UK Ocean Acidification Research Programme

ROAM

Regional Ecosystem & Biogeochemical Impacts of Ocean Acidification – a Modelling Study.

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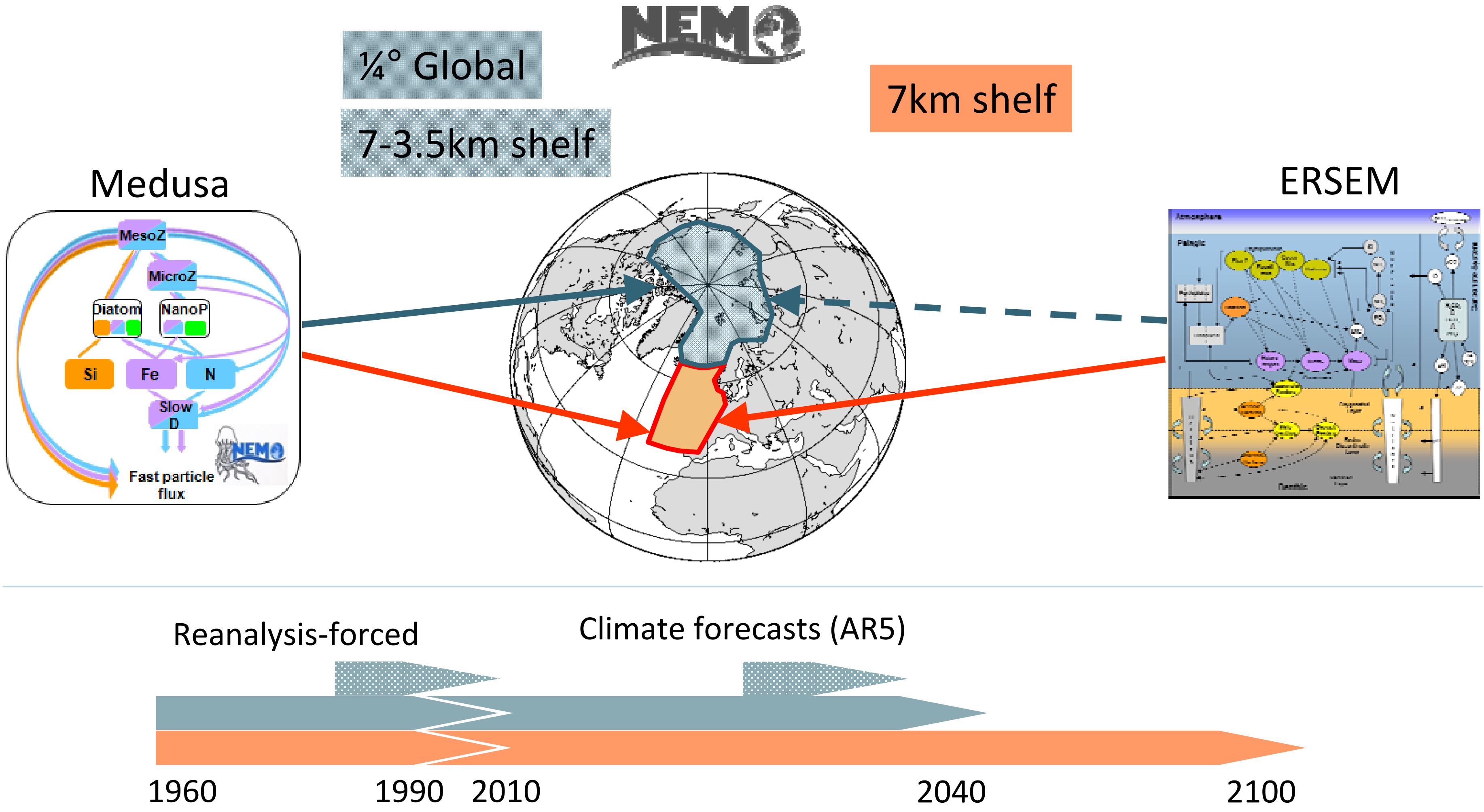
PML PLYMOUTH MARINE LABORATORY

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

Met Office Hadley Centre



Climate forcing from the AR5 simulations. Three emissions scenarios will be considered; relating to changes in radiative forcing of 2.6, 4.5 and 8.5 W/m2 by 2100.

Key science questions:

1. How will forecast CO_2 emission scenarios impact on the spatial and seasonal patterns of carbonate chemistry (pH, , etc.) and other key niche defining parameters (T, O_2) via the processes of ocean acidification, climate moderated hydrodynamics, modified fluvial inputs and biological feedbacks.

2. How will the modified physical controls, biological moderators and atmospheric & terrestrial drivers combine to impact carbon pumping and ocean – shelf coupling from a perspective of both regional carbon cycling and impacts on earth system cycles.

3. How will predicted changes in processes that control, for example, carbon-nutrient stoichiometry, calcification and the microbial – classical food web dynamic impact on the functionality and productivity of the target ecosystems.

Knowledge exchange

The aim is to deliver policy & management ready information by providing quantified spatially resolved indicators of impact with uncertainty estimates related to specified AR5 emission scenarios. Our results will be configured for a range of stakeholders contributing to a knowledge based assessment of impacts and strategies.

- **HMG & IPCC access through the AVOID programme.**
- Non governmental stakeholders.
- International Scientific dissemination.
- Synergies with other programmes.
- Interactions with other elements of the UK OA programme.
- Media
- Factsheet

Possible interactions with other elements of the UK OA programme.

