Modeling shelf seas dynamics, ecosystems, and ocean-shelf coupling in the North Atlantic and Arctic

Jason Holt

Contributions from:

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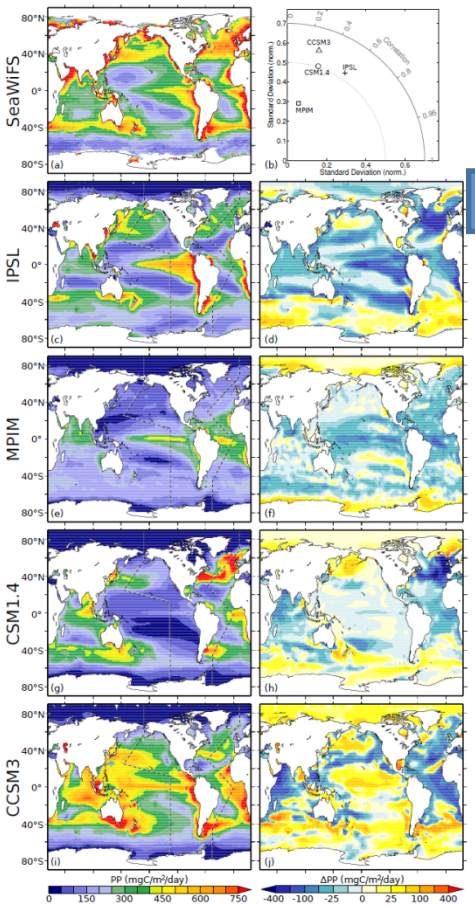
Momme Butenschon, Yuri Artioli, Icarus Allen, PML

A driver for coastal-ocean modelling

Projected changes

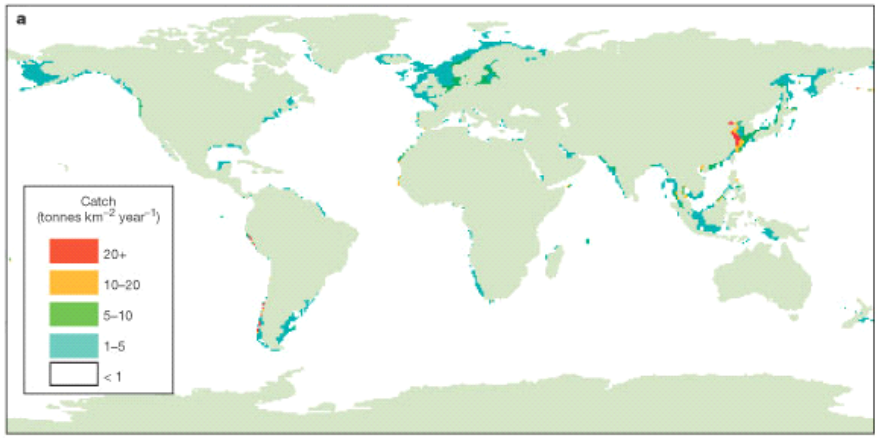
netPP Δ netPP



Streinacher et al 2010

?

Global Fish Catch



Watson and Pauly, 2001

Big mismatch in scales between climate change information and societally relavent impact

Multi model ensemble (AR4):

Decrease in mid- low- latitude basins

- Increased stratification, slowed circulation

Increase (variable) in high latitudes

- Relaxation of light limitation

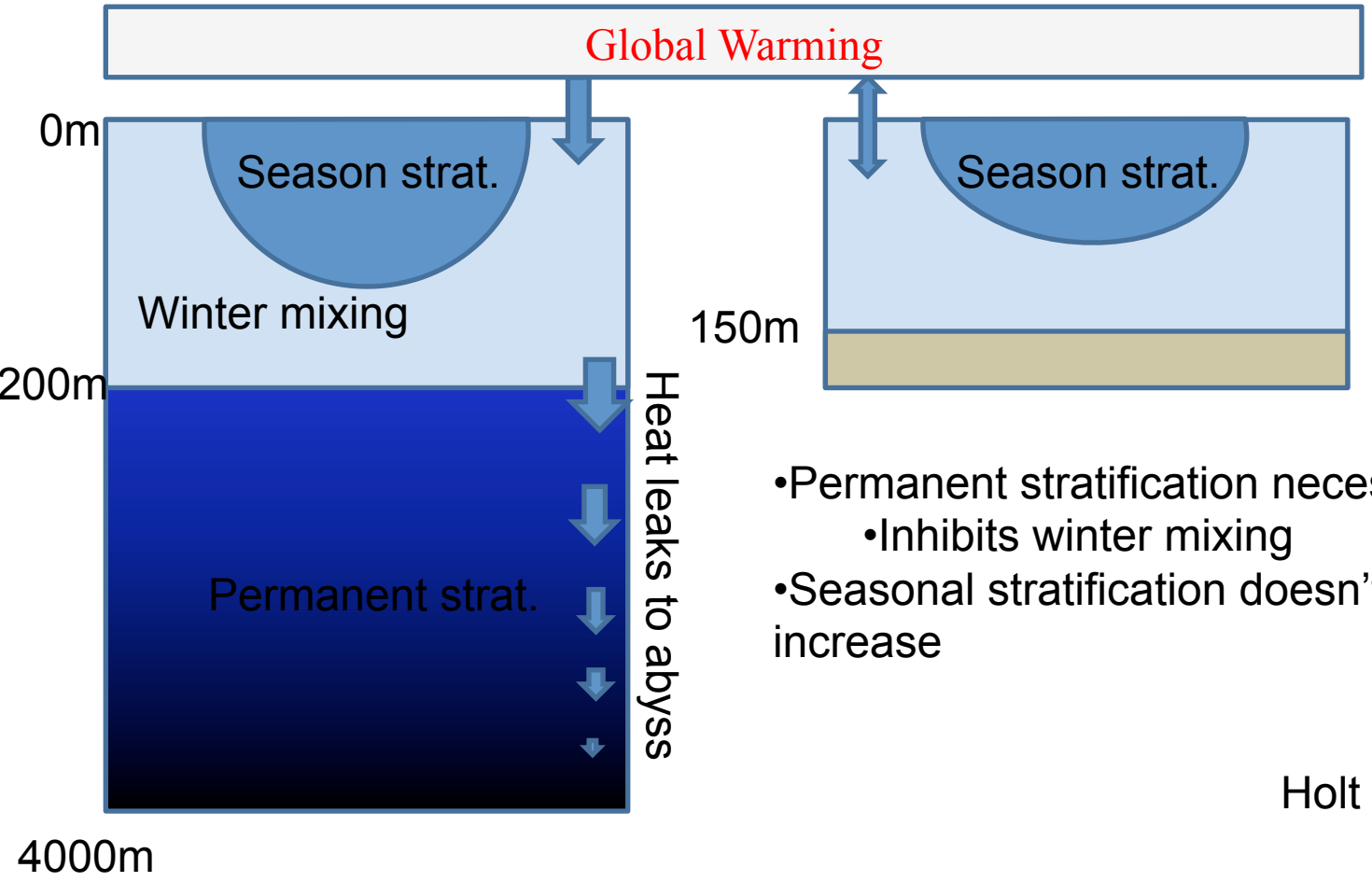
Shelf Sea dynamics: Physics

Physics characterised by proximity to land and shallow depth

- Turbulent mixing at multiple boundary layers, inc surface waves
- Growing coastal-trapped waves (e.g. tides, surges)
- Small horizontal length scales (~$h^{0.5}$)
- Freshwater flux from land
- Air-sea fluxes dominant, low (thermal/mechanical) inertia
- Exchange with open-ocean – often constrained by PV
- Complex coastlines, regions of restricted exchange

A key difference between open ocean and shelf seas

- Shelf seas are in (dynamic) thermal equilibriums,
- Deep ocean/regional seas are not



- Permanent stratification necessarily increases
  - Inhibits winter mixing
- Seasonal stratification doesn't necessarily increase

