Modelling short-term & long-term variability in air-sea CO_2 exchange

Rosa Barciela, Matt Martin, John Hemmings and many others.

Modelling ~~short-term & long-term~~ variability in air-sea CO_2 exchange

Rosa Barciela, Matt Martin, John Hemmings and many others.

Outline

- Aims
- Modelling framework
- Model results
- Assimilation of satellite-derived chlorophyll
- Applications
- Conclusions

What are the aims?

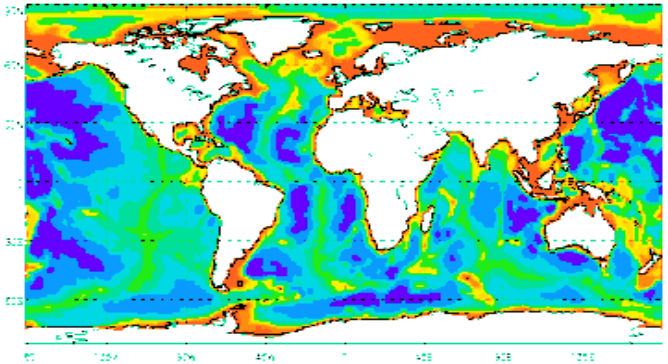
- This work is part of the Centre for observation of Air-Sea Interactions and fluXes (CASIX), a NERC-UK project.
- The primary goal of CASIX is to quantify accurately the global air-sea fluxes of carbon dioxide.
- More accurate knowledge of the ocean biology is also required for:
  - water clarity predictions.
  - improvement of light attenuation estimates: SST, MLD, sea-ice.
  - the Royal Navy's ability to minimise risks to the maritime environment when deploying active sonar systems.
  - supplying boundary conditions for the Shelf Seas system.

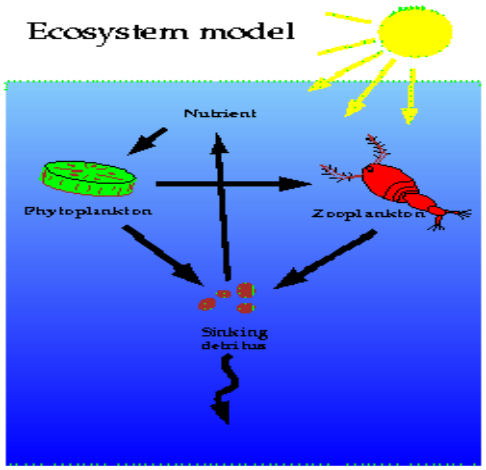
What tools are we using?

- Coupling together (on-line!) two models …

  – FOAM

    Forecasting Ocean Assimilation Model





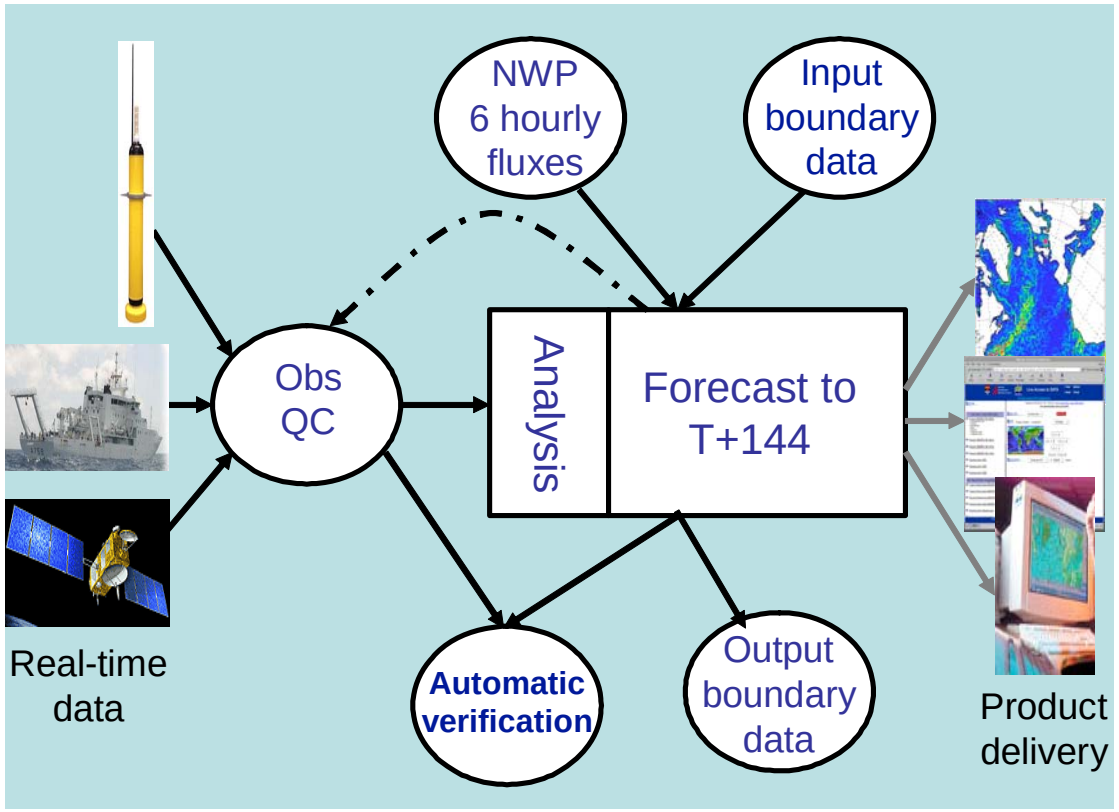
  – HadOCC

    Hadley Centre Ocean Carbon Cycle Model

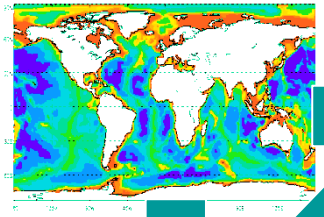
Forecasting the open ocean: the FOAM system

- Operational real-time deep-ocean forecasting system
- Daily analyses and forecasts out to 6 days
- Low resolution global to high resolution nested configurations
- Relocatable system deployable in a few weeks
- Hindcast capability (back to 1997)
- Assimilates T and S profiles, SST, SSH, sea-ice concentration

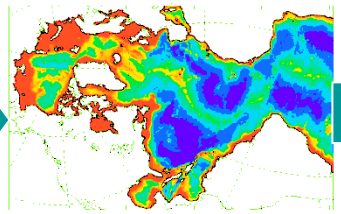
FOAM = Forecasting Ocean Assimilation Model



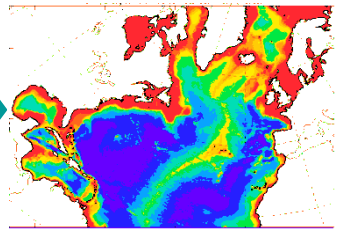
Overview of the current FOAM system: *Operational configurations*