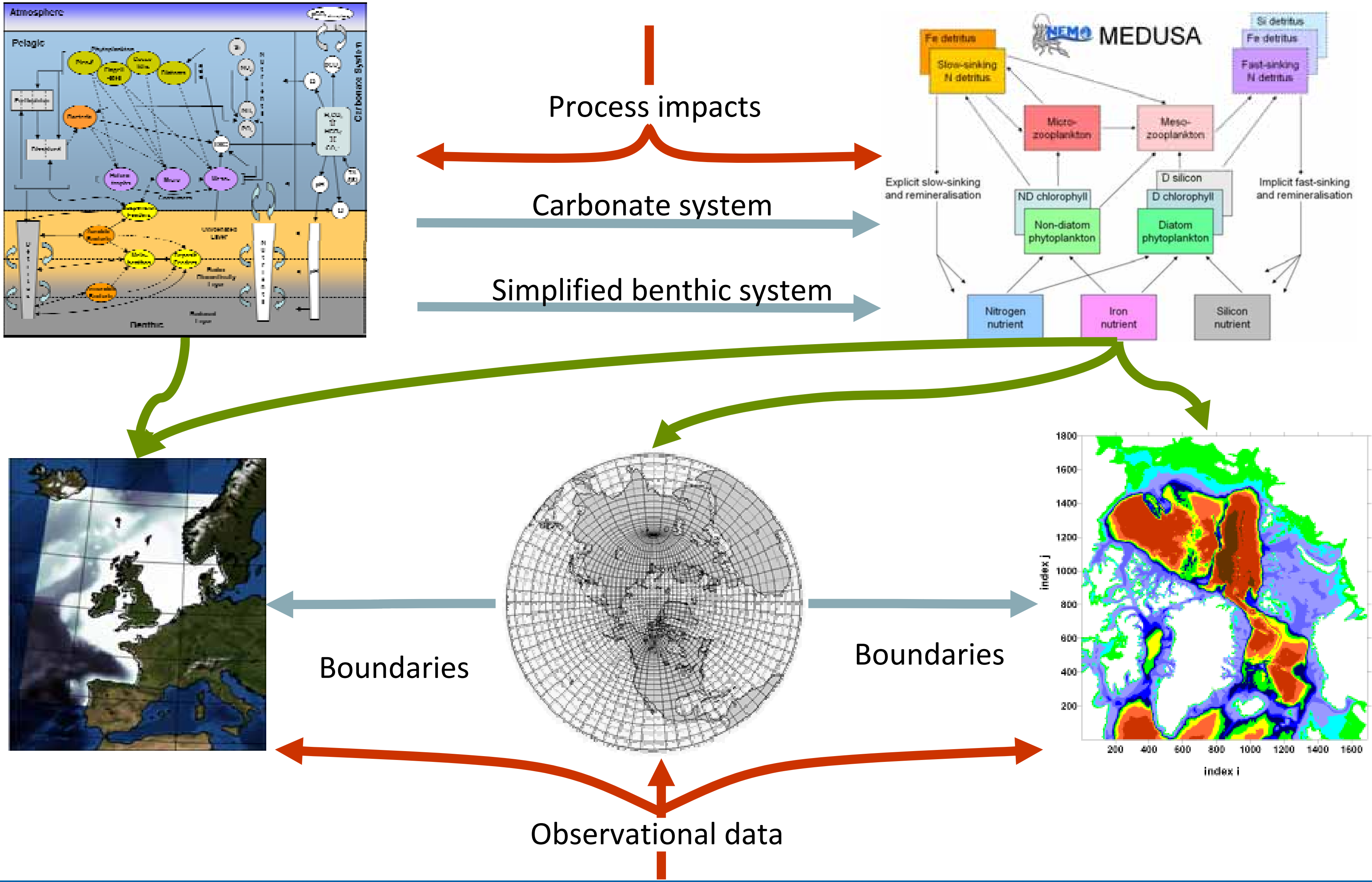
Area A: resource for evaluating the carbonate chemistry. In return: integrated, spatially and temporally resolved estimates of carbon uptake and acidification contributing to area A's aims.

Areas B & C (benthic and pelagic responses): are likely to deliver significant novel insights on specific responses to OA which will, depending on the time frame of delivery, could be tested within our model systems and their impact evaluated.

Area D (commercial species): we will be able to provide spatially and temporally evolving indicators, including fields of carbonate chemistry, temperature, stoichiometry and productivity.

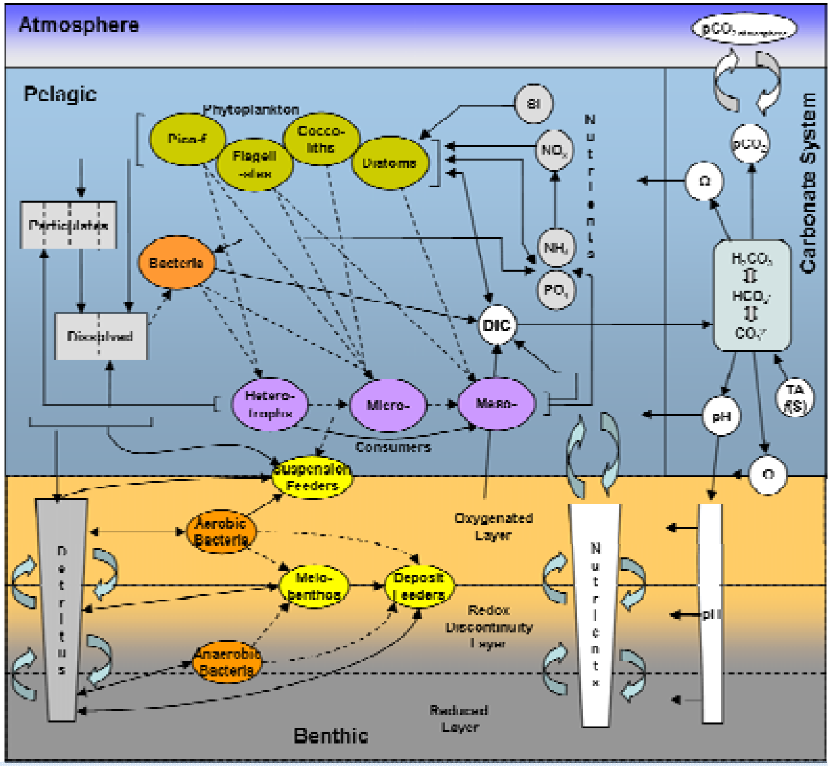
Areas E & F (Paleo): qualitative information on gross system function, identifying long-term rates of change, natural variability and adaptive potential?