Holt et al BGSD 2014

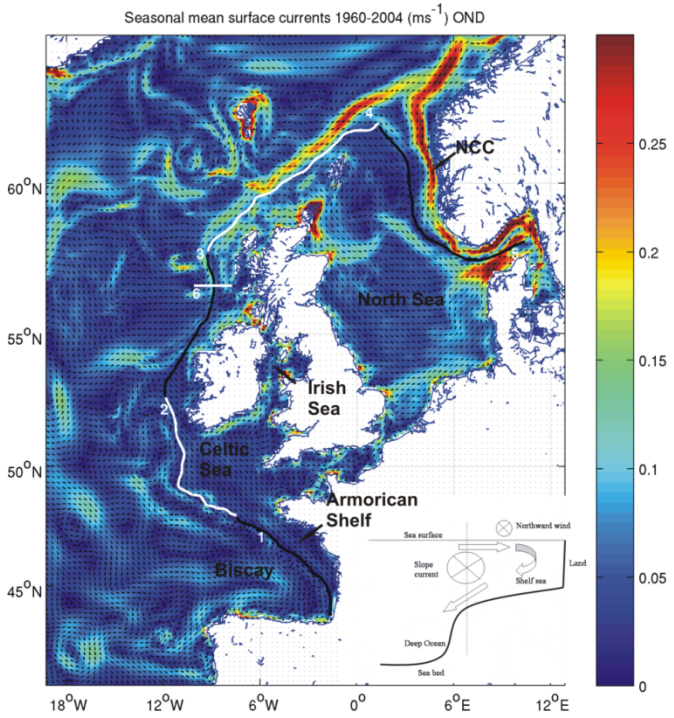
Shelf sea dynamics: Ecosystems

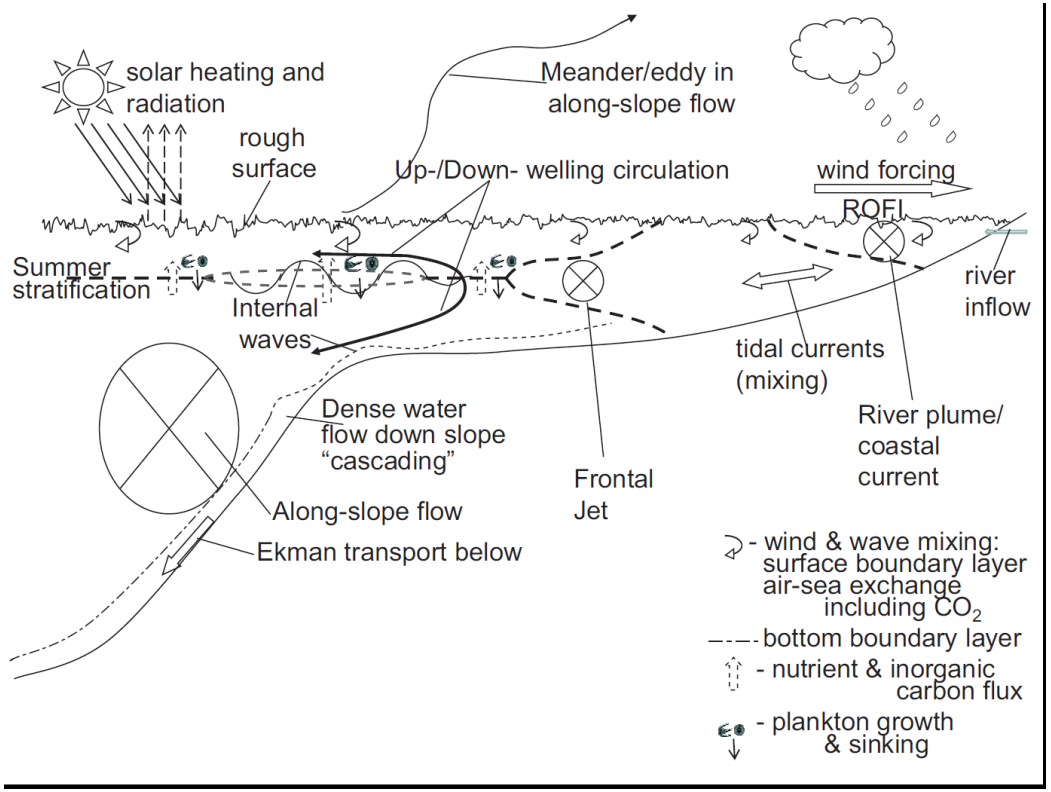
Ecosystem characterised by proximity to land and shallow depth

- Flux from land: CDOM, carbon, nutrients, etc
- Benthic-pelagic coupling
- Complex optics (CDOM, sediments)
- Soft tissue carbon pump requires lateral transport or burial (hard tissue largely unquantified) – if well mixed sometime during the year
- Interaction with shelf-sea physics (fronts, coastal currents, internal tides etc): highly heterogeneous

The Northwest European Continental Shelf

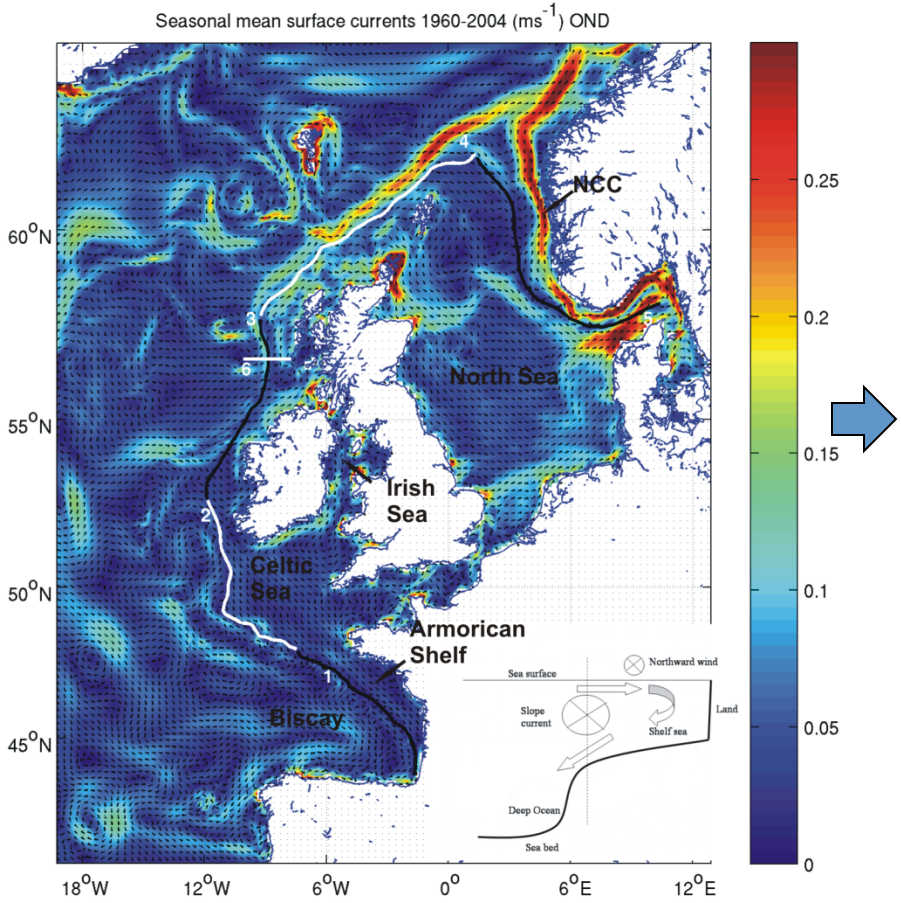
Broad tidally dominated, downwelling shelf
Boarders subpolar and subtropical gyres
Strong deep winter mixing