1º Global

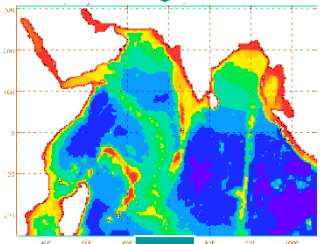


36km (1/3º) North Atlantic and Arctic

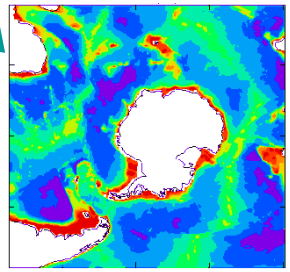


12km (1/9º) North Atlantic

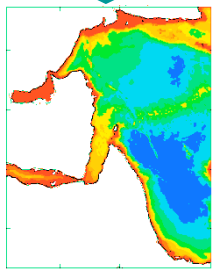
Boundary data for shelf-seas



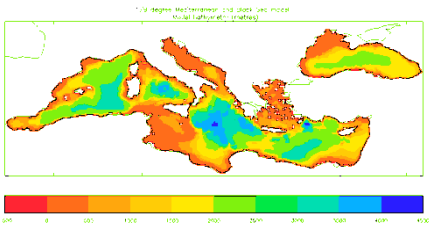
36km (1/3º) Indian Ocean



27km (1/4º) Antarctic



12km (1/9º) Arabian Sea



12km (1/9º) Mediterranean

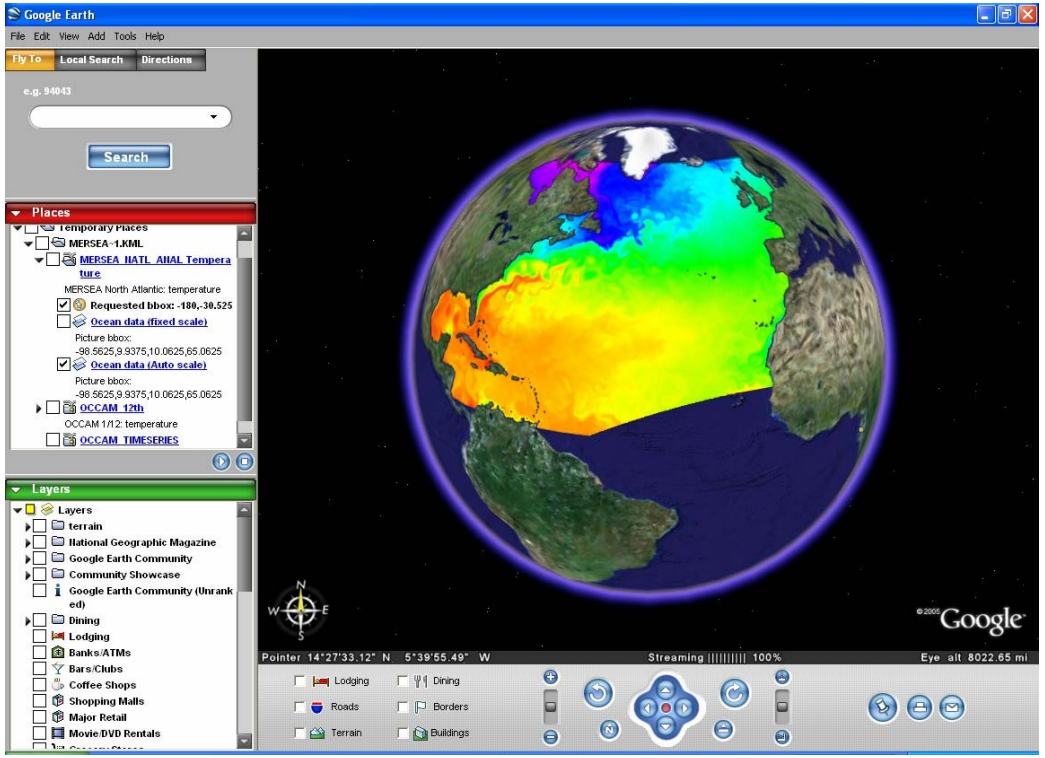
- All configurations have 20 vertical levels
- All run daily in the operational suite

Overview of the current FOAM system: *Products distribution*

- Direct links to UK Royal Navy forecasters.
- For commercial use, data is available from the Met Office's Data and Products Distribution System (DPDS) at http://www.metoffice.gov.uk/research/ncof/foam/dpds.html

• Data available for research use from Live Access Server at http://www.nerc-essc.ac.uk/godiva/

• A new prototype data server has been developed and is undergoing testing. One new advance with this server is the ability to visualise NCOF data using Google Earth.

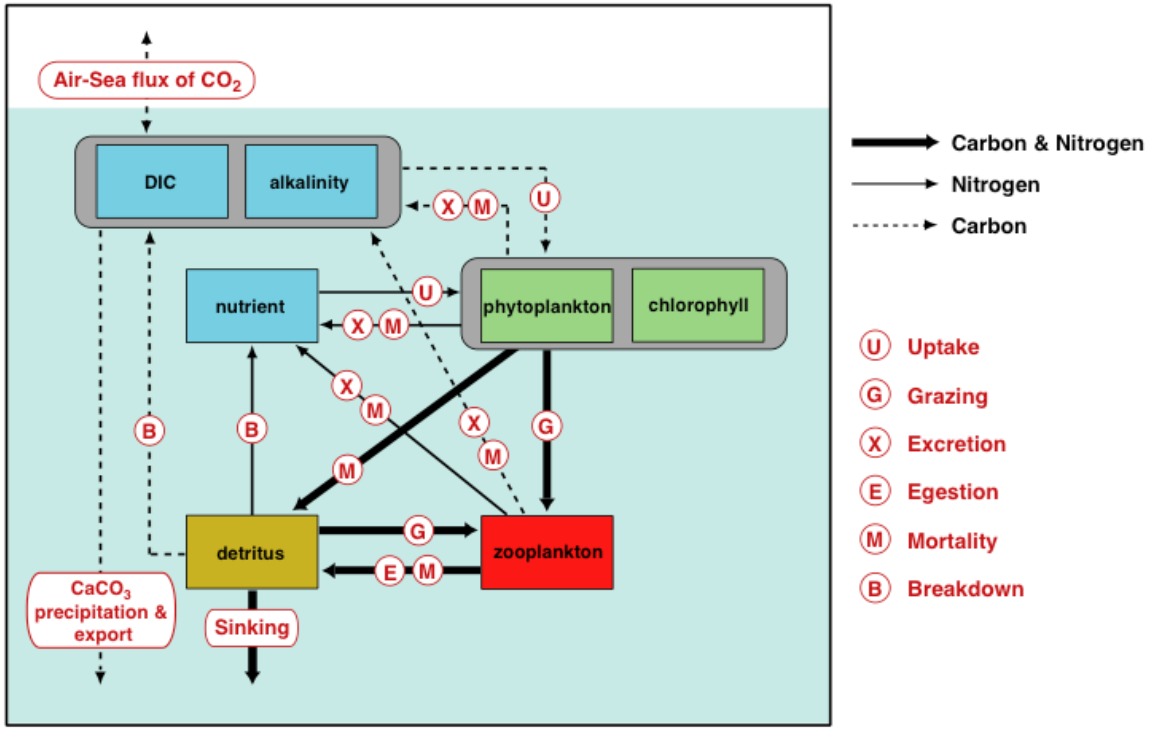


Hadley Centre Ocean Carbon Cycle Model

- HadOCC is a NPZD (plus DIC and alkalinity) biogeochemical model used at the Hadley Centre for climate studies.

- HadOCC has been coupled (on-line!) within the FOAM system.

- Initial tests have been run with 1˚ global, 1/3˚ NA and Arctic and 1/9˚ NA FOAM configurations.



Palmer, J.R. & Totterdell, I.J. (2001). Deep-Sea Research I, 48, 1169-1198

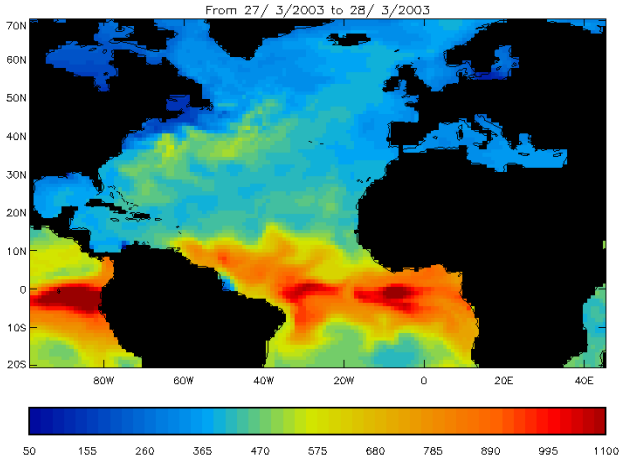
Model Results

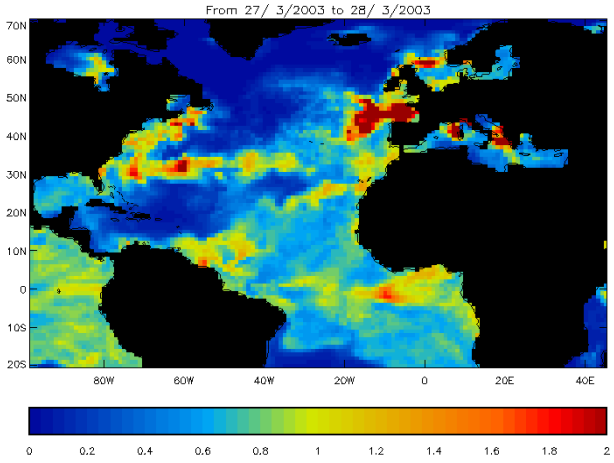
FOAM-HadOCC –
1º global & 1/3º North Atlantic & Arctic resolution

pCO_2 (ppm)