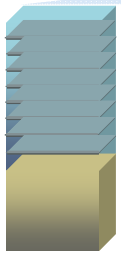
Area G (Global modelling): Identifying potentially globally significant processes or feedbacks, model complexity.

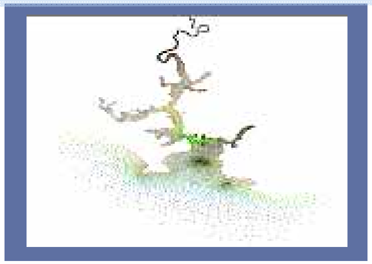

Atmosphere
Pelagic
Benthic
Carbonate System
NEMO MEDUSA
Fe detritus
Slow-sinking N detritus
Si detritus
Fe detritus
Fast-sinking N detritus
Micro-zooplankton
Meso-zooplankton
Explicit slow-sinking and remineralisation
Implicit fast-sinking and remineralisation
ND chlorophyll
D silicon
D chlorophyll
Non-diatom phytoplankton
Diatom phytoplankton
Nitrogen nutrient
Iron nutrient
Silicon nutrient
Process impacts
Carbonate system
Simplified benthic system
Boundaries
Boundaries
Observational data
index j
index i
1800
1600
1400
1200
1000
800
600
400
200
200
400
600
800
1000
1200
1400
1600

NW European Shelf modelling.

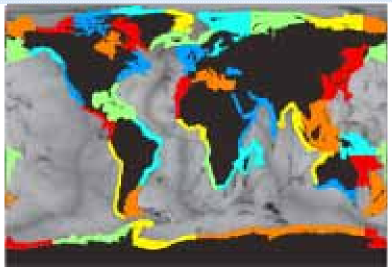
ERSEM / POLCOMS / NEMO
Relatively complex
Variable C:N:P stoichiometry.
Uses standard carbonate system protocols based on DIC & TA.
Includes benthic processes.
(to be developed within the benthic consortium).
Continuation of EPOCA work & complimentary to BIOACID programme.

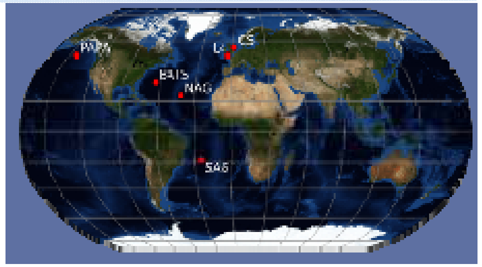



Water –column


Local – fine scale


UK shelf seas


Global shelf seas


Global ocean

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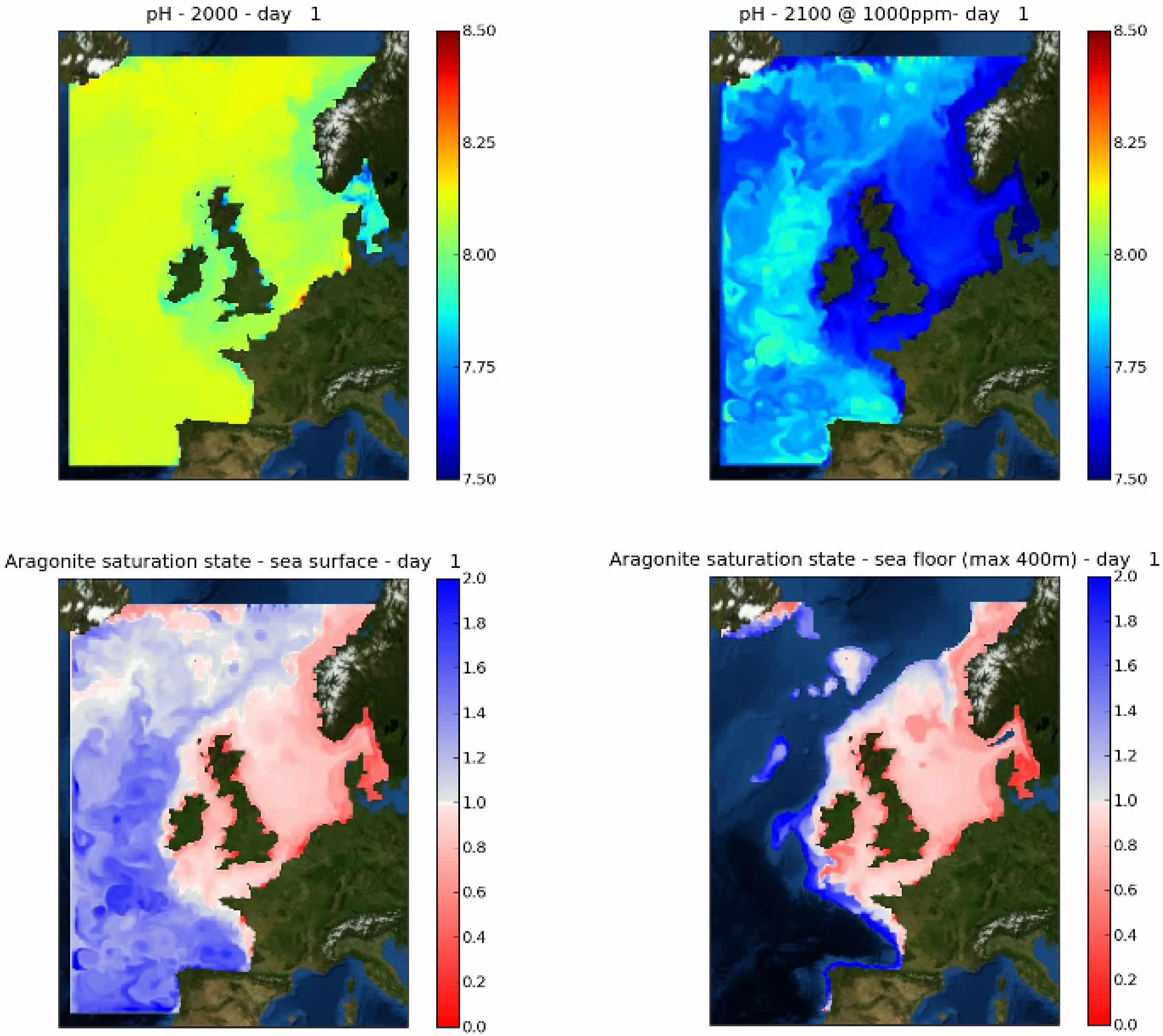
PRESENT pH