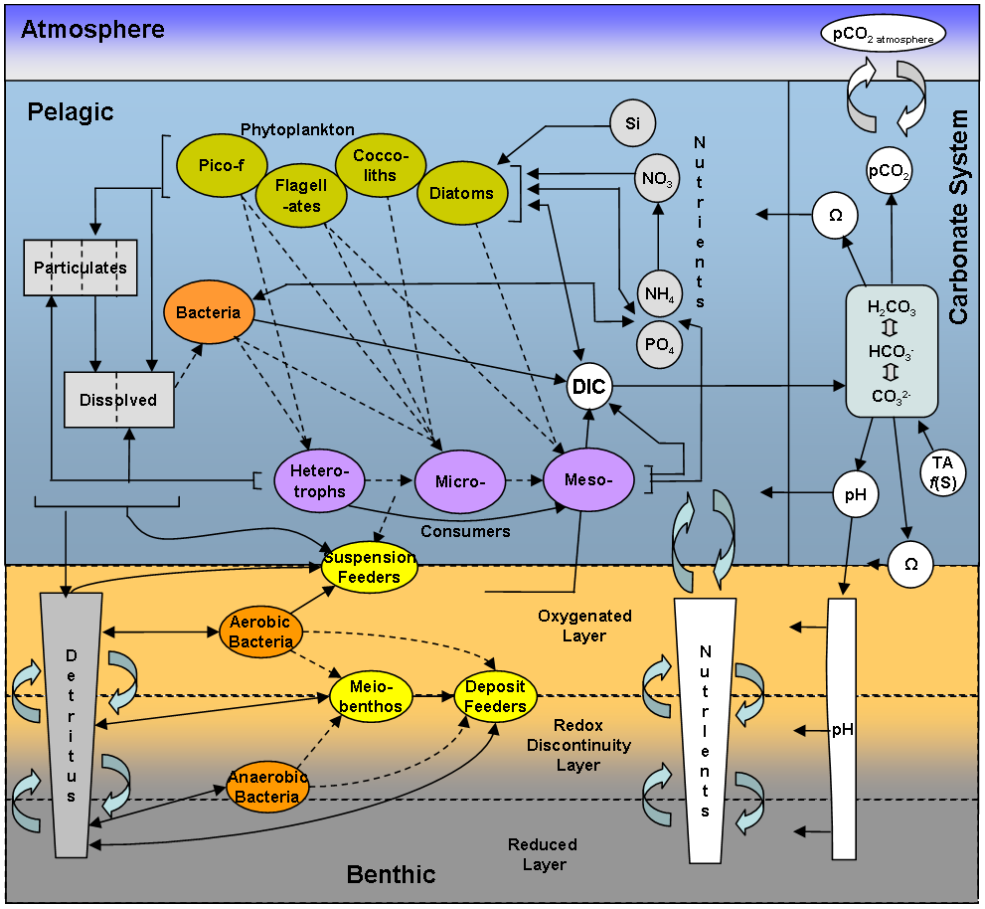




Holt, Huthnance et al Coastal-Ocean Circulation Dynamics, In Press

POLCOMS-ERSEM

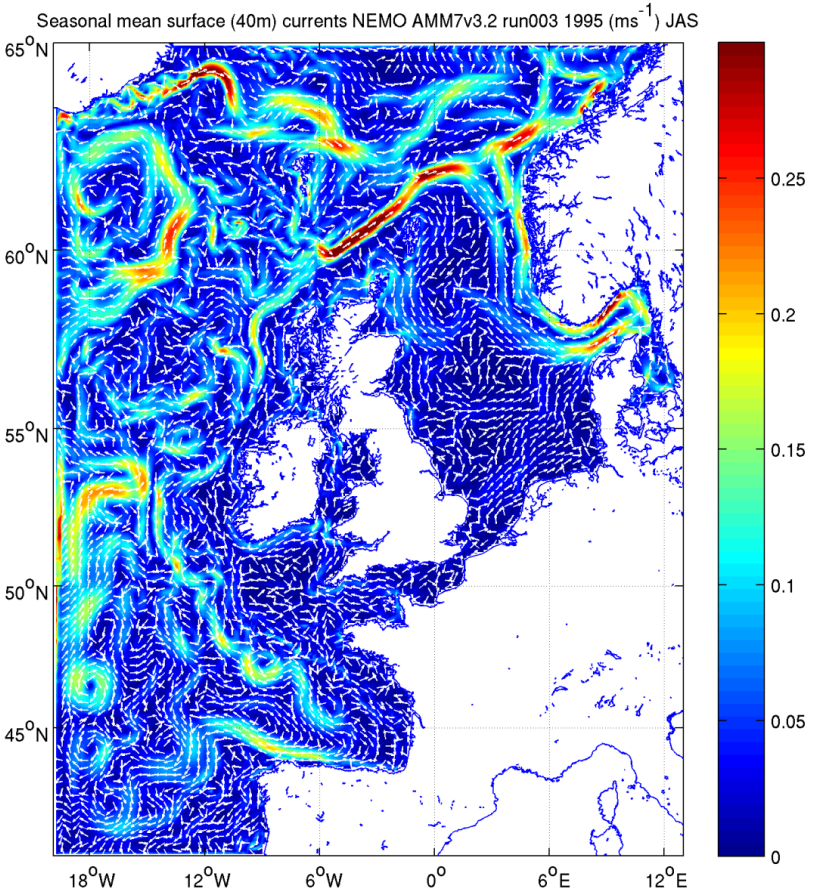


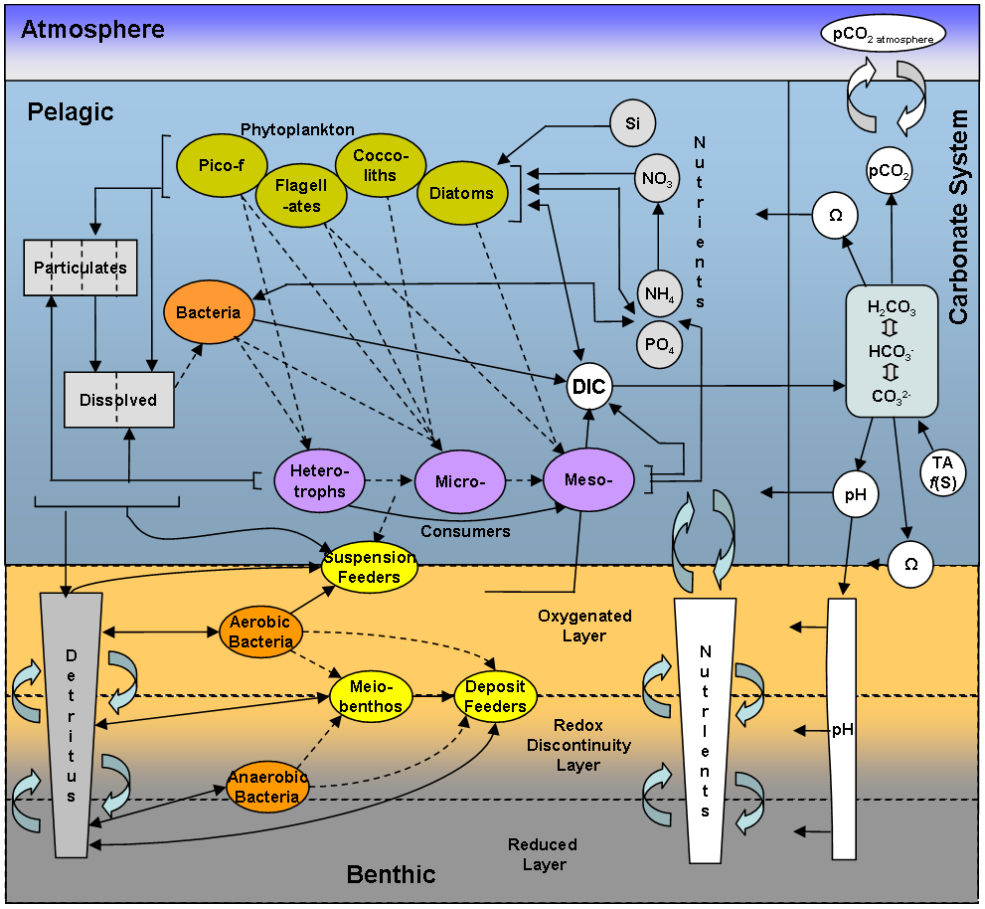


1/6° x1/9°~12 km resolution, 42 s-levels
Holt et al *GRL* 2009
Wakelin et al *Ocean Dyn.* 2009

Allen et el *Sarsia* 2001
Blackford et al *JMS 2004*

NEMO-ERSEM





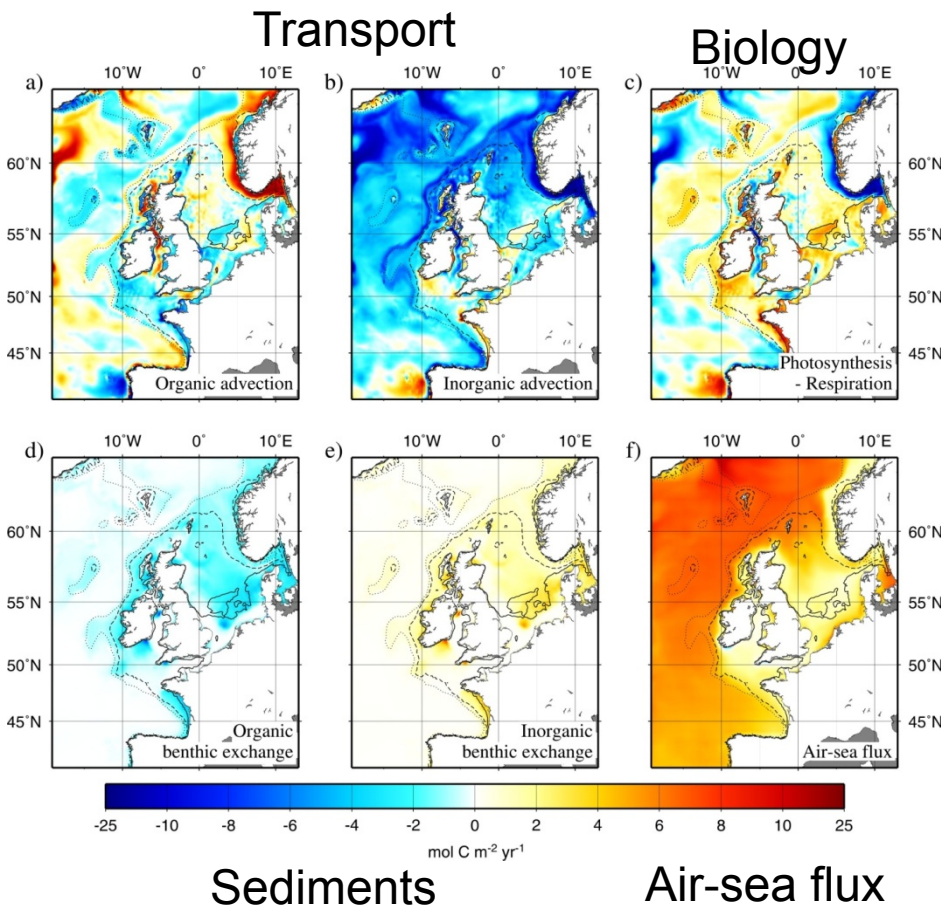
O'Dea et al 2012
Edwards et al 2012

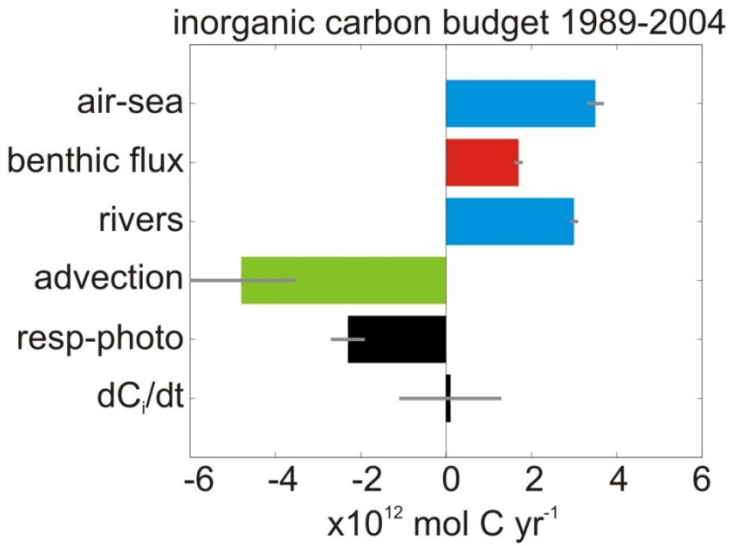
Allen et el *Sarsia* 2001
Blackford et al *JMS 2004*

