulation
- This enables efficient carbon sequestration despite the lack of export flux of POC
- The net air-sea C-flux closely matches the flux to deep ocean
- This model provides LOWER bounds on C-fluxes
- The global implications of the shelf-sea pump are largely un-quantified