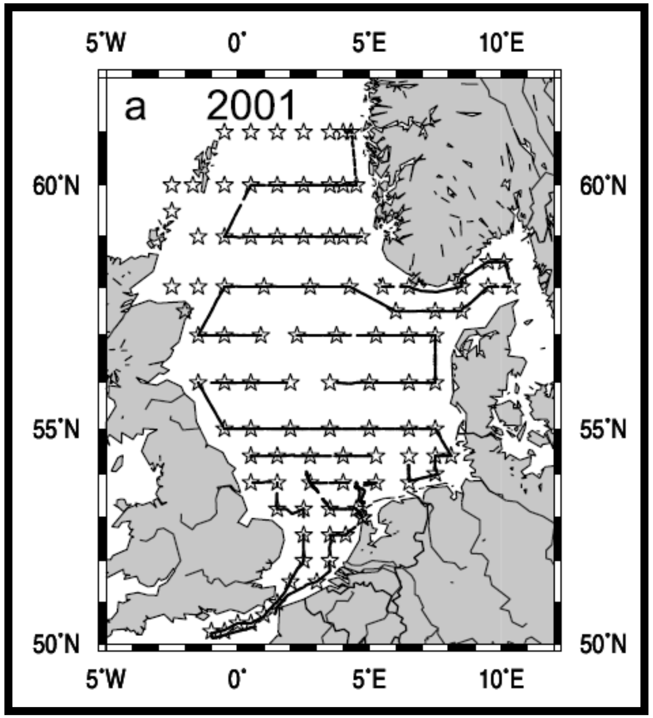
1000ppm: pH

1000ppm Ω surface

1000ppm Ω sea floor



Model Validation



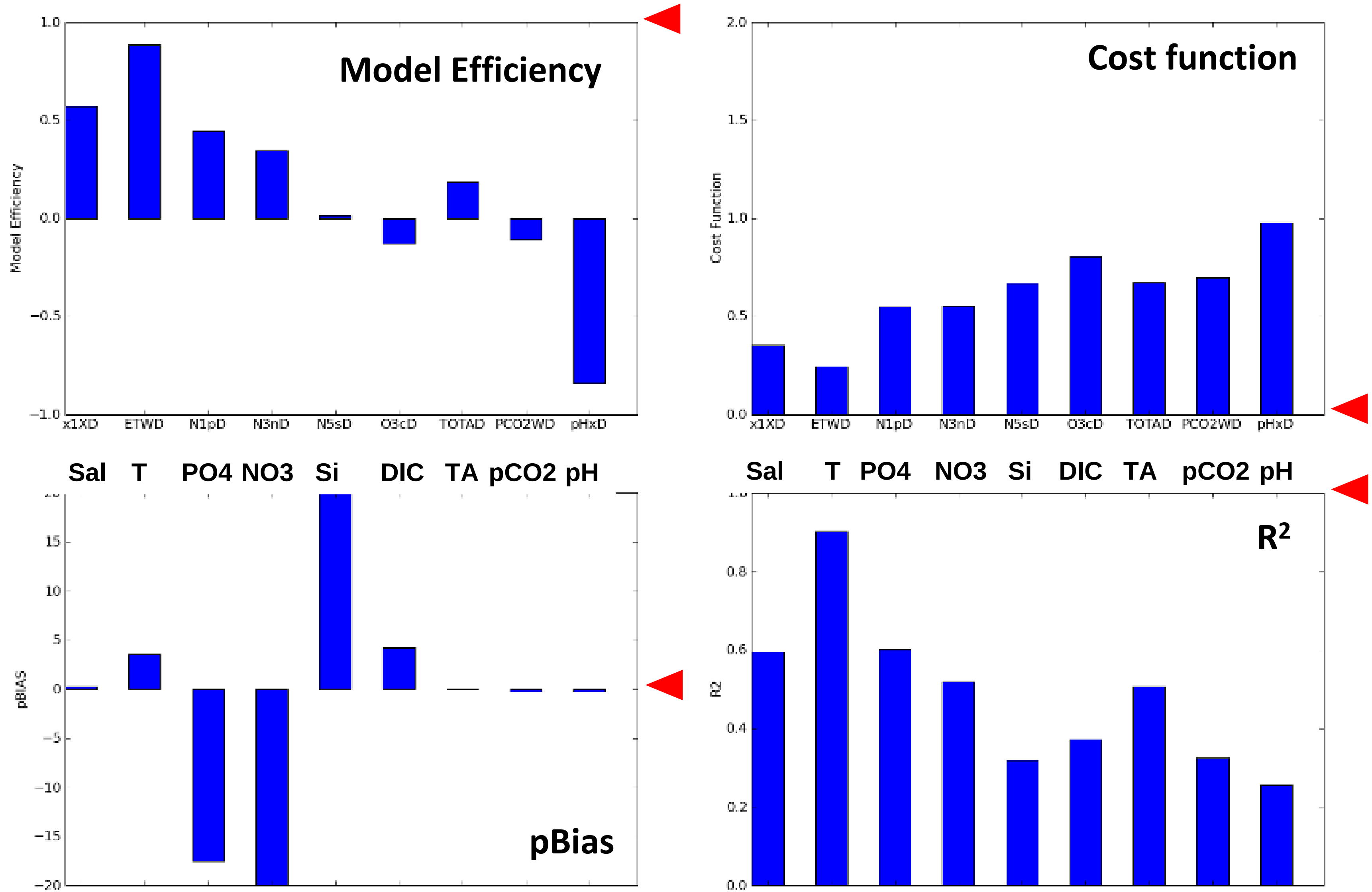
"like-with-like" comparison using the CANOBA dataset: 4 cruises in the North Sea (Thomas et al., Science 2004)