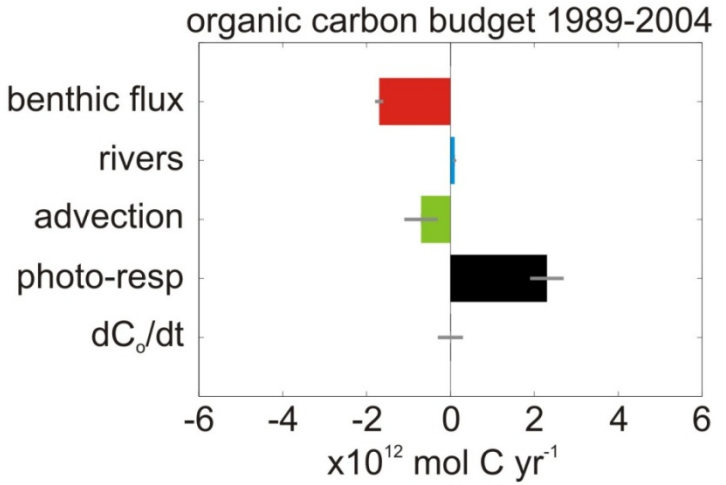
More later…….

Carbon Budgets of NW European Shelf

Diagnosing the shelf seas carbon pump







National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

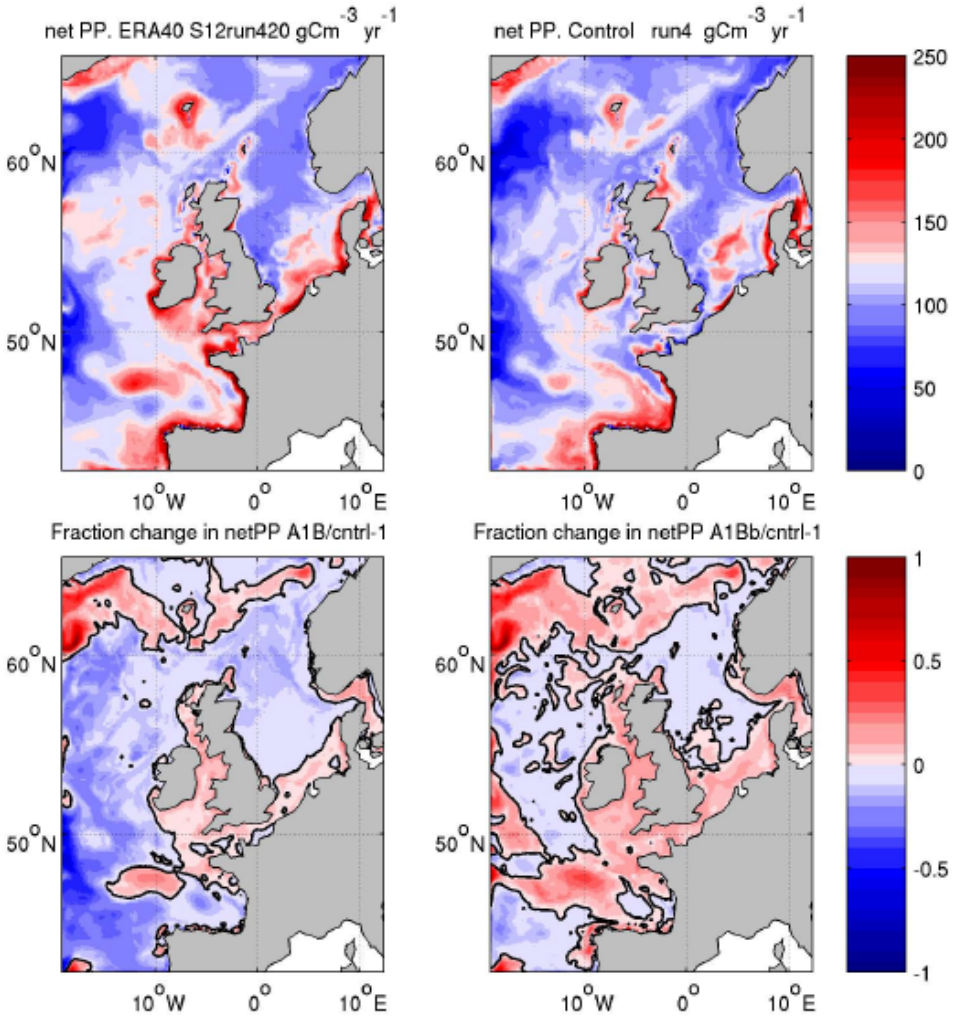
Wakelin et al JGR 2012

Future Climate Impact experiments

Change in Primary Production between:

CONTROL:1981-2000
A1B: 2080-2099

Direct forcing from IPSL-CM4
Inc. nutrient bc.s



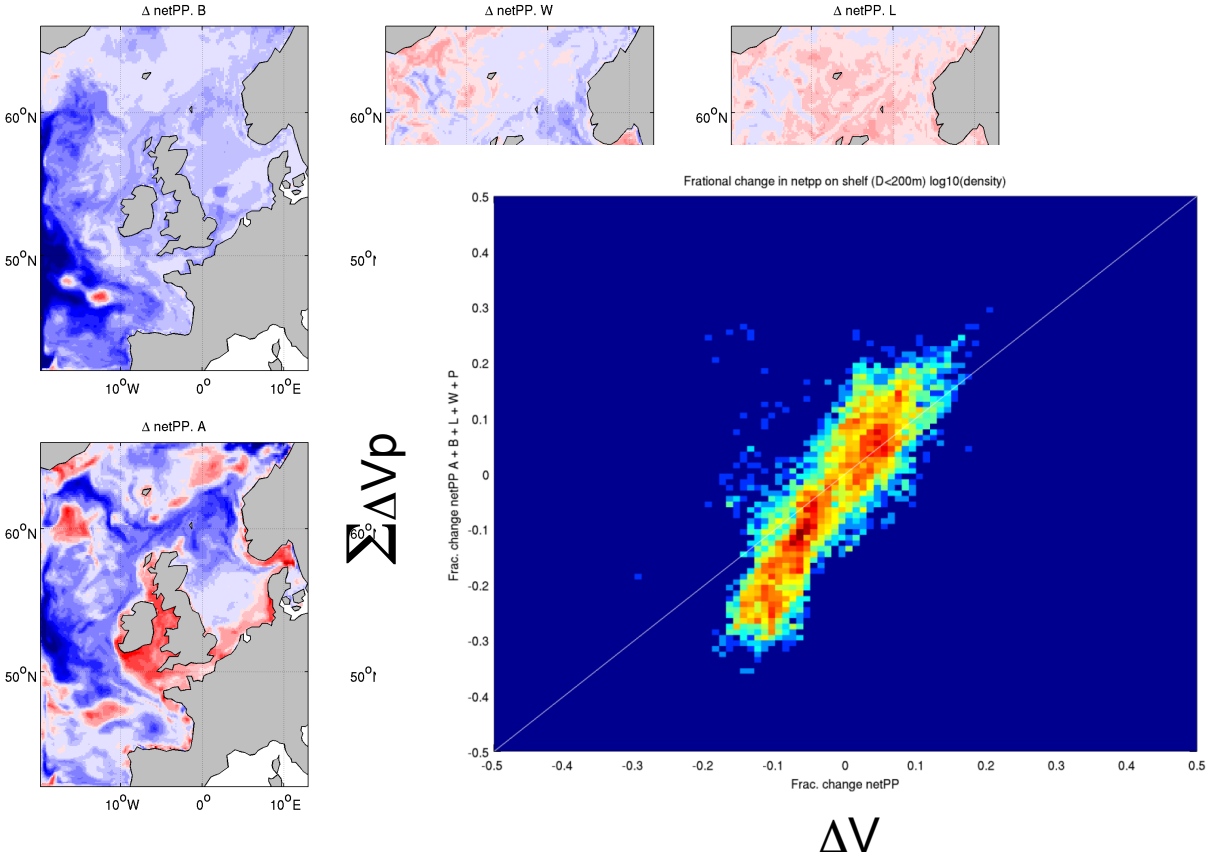
Holt et al *BGS* 2012

Impacts of climate change in shelf sea ecosystem Driver – Response experiments

- B: Boundary nutrients
- W: Wind
- L: SWR
- A: Air temp
- P: Precip

Random present day year is swapped in to future forcing

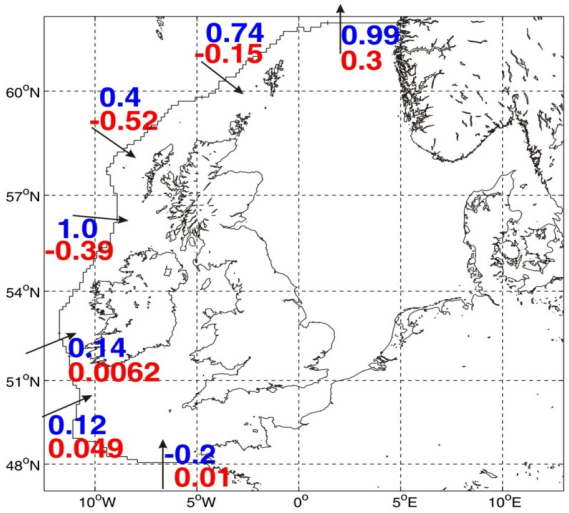
$\Delta V_p = \Delta V - \Delta V_{p'}$



Holt et al BGSD 2014

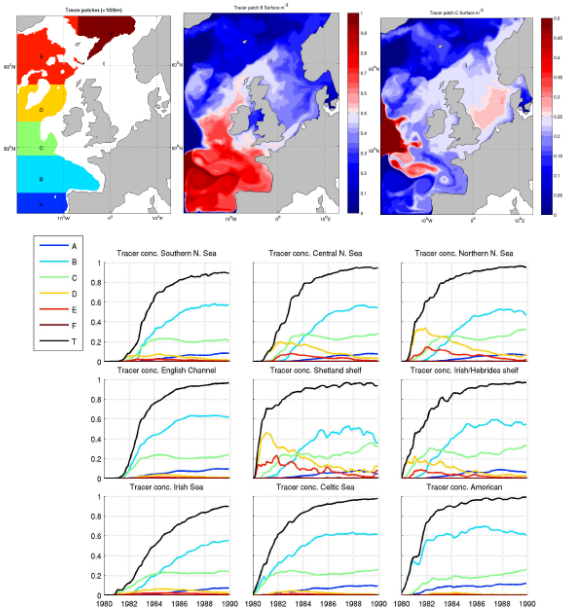
Model views of Ocean-shelf exchange

Summed across sections



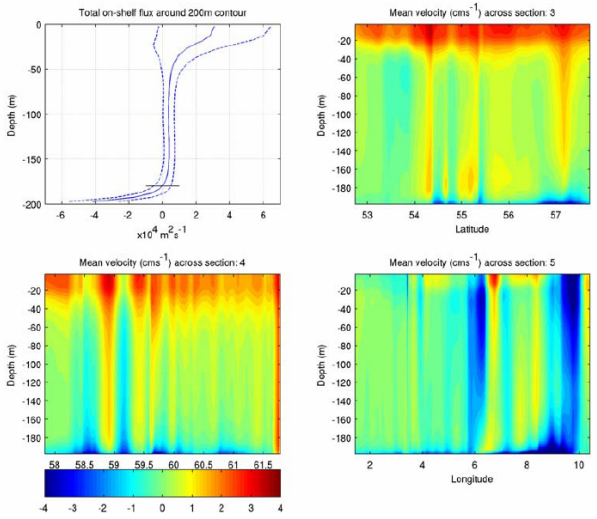
Huthnance et al OS 2009

Tracers



Holt et al BGS 2012

Detailed sections and profiles



Holt et al GRL 2009

Not much open-ocean in this model: Can't identify

- Where water comes from
- Fate of carbon

Need a bigger model…..

Hybrid-Ocean-Shelf Modelling

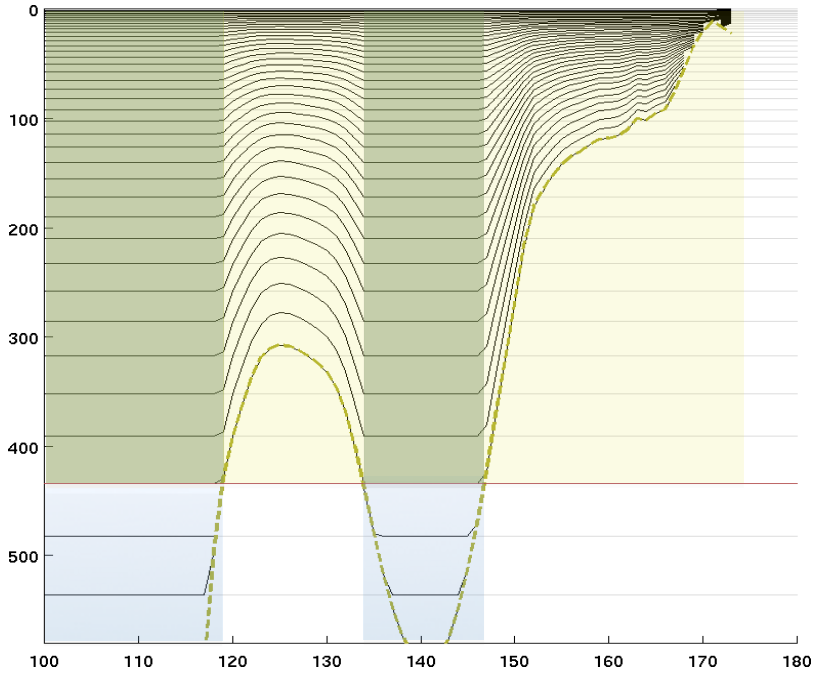
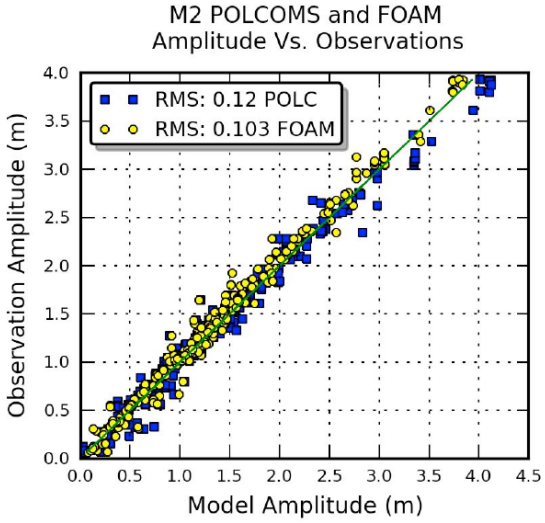


Figure : New transitional vertical coordinate system (SZT).

NEMO: original designed as a global GCM
French and Italian ocean model in CMIP5;
UK in CMIP6, UKESM1

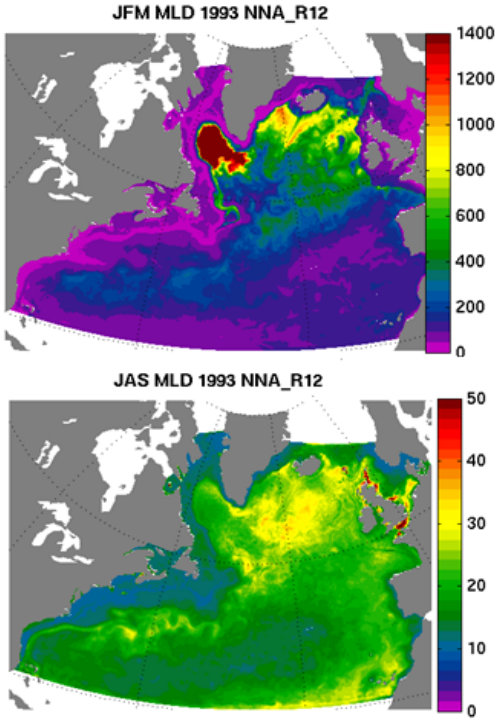
Now developed for shelf sea applications:
Free surface, timesplit surface pressure gradient
Variable Volume
GLS mixing
Hybrid vertical coordinates
O'Dea et al *JOO* 2012