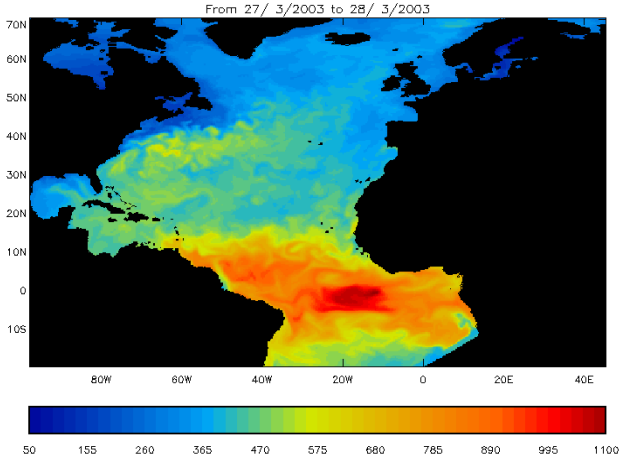
Chlorophyll (mg m^{-3})

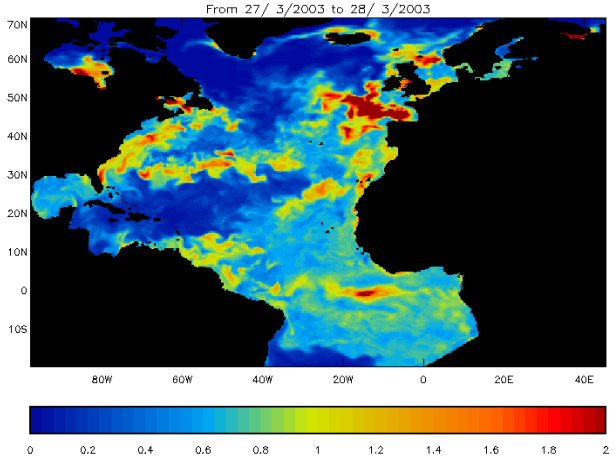
1º global





1/3º NA

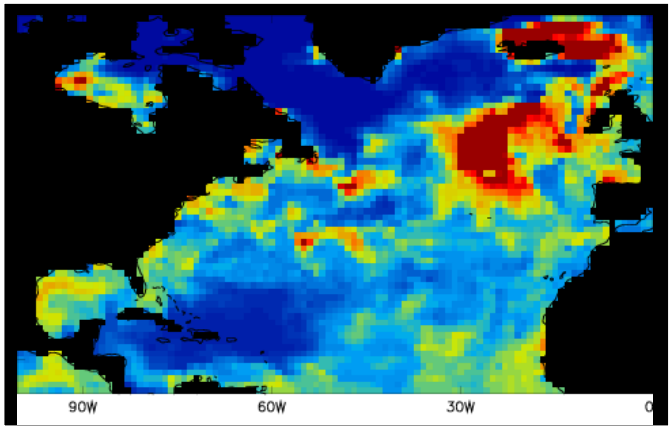


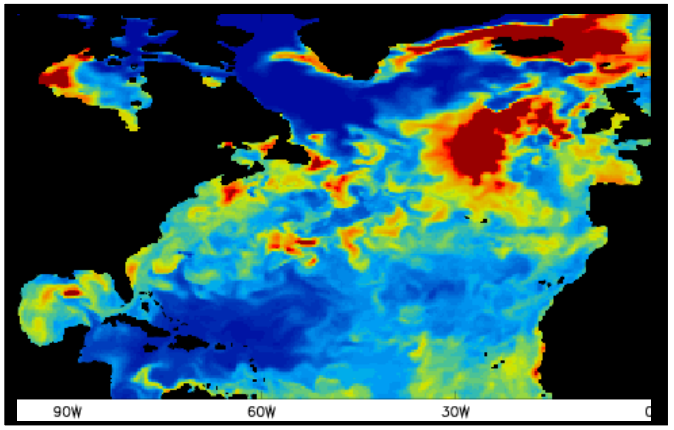


FOAM-HadOCC *versus* SeaWiFS

Daily mean North Atlantic fields for 20th April 2003

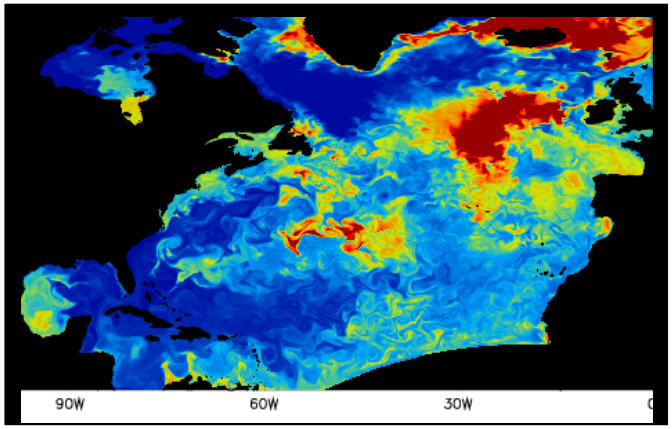
1º Global

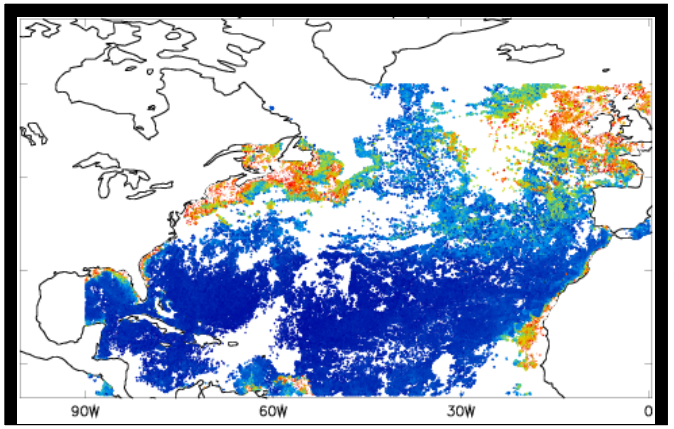