different metrics:

- Model Efficiency (ME - Nash & Sutcliff, 1970)
- Cost Function (CF - OSPAR, 1999)
- Correlation coefficient R^2

$$ME = 1 - \frac{\sum_i (O_i - M_i)^2}{\sum_i (O_i - \overline{O})^2}$$

$$CF = \frac{1}{N} \sum_i \frac{|O_i - M_i|}{\sigma_O}$$


Model Efficiency
Model Efficiency
1.0
0.5
0.0
−0.5
−1.0
x1XD
ETWD
N1pD
N3nD
N5sD
O3cD
TOTAD
PCO2WD
pHxD
Cost function
Cost Function
2.0
1.5
1.0
0.5
0.0
x1XD
ETWD
N1pD
N3nD
N5sD
O3cD
TOTAD
PCO2WD
pHxD
Sal T PO4 NO3 Si DIC TA pCO2 pH
Sal T PO4 NO3 Si DIC TA pCO2 pH
pBias
pBIAS
15
10
5
0
−5
−10
−15
−20
R2
R^2
0.8
0.6
0.4
0.2
0.0

Issues:

Total Alkalinity

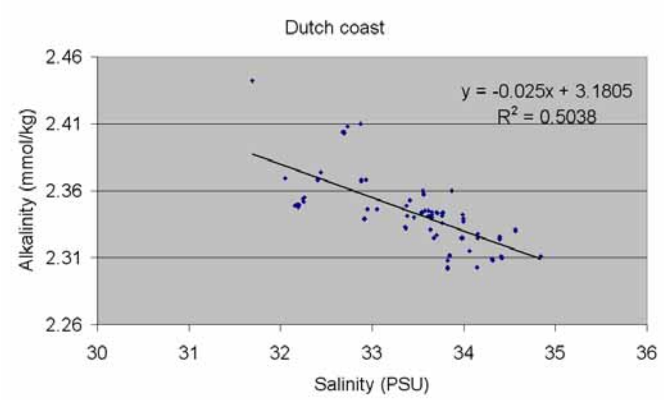
$TA=f(S)-DNO_3+DNH_4-DPO_4+TA_{riv}$

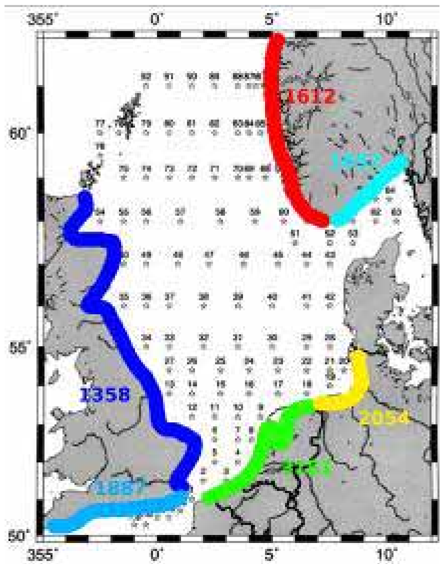
Riverine alkalinity extrapolated from the Canoba dataset.

Organics?

Calcification function (currently after Merico/Tyrrell, 2006)

Other impacts of increased CO_2 – consensus???