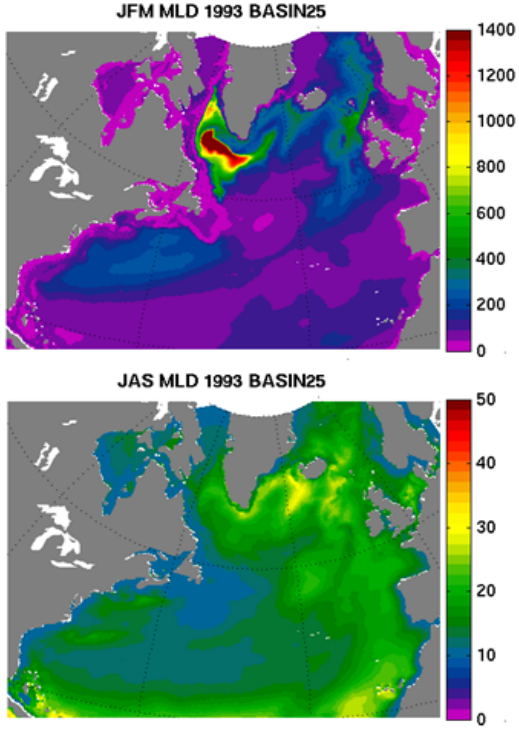
Northern North Atlantic Model

MLD

NEMO-shelf: 1/12

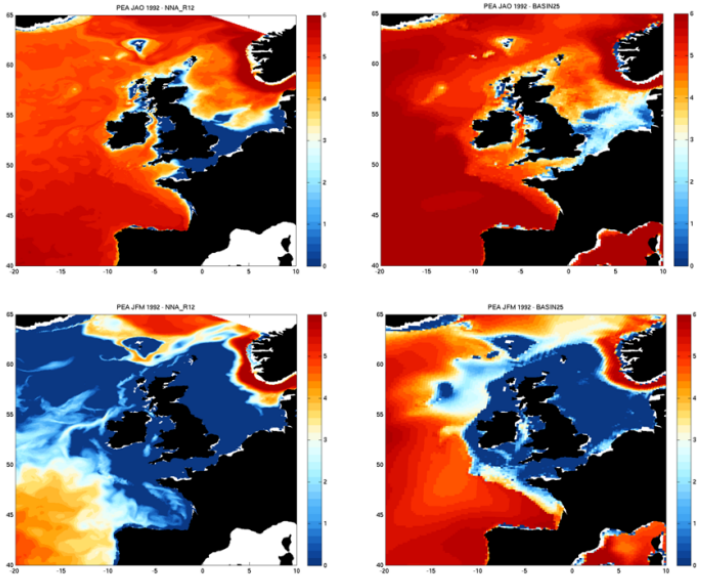


NEMO: 1/4



PEA:

1/12 1/4



NEMO-shelf features in a northern North Atlantic extraction of 1/12 global model

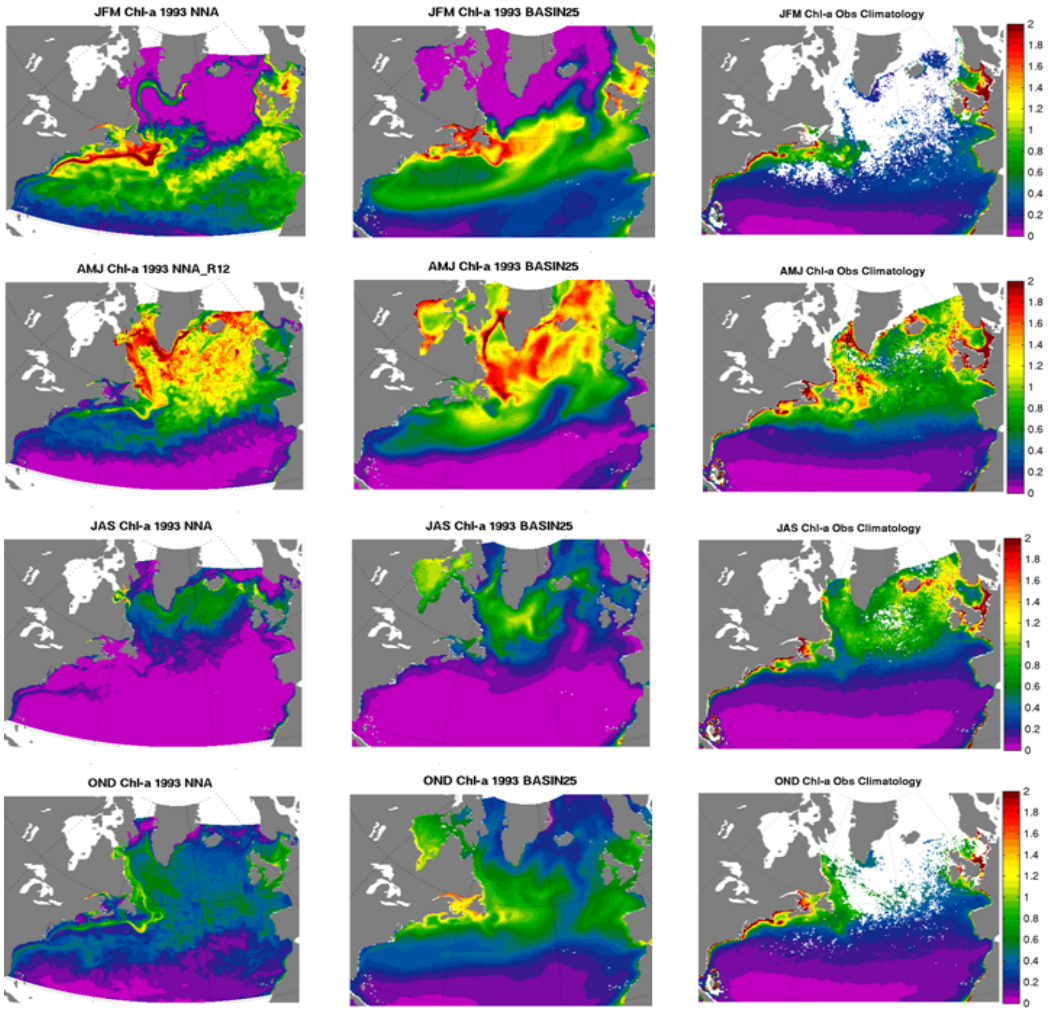
This mixes up changes in resolution, tides, coordinates and turbulence model

Early NEMO-ERSEM NNA results
Thanks to James Harle

NNA NEMO-ERSEM

Surface CHL

NEMO-shelf 1/12 | NEMO ¼ | SeaWiFs



JFM

AMJ

JAS

OND

Pan-Arctic coastal-ocean modelling

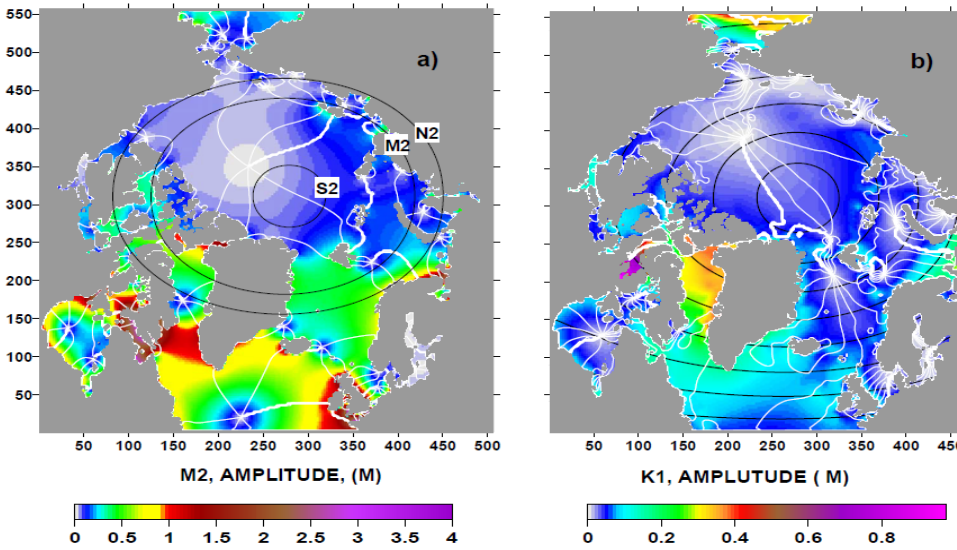
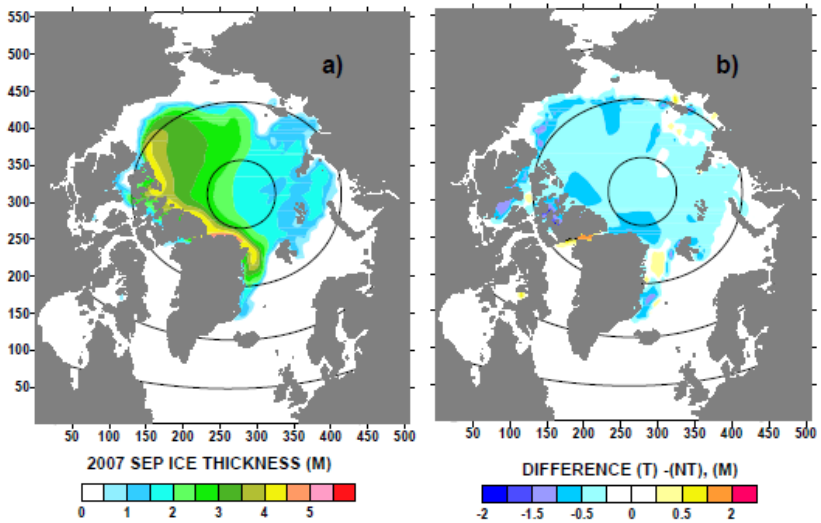
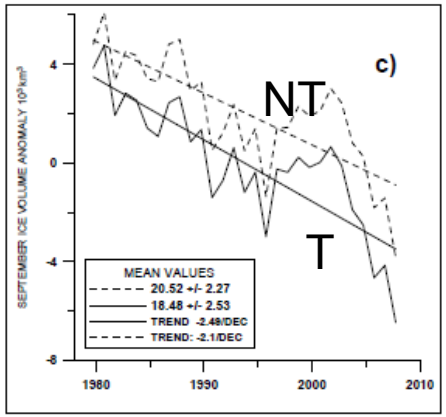


Figure 1

Tides have a substantial effect on ice formation
Relates to several processes including increased shear in clockwise component of ocean-ice boundary layer near critical lat.