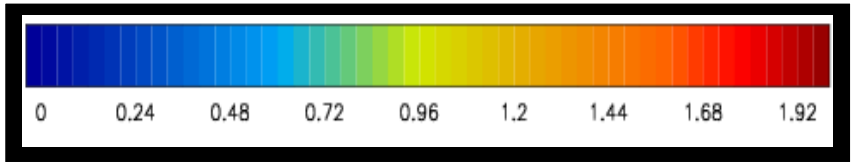
1/3º North Atlantic & Arctic

1/9º North Atlantic



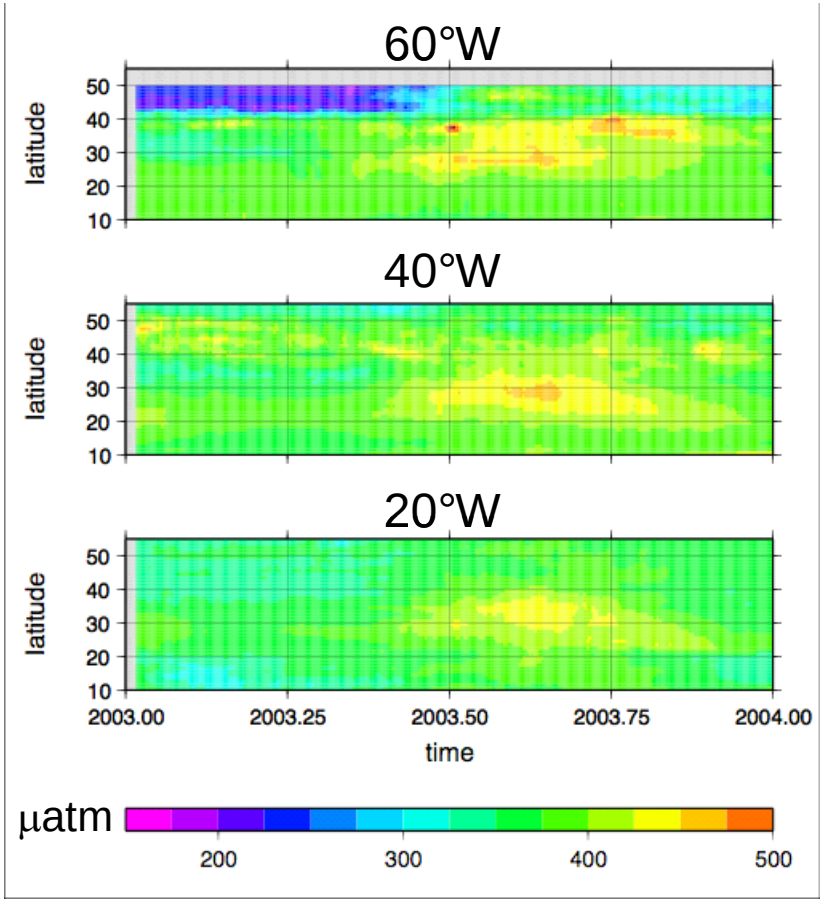


SeaWiFS 5-day composite

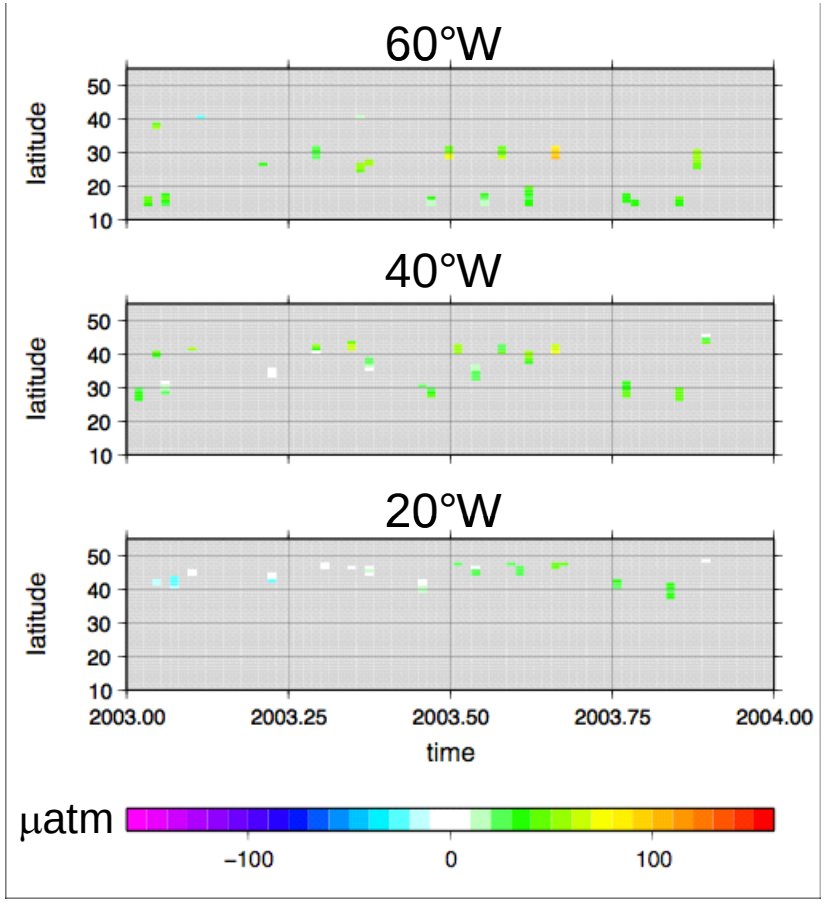


Surface pCO_2

1° Model



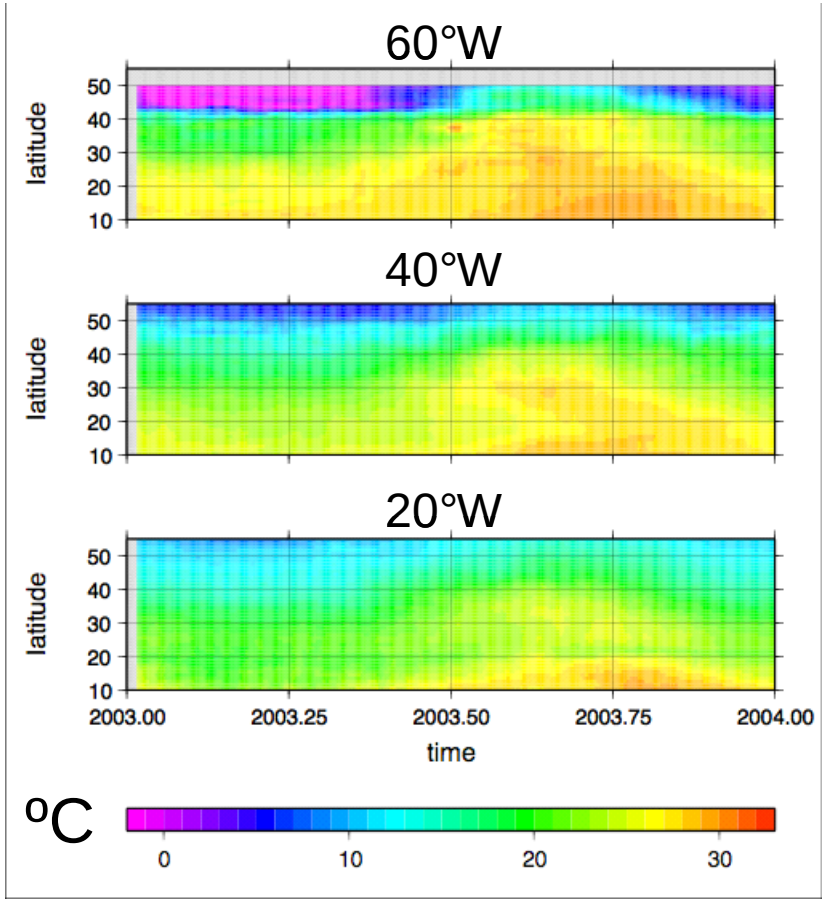
Model - CAVASSOO



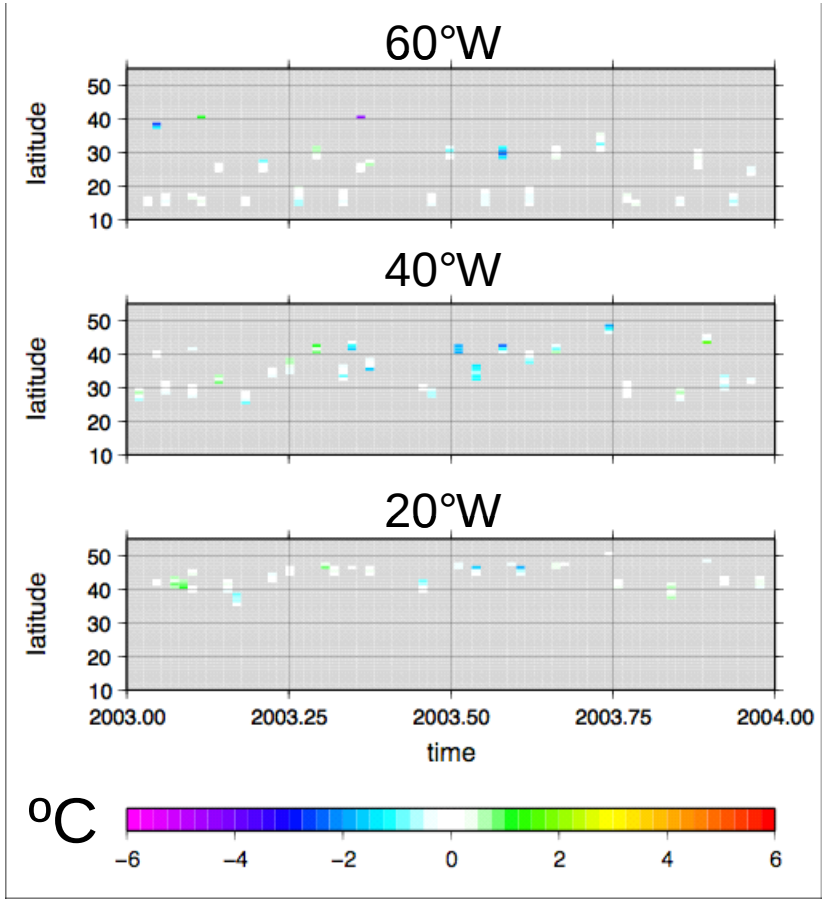
Data courtesy of CAVASSOO community & Carbo-ocean project