Model of Ecosystem Dynamics, nutrient Utilisation, Sequestration and Acidification

Overview

NOC-S activities for ROAM will utilise a global instance of the NEMO GCM and the MEDUSA ecosystem model in a series of hindcast and forecast (to 2050; using UKMO IPCC AR5 output) simulations

The focus of analysis will be on acidification- and climate-driven changes to carbonate chemistry and impacts on plankton actors in the NW European Shelf and Arctic Ocean

Simulations will use ¼-degree NEMO to overlap complementary regional models at PML and NOC-L; spin-up and sensitivity runs will utilise 1-degree NEMO

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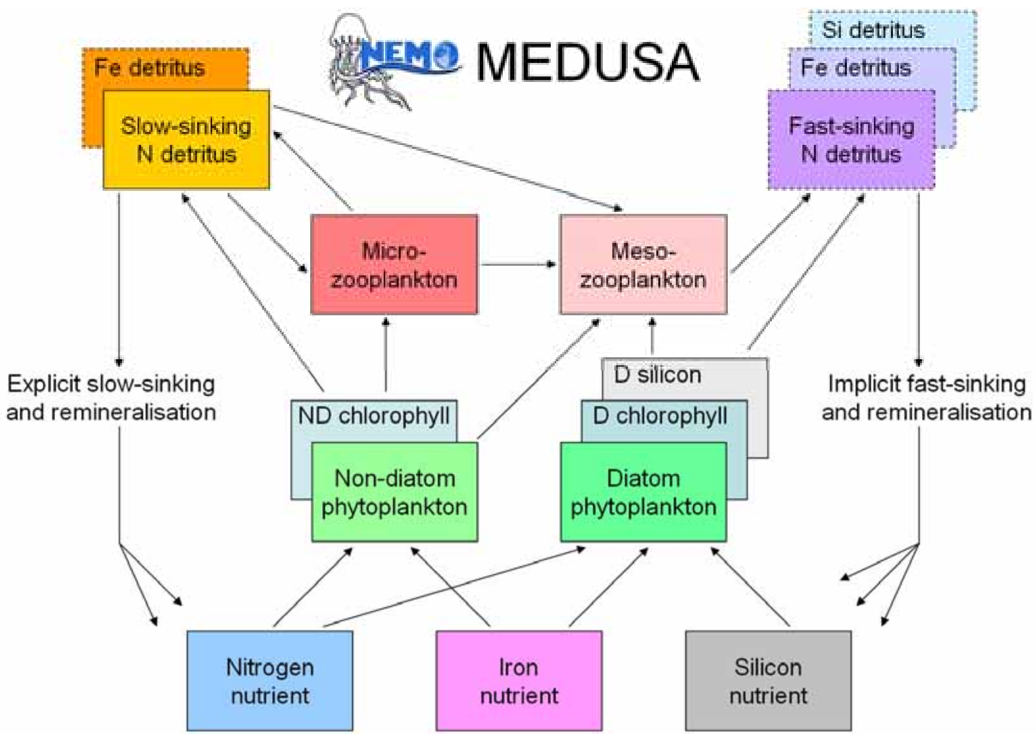
NEMO



- Nitrogen-based plankton ecosystem model
- Size-structured plankton community (P2-Z2-D2)
- Simplified iron cycle to permit HNLC regions
- Silicon cycle for export-important diatoms
- Slow- / fast-sinking detritus pathways for export
- Inclusion of ballast model of export remineralisation
- Favoured complexity level and lower computational cost compared to rivals

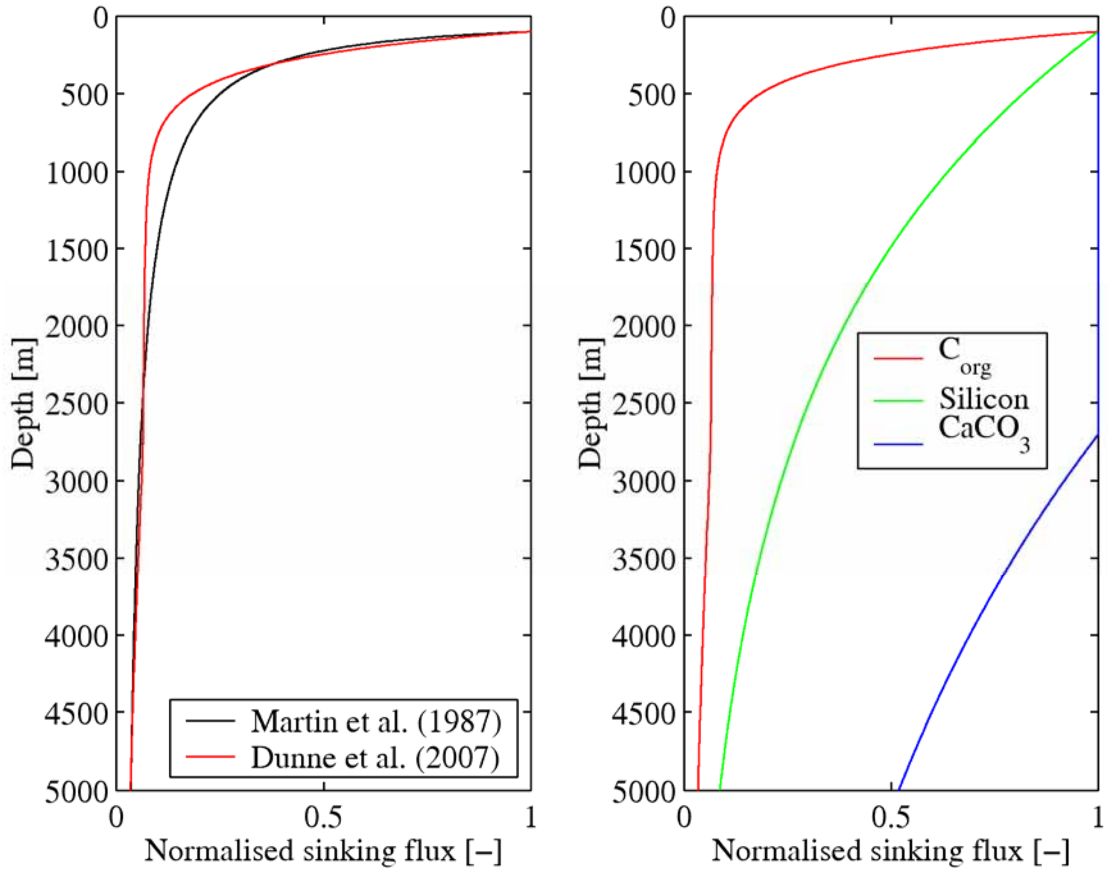
In MEDUSA, calcium carbonate production occurs as a function of local primary production and latitude:

$$CaCO_3 = PP * f(\text{latitude})$$

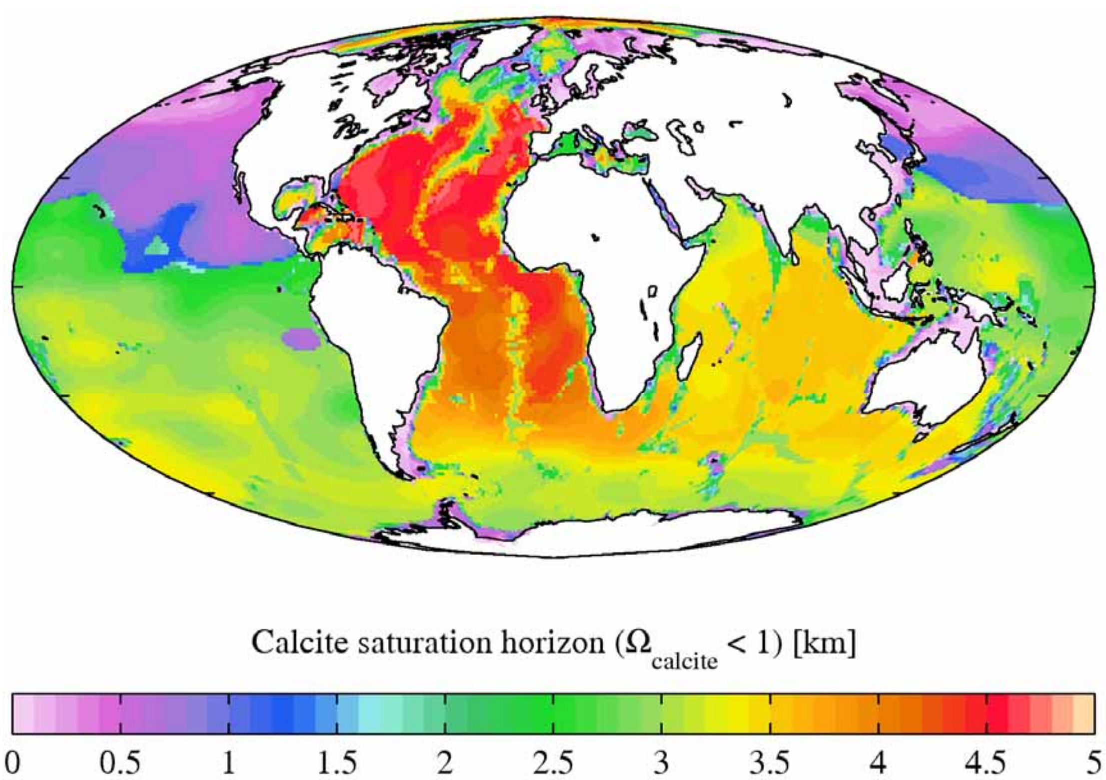
Where *f* is 0.1 at the equator and 0.02 at the poles

$CaCO_3$ is then used within the fast-sinking detrital submodel in its ballast calculations

Is this description sufficient?



NEMO



$CaCO_3$ in fast-sinking detritus is then allowed to dissolve below the local CCD

This is calculated from fields in the GLODAP climatology, and is much deeper in the Atlantic than the Pacific

Since carbon and alkalinity are not currently implemented in MEDUSA, this CCD field is fixed

NEMO

Questions and comments

- UKMO's simulations for IPCC AR5 cover a range of different scenarios but only a handful can be run; are there particular ones that the UKOARP community would prefer?
(AR5 scenarios: radiative forcing of 2.6, 4.5 and 8.5 W/m2 by 2100.)

- MEDUSA has a highly simplified calcification submodel that assumes a basic geographical gradient (cf. Dunne *et al.*, 2007); are there any particularly favoured alternatives?

- ROAM workflow is extremely tight (e.g. simulations at ¼ will take ~1 year) so specification decisions will be made soon

Popova *et al.*: Control of primary production in the Arctic by nutrients and light: insights from a high resolution ocean general circulation model, *Biogeosciences* **7**, 3569-3591, 2010.
Yool *et al.*: MEDUSA: A new intermediate complexity plankton ecosystem model for the global domain, *Geoscientific Model Dev. Discuss.*, 2010.

WP 1 Model development (Tom)

Task 1.1 Nemo development, shelf, ocean, ice	*(M 1-12)*
Task 1.2 Model development	*(M 3-12)*
Task 1.3 Forcing and evaluation data	*(M 1-18)*
Task 1.4 Acidification and climate driven responses	*(M 9-24)*

WP 2 Hindcast simulations & evaluation. (Katya)

Task 2.1 Hindcast Simulation	*(M 12-24)*
Task 2.2 Evaluation and intercomparison	*(M 18-27)*

WP 3 Prediction. (Jason)

Task 3.1 Forecast simulations	*(M 12-32)*
Task 3.2 Forecast analysis	*(M 24-35)*

WP 4 Knowledge transfer & Community Interactions. (Jerry)

project deliverables

Month	Task	Deliverable
1	4	Project fact sheet / summary distributed & publicised ☑
12	4	Lead & contribute papers to special session at AMEMR **www.amemr.info**
12	M	First annual progress report
24	2.1	Hindcast simulations archived, available in netCDF format.
24	M	Second annual progress report
32	3.1	Forecast scenarios archived, available in netCDF format.
36	4	Project summary report for stakeholders
36	4	Educational fact sheet distributed and publicised
36	4	Model forecasts with interpretation delivered to HMG via AVOID
36	M	Final project synthesis report

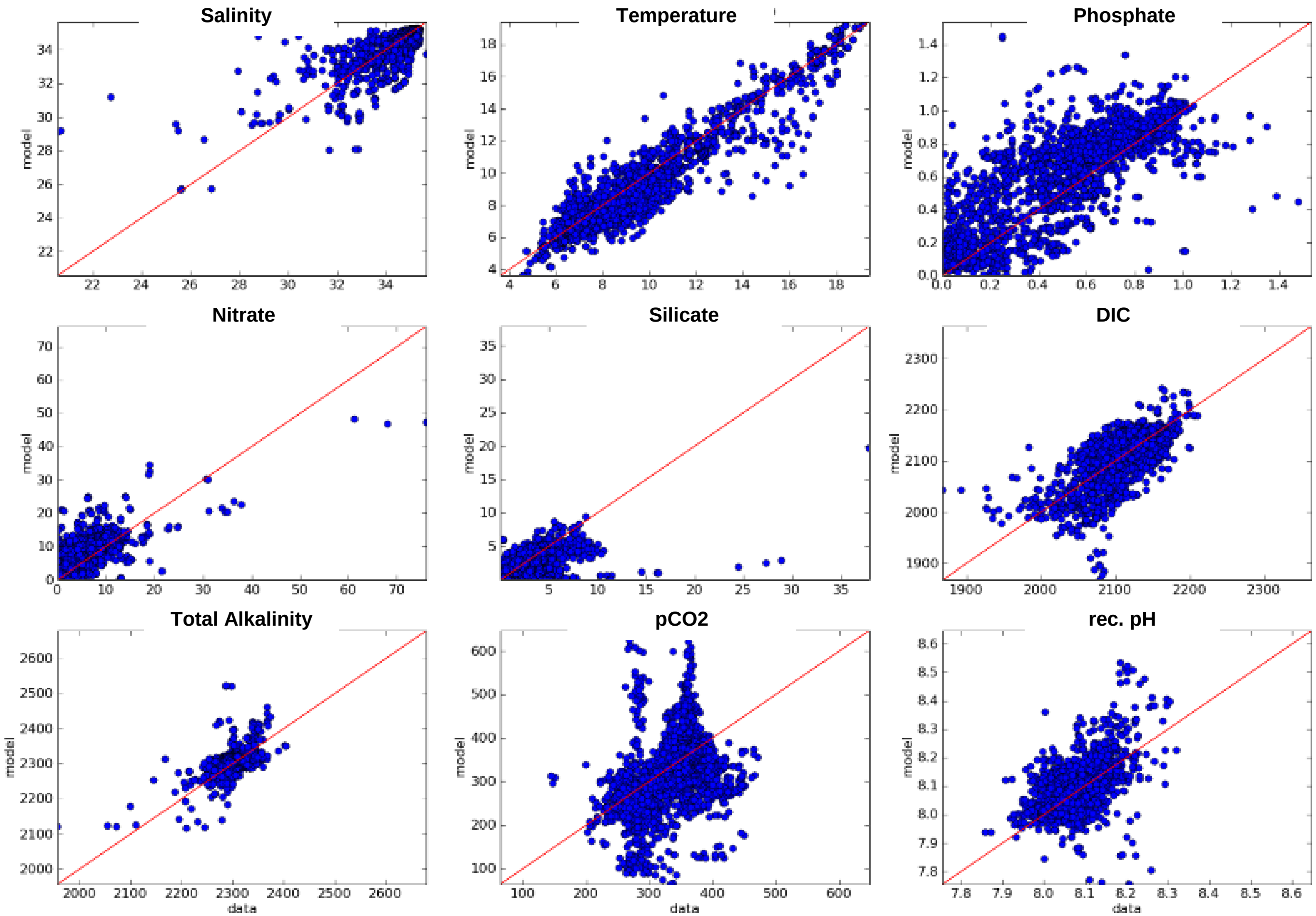
Impact Plan

- engage with stakeholders to optimise our research and subsequent knowledge transfer
- directly transfer our scientific advances to end users.
- provide data and advice to policy makers on the magnitude and timescale of risks and underpin the development of mitigation and adaptation strategies.
- work with the KE coordinator to maximize access to relevant UK and International stakeholders.

stakeholders:

- Policy makers and government agencies and regulators (e.g. Defra, DECC, MPs, MSPs, MEPs, Marine Scotland, Environment Agency).
- Conservation agencies, *e.g.* Natural England & the IUCN
- Environmental NGOs Greenpeace, FoE, WWF and the general public.
- Research communities EPOCA, BIOACID, MEECE, UKOARP
- Inter governmental organisations IPCC, OSPAR,
- Organisations with commercial and non-commercial interests

Validation results scatterplots



Recent work

Popova *et al.*: Control of primary production in the Arctic by nutrients and light: insights from a high resolution ocean general circulation model, *Biogeosciences* **7**, 3569-3591, 2010.

- ¼° resolution hindcast simulation (1988 to 2007)
- Focus on MEDUSA's performance in Arctic
- Derivation of empirical algorithm that correlates PP with physical factors

Yool *et al.*: MEDUSA: A new intermediate complexity plankton ecosystem model for the global domain, *Geoscientific Model Dev. Discuss.*, 2010.

- 1° resolution hindcast simulation (1958 to 2007)
- Full MEDUSA description (including code)
- Focus on MEDUSA "equilibrium" performance at global scale
- Evaluated against nutrient, chlorophyll, PP metrics