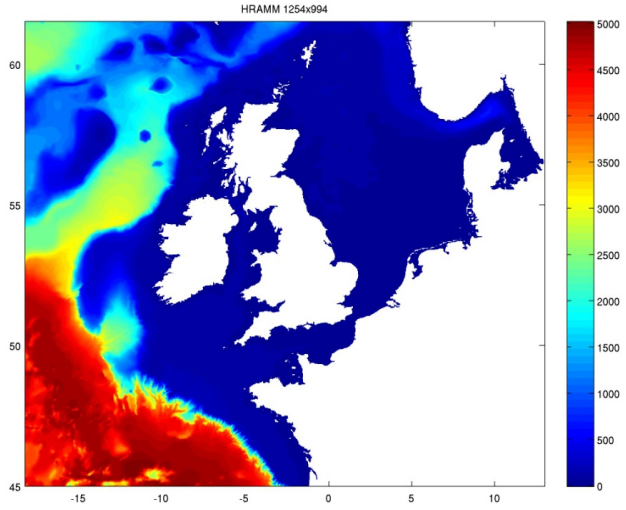


Trends:
NT : - 2.1 x $10^2 km^3 a^{-1}$
T : - 2.5 x $10^2 km^3 a^{-1}$
PIOMASS : - 2.8 x $10^2 m^3 a^{-1}$
with 2008-2010 included.

Luneva et al 'In prep.' for GRL

Conclusions

- On annual to decadal time-scales Ocean-Shelf exchange cannot be neglected in Coastal-Ocean Modelling. Requires
  - Appropriate process and scale representation
  - Robust nesting approaches
  - Basin scale models
- Connections between open-ocean and coastal-ocean modelling communities helps
- Currently building a 1.5km NW European shelf model as part of a regional coupled system



Some light reading….

Edwards, K.P., et al., 2012. Validation of the NEMO-ERSEM operational ecosystem model for the North West European Continental Shelf, Ocean Sci. 8, 983-1000

Holt, J., et al., 2014. Coastal Ocean Circulation Dynamics in: Craig, P., et al. (Eds.), Coupled Coastal Wind-Wave-Current Dynamics. Cambridge University Press

Holt, J., et al., 2014. Physical processes mediating climate change impacts on regional sea ecosystems, Biogeosciences Discussions 11, 1909-1975

Holt, J., et al., 2012. Oceanic controls on the primary production of the northwest European continental shelf: model experiments under recent past conditions and a potential future scenario, Biogeosciences 9, 97-117

Holt, J., et al., 2009. Down-welling circulation of the northwest European continental shelf: A driving mechanism for the continental shelf carbon pump, Geophysical Research Letters 36, L14602 doi:14610.11029/12009GL038997

Huthnance, J.M., et al., 2009. Deep ocean exchange with west-European shelf seas, Ocean science 5, 621-634

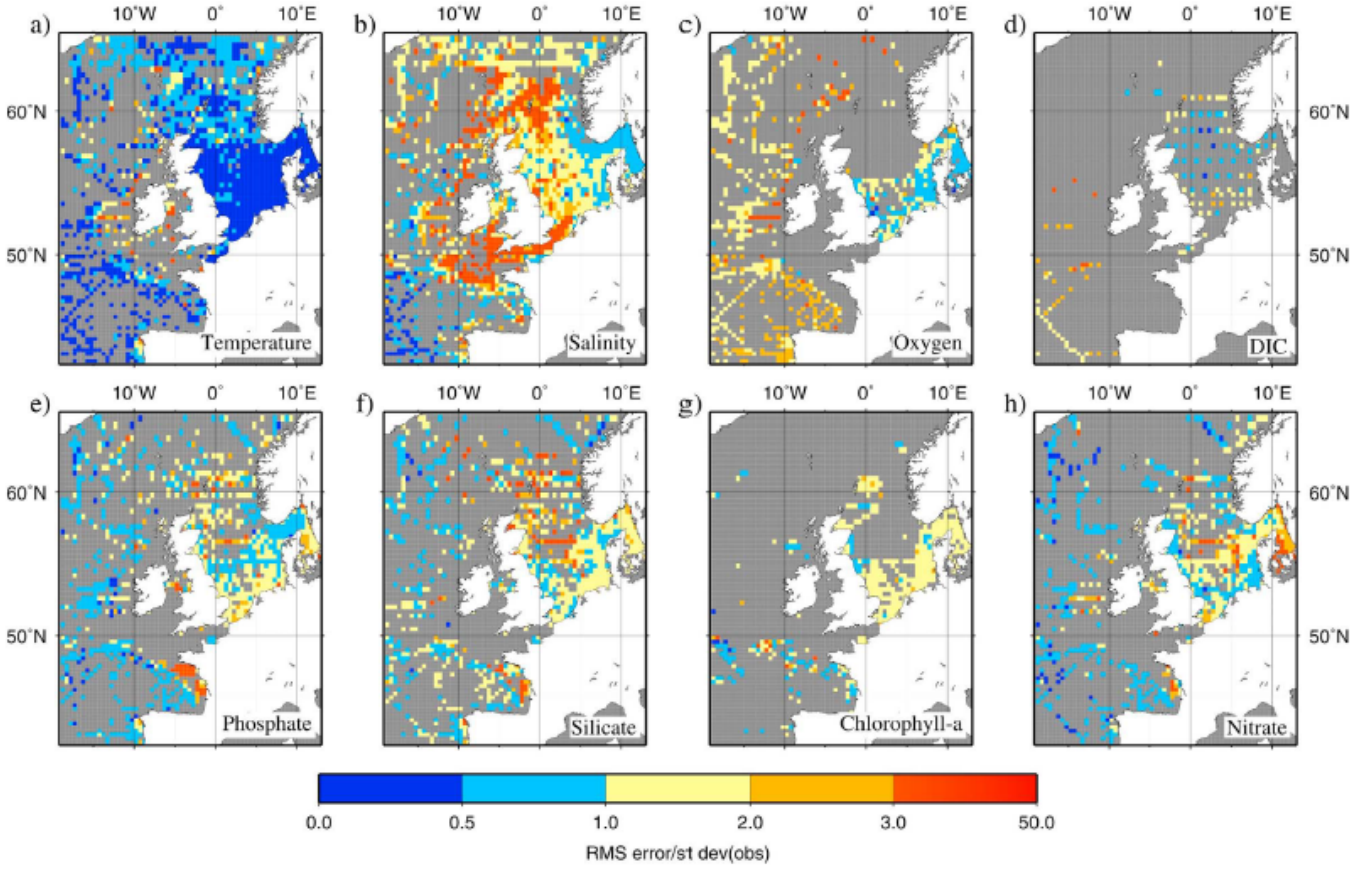
O'Dea, E.J., et al., 2012. An operational ocean forecast system incorporating NEMO and SST data assimilation for the tidally driven European North-West shelf, Journal of Operational Oceanography 5(1), 3-17

Wakelin, S.L., et al., 2012. Modelling the carbon fluxes of the Northwest European Continental Shelf: validation and budgets, Journal of Geophysical Research 117, C05020, doi: 10.1029/2011JC007402

Thank you for your attention…….