Surface temperature

Model

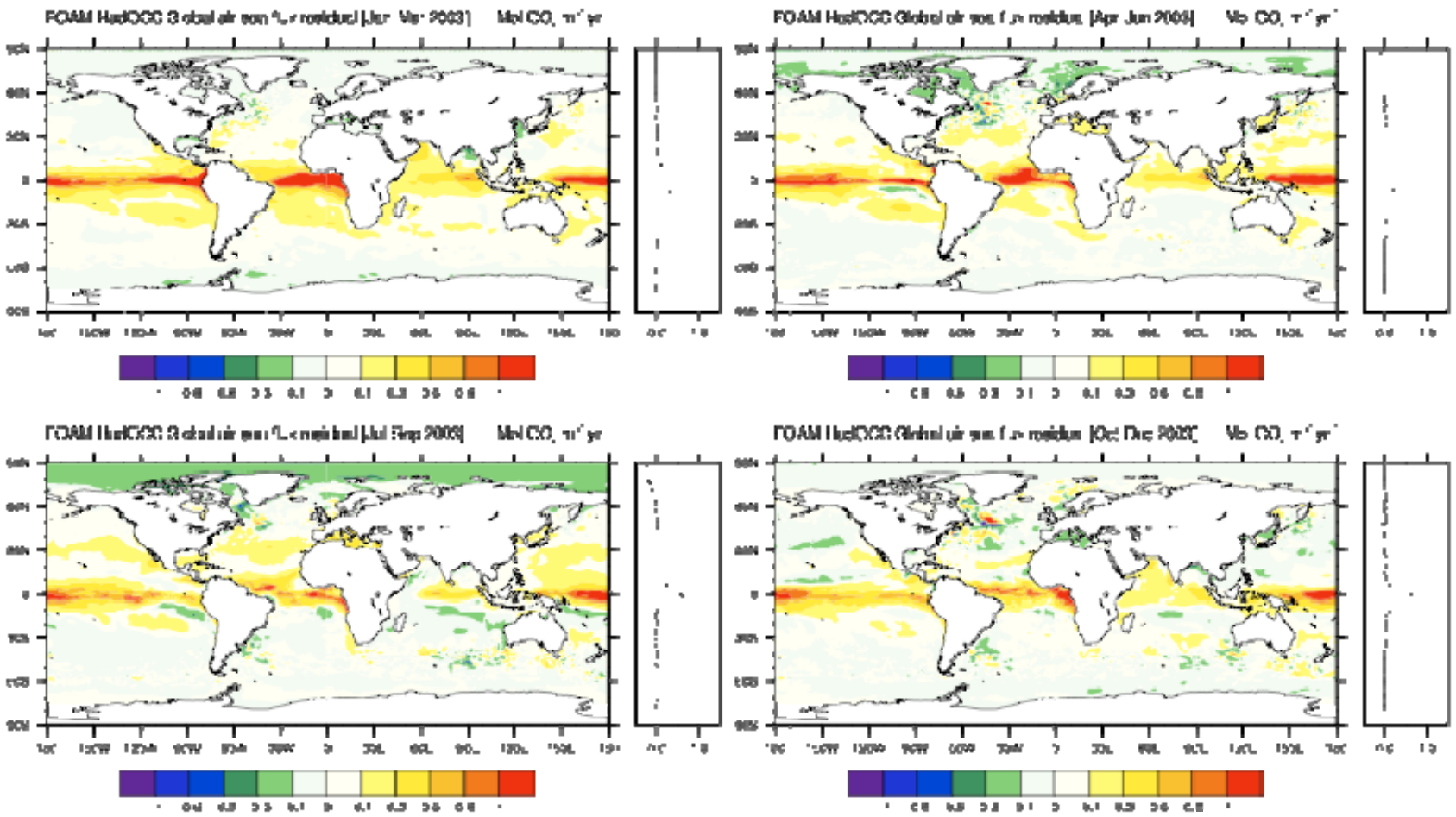


Model - CAVASSOO



Data courtesy of CAVASSOO community & Carbo-ocean project

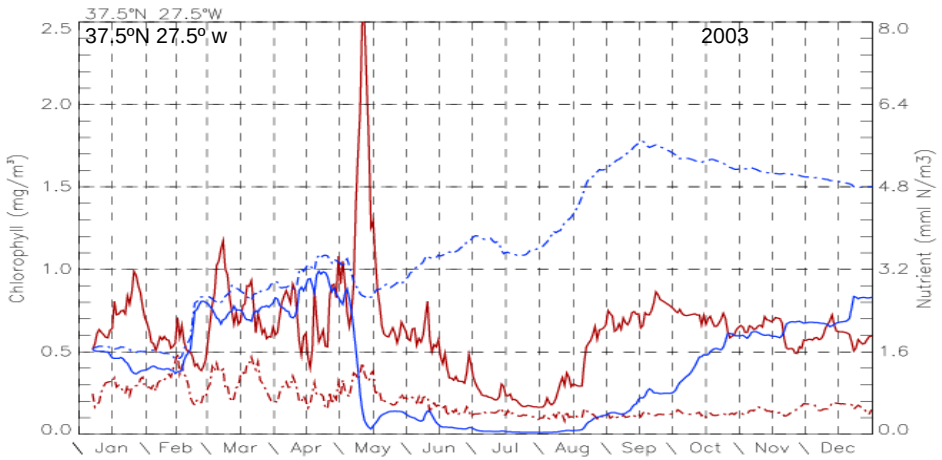
Global significance using FOAM-HadOCC

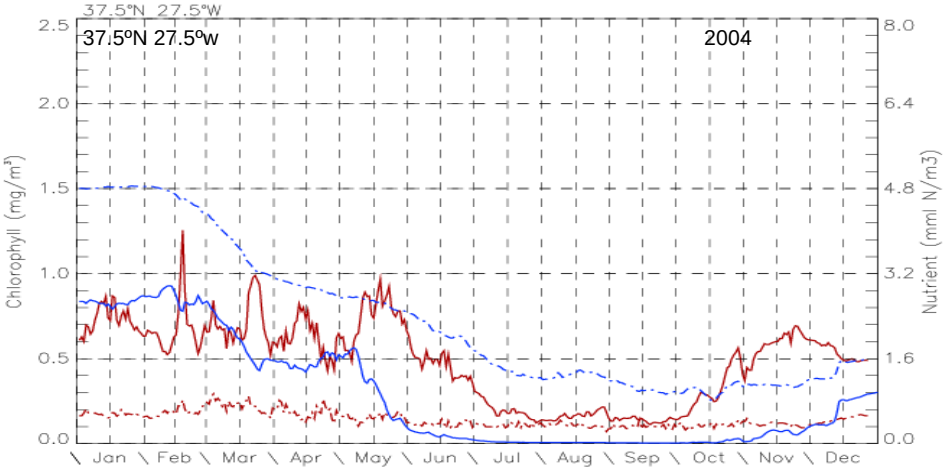


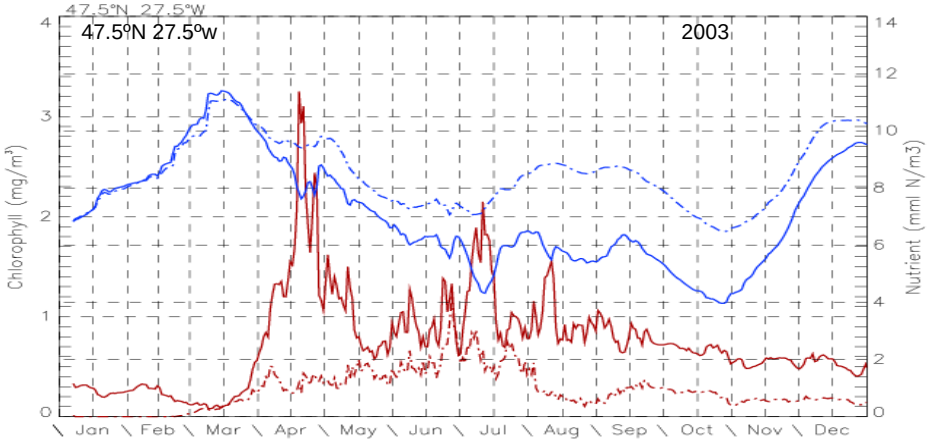
Convective COARE k – COARE k (no convective effects)
Net global flux increased by 5-6%

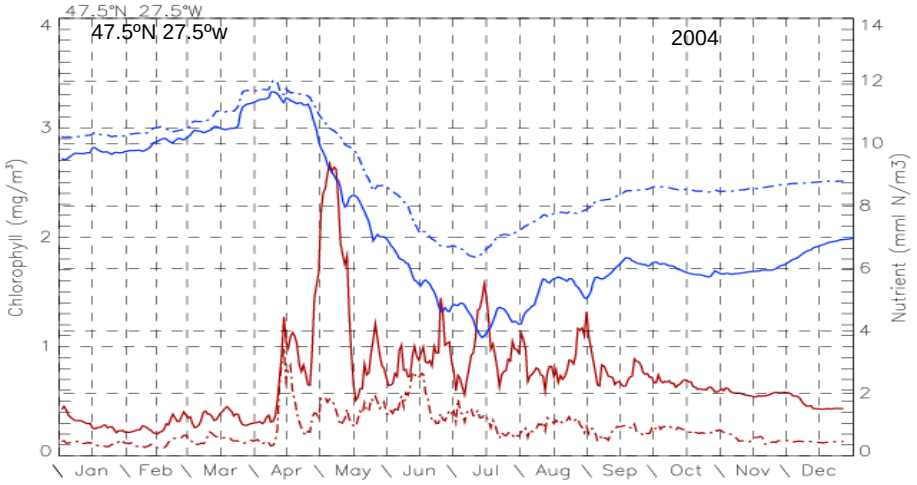
Figure courtesy of C. Jeffery

Inter-annual variability









Red: Chlorophyll
Blue: Nutrient

Solid line: physical da only
Dashed line: Chl +physical da

Biological data assimilation

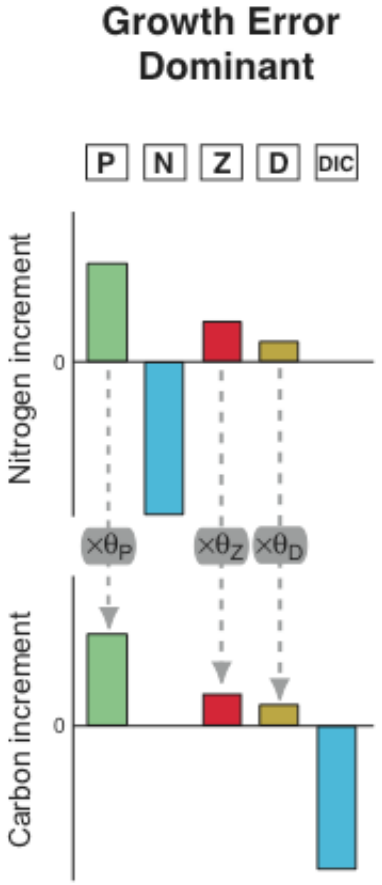
Assimilation of satellite-derived products

Observations

- SeaWiFS data processed at the University of Plymouth: derived chl (GSM)
- For each observation, an estimate of the error is also provided.
- Data assimilation schemes generally assume observations to have Gaussian error statistics. However, chlorophyll obs do not have this property.
- To get around this problem, the data is converted into observations of log10(Chl) which has been shown to then have approximately Gaussian behaviour.

Chlorophyll data assimilation scheme

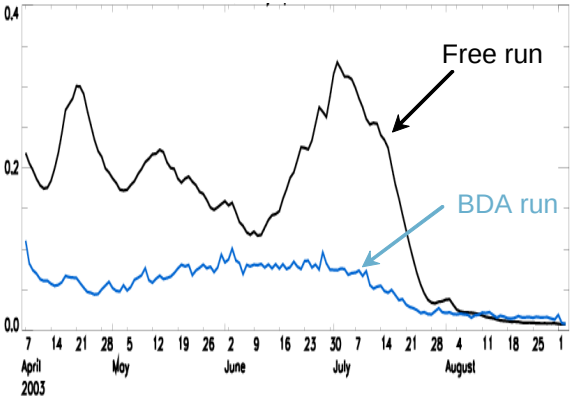
- Two stage analysis scheme:
  - Model chl *vs.* satellite obs: increments (ACS)
  - Balancing increments to biogeochemical variables
- Increments to other pools (N, Z, D, DIC, Alk) depend on the likely contributions to phytoplankton error from errors in growth and loss
- Increments constrained to conserve total nitrogen & carbon at each grid point (if sufficient nitrogen is available)
- Surface increments applied to mixed layer. Nutrient-profile correction increments below mixed layer.
- Hemmings, Barciela and Bell (2008). Accepted by JMR.



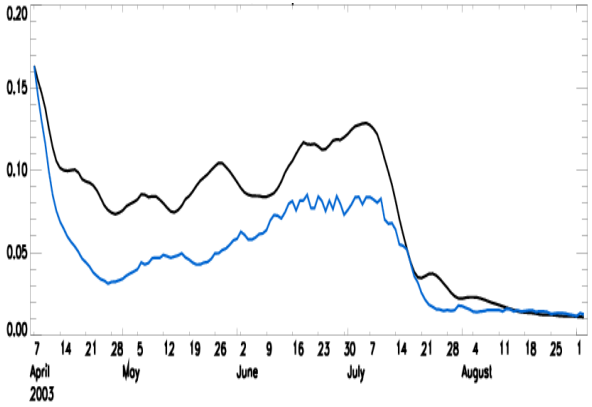
National Oceanography Centre, Southampton

3-D Twin experiments: daily mean RMS errors in the North Atlantic

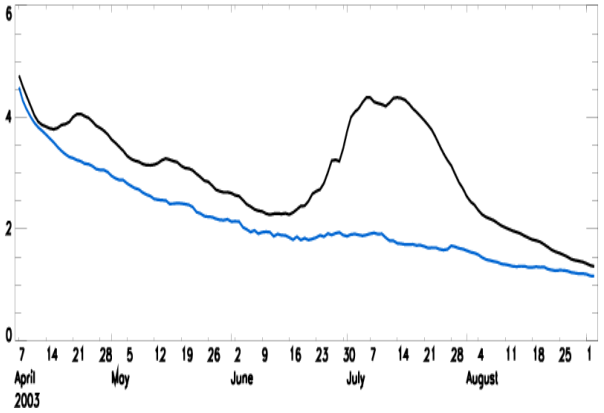
Phytoplankton (mmol N/m^3)



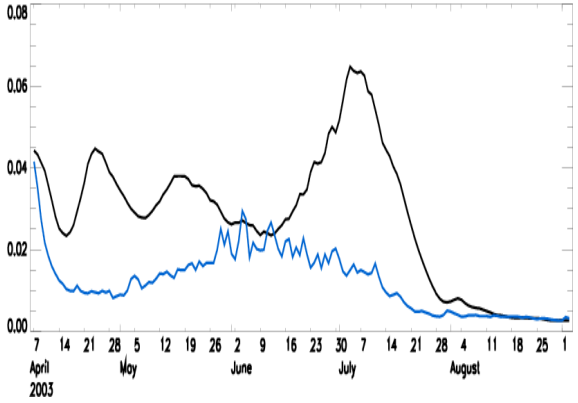
Zooplankton (mmol N/m^3)



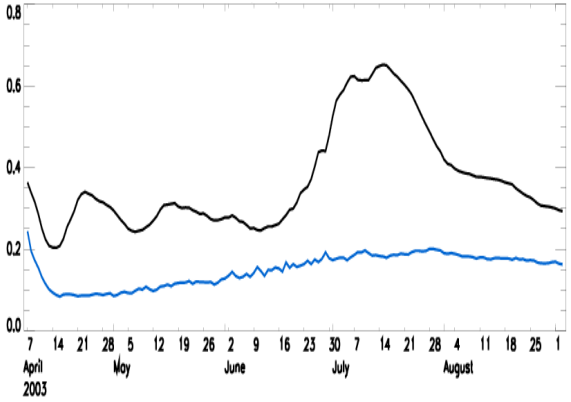
Total DIC (mmol C/m^3)



Detritus (mmol N/m^3)



Nutrients (mmol N/m^3)



- Air-sea exchange of CO_2 significantly improved after assimilating ocean colour data

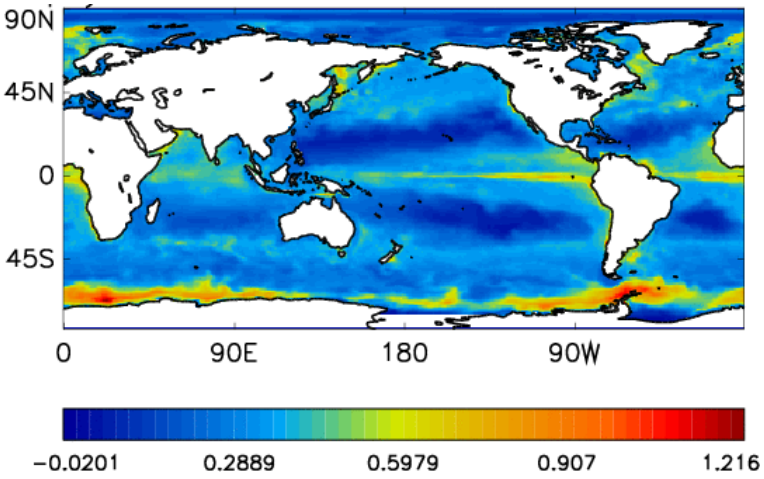
Control - truth

Assimilation - truth

National Oceanography Centre, Southampton
University of Southampton and Natural Environment Research Council

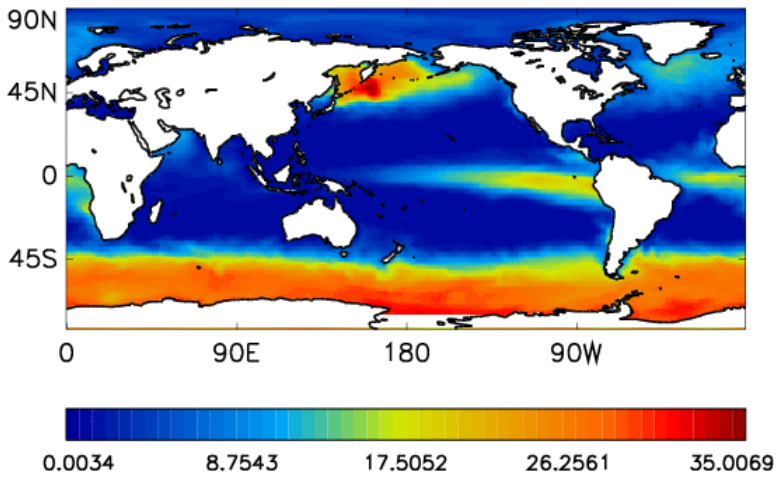
Real world experiments – annual mean

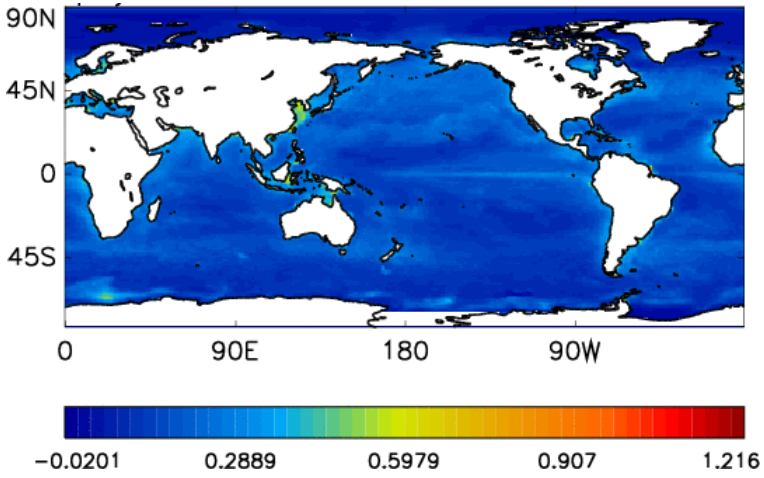
Phytoplankton



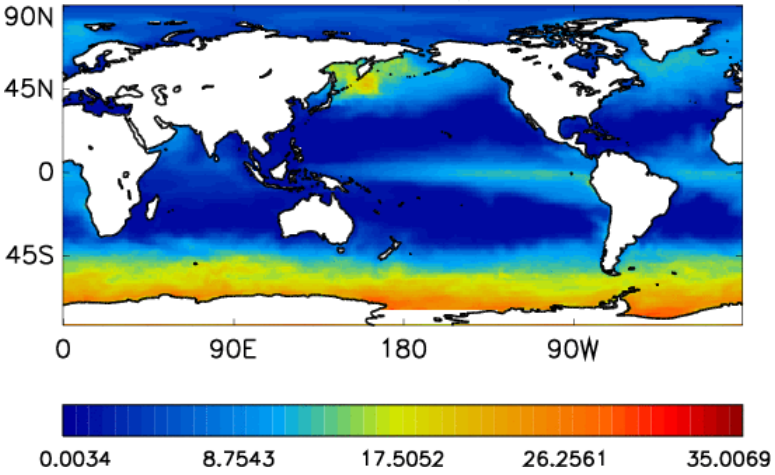
No biological assimilation

Nutrients



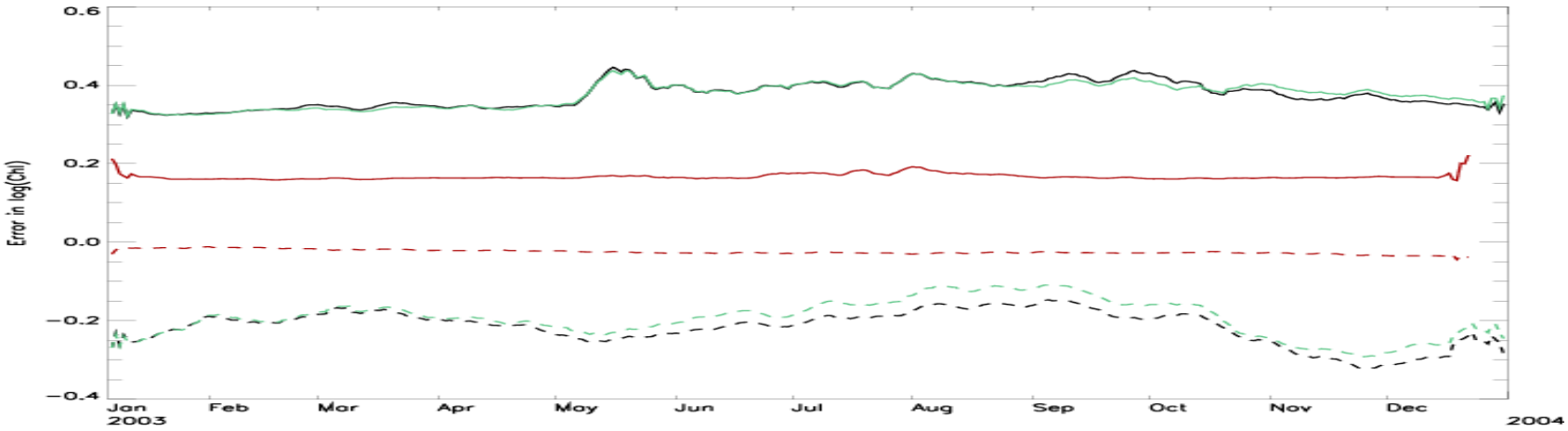


With biological assimilation



Is the biological assimilation scheme performing adequately?

- Global average RMS (solid lines) and mean (dashed lines) errors compared to satellite chlorophyll data.



Green: no DA Black: only physical DA Red: physical and biological DA

- The scheme appears to be effective at correcting chlorophyll

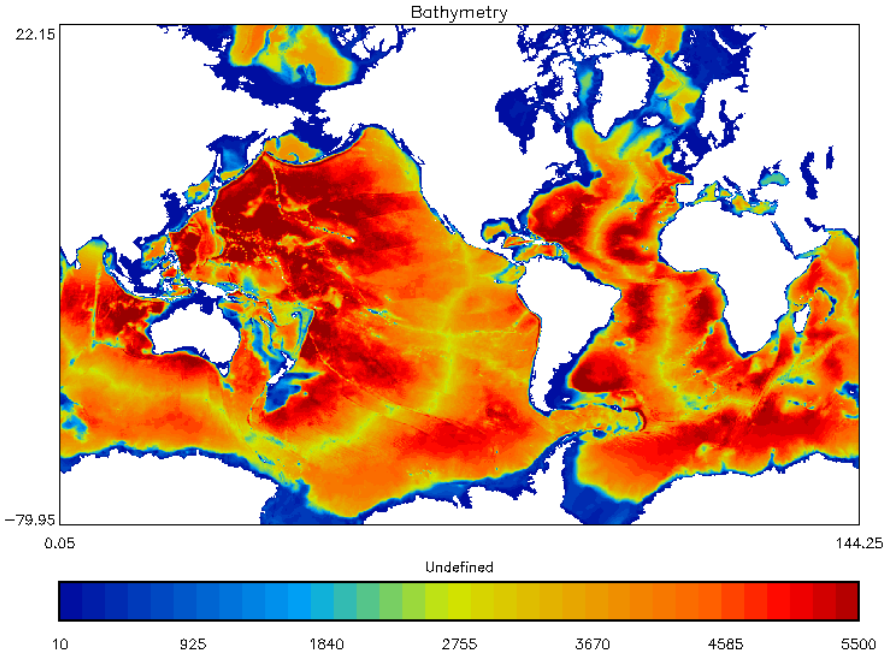
Applications

Marine Core Service - GMES

- Better exploit and manage ocean resources (e.g. offshore oil and gas industry, ecosystems, fisheries).

- Anticipate and mitigate the effects of environmental hazards and pollution crisis (e.g. oil spills, harmful algal blooms).

- Marine research (e.g. better understanding of the oceans and their ecosystems, of ocean climate variability).



Met Office Global ¼° (ORCA025)

CarbonOPS

- Met Office, PML, UEA & BODC
- Near-real time monitoring of ocean pCO_2 from combination of *in situ* observations and high-resolution models

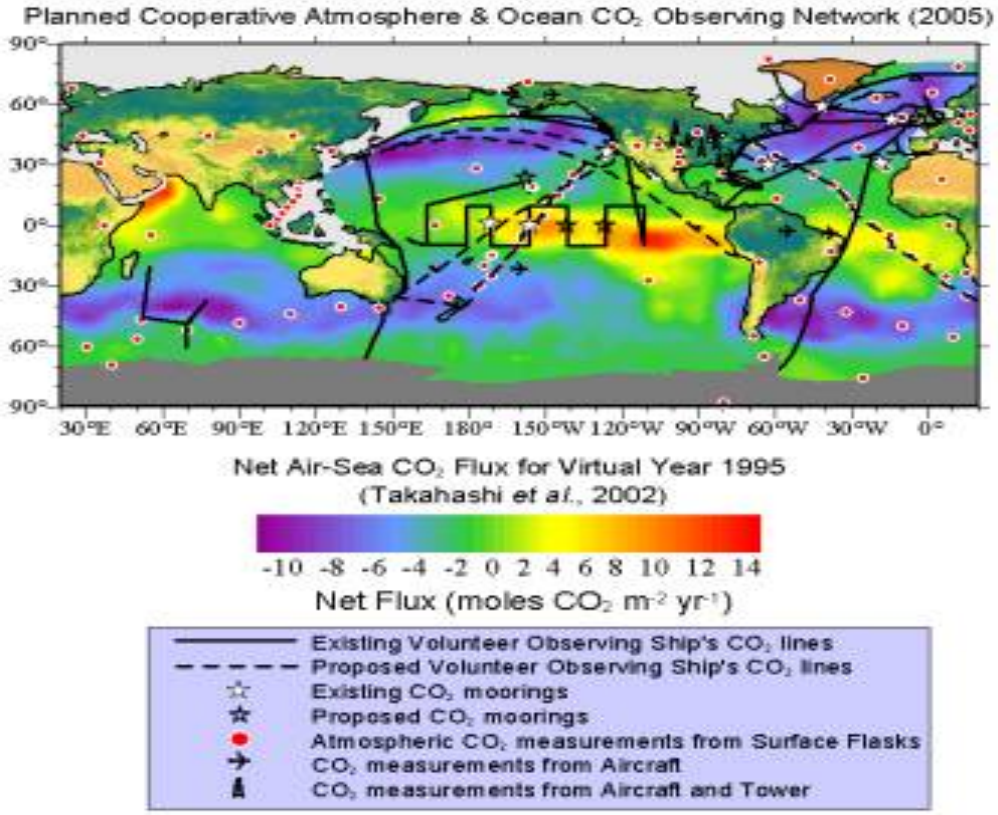
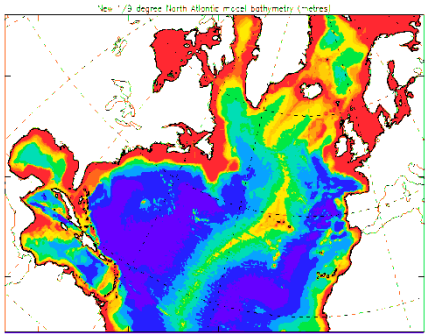
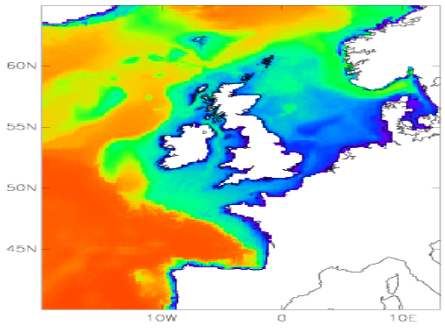


Image courtesy of SCOR-IOC-UNESCO

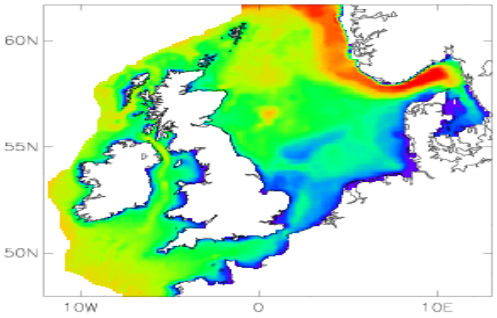
Boundary conditions for shelf-seas ecosystem models



FOAM 1/9° NA model



Atlantic Margin Model



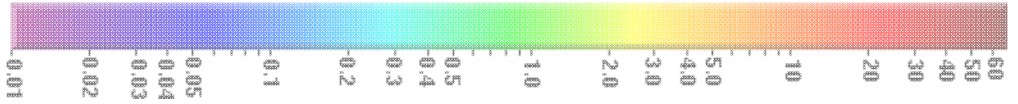
Medium-Resolution ContinentalShelf

POLCOMS-ERSEM

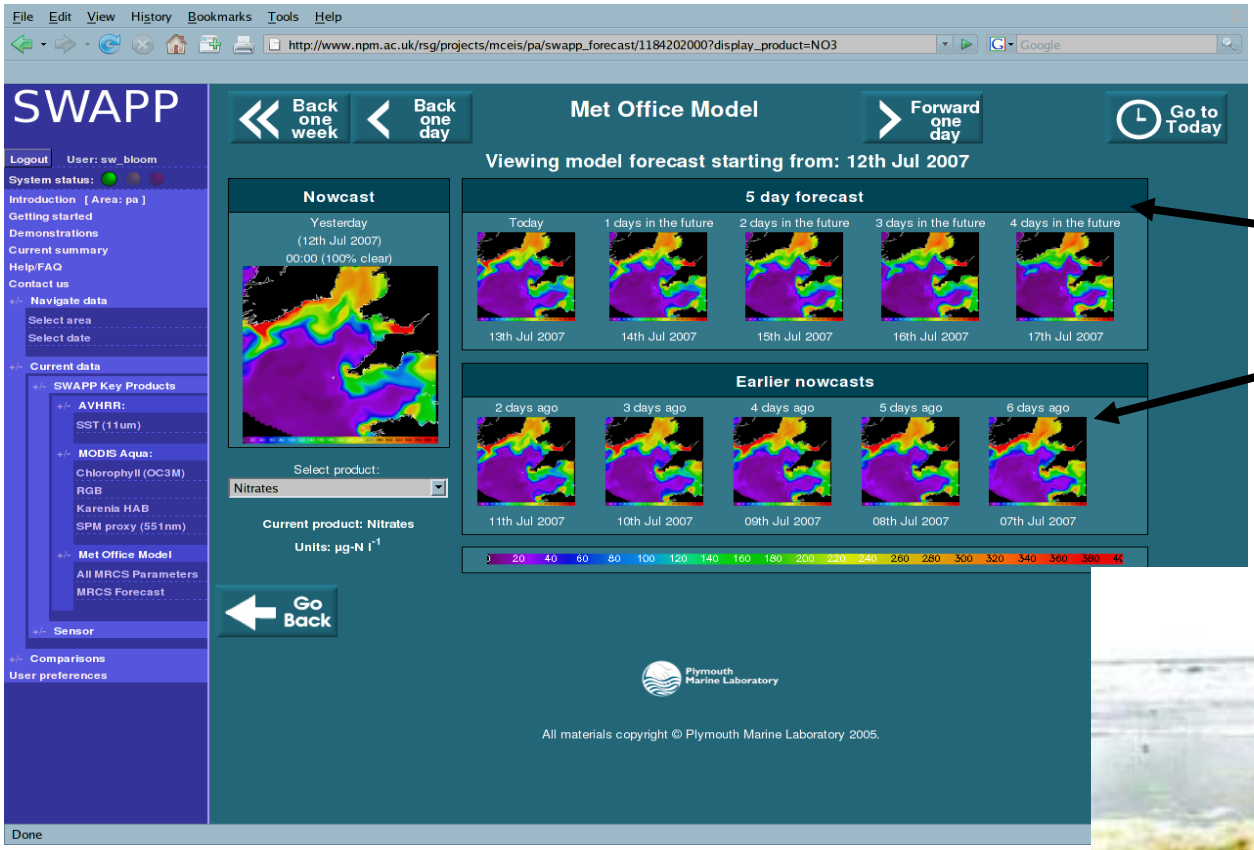
North Eastern Atlantic MERSEA system

AlgaRisk08 Project

- Provide satellite and model information to the EA
- Help focus monitoring for bloom events
- Enable EA to advise local authorities
- Early warning for fish farming and aquaculture
- Demonstrate potential to assist with EU directives



AlgaRisk08 project integrates EO with ecosystem models