Validation

Normalised error: RMSE/σ_o



Over 120k obs for each variables

Wakelin et al JGR 2012

Nucleus for European Modelling of the Ocean

- A partnership between:
  - UK: NOC, Met office
  - France: CNRS, MERCATOR
  - Italy: INGV, CCMC
- Widely used across Europe and internationally,
  - 240 projects in 27 countries (14 in Europe, 13 elsewhere), in excess of 600 registered users worldwide
  - Ocean model in French and Italian IPCC contributions, and for the UK in the next IPCC process
- Open source and freely available

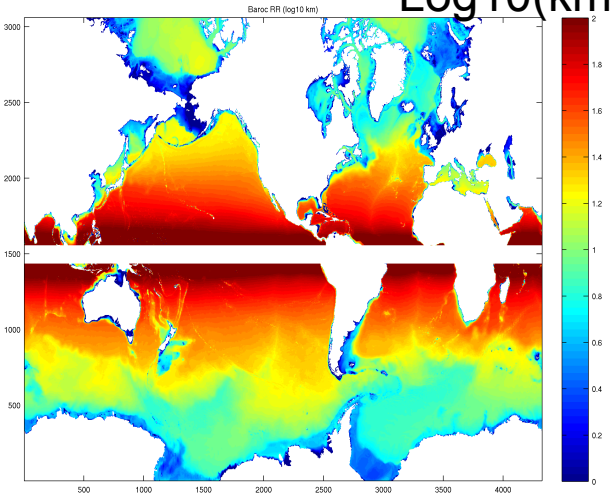
http://www.nemo-ocean.eu

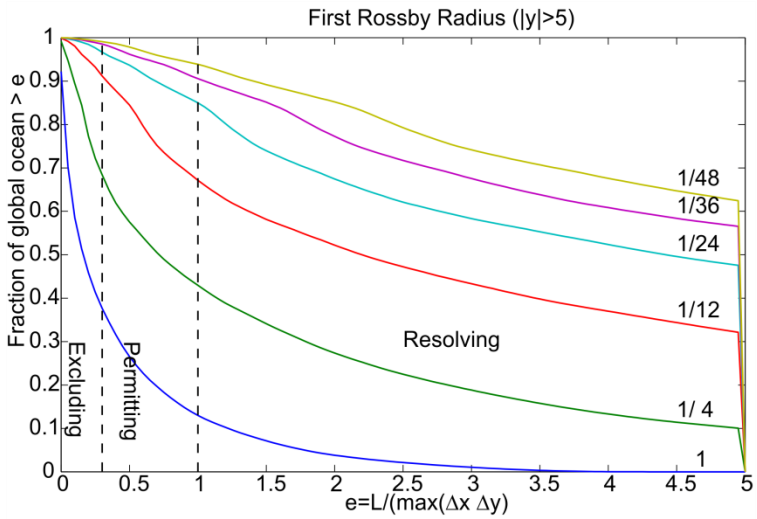
Scales: the motivation for finer resolution

Log10(km)

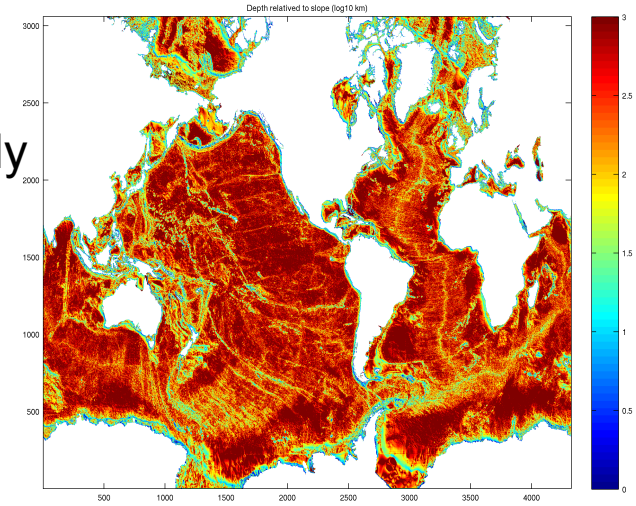
Cumulative distributions

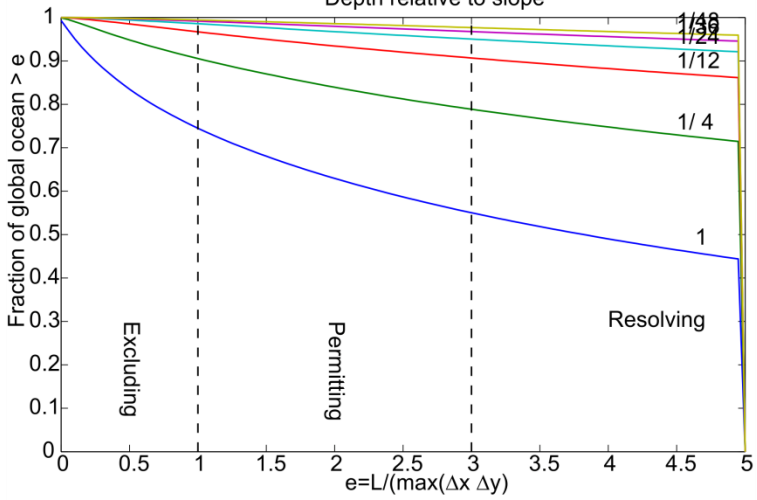
1st Rossby Rad
- •Eddies
- •Fronts
- •Coastal upwelling
- •Internal Tides





H/(dH/dx)
Scale of topographically steered barotropic currents

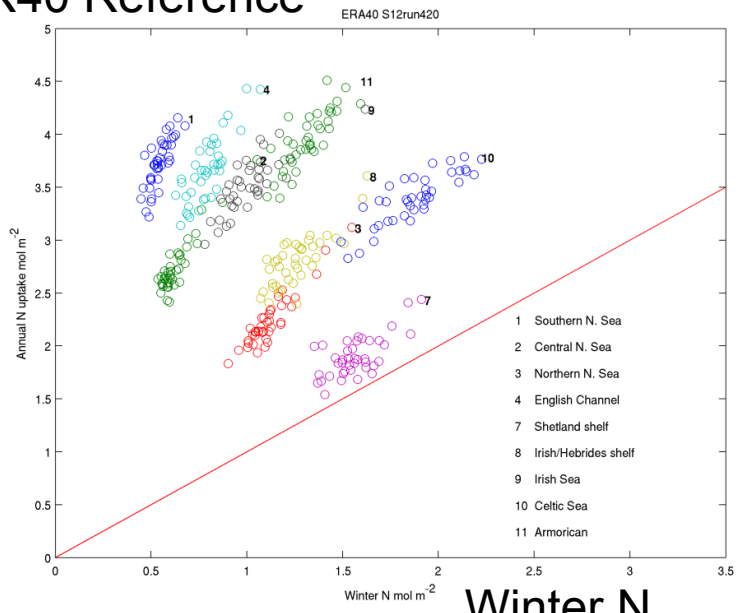


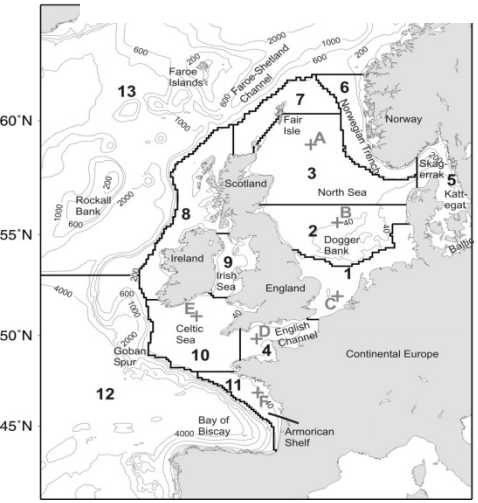


ΔXΔY based on scaling ORCA083

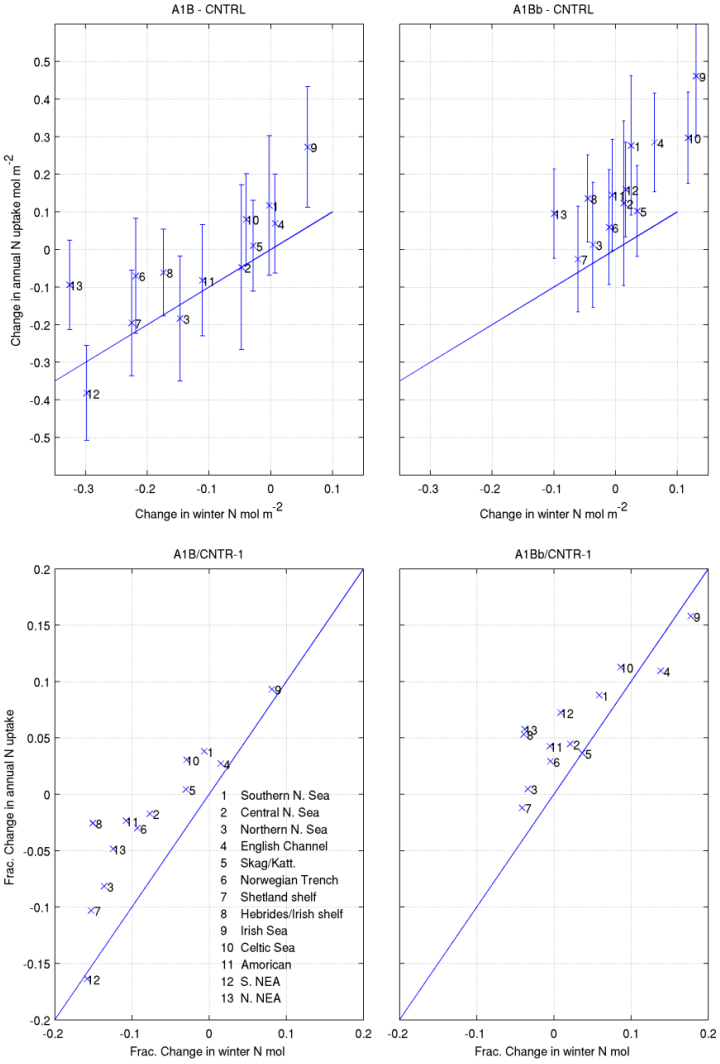
Regional winter N v's N uptake following year

ER40 Reference





A1B - CNTRL



Δ_f Winter N

Holt et al *BGS* 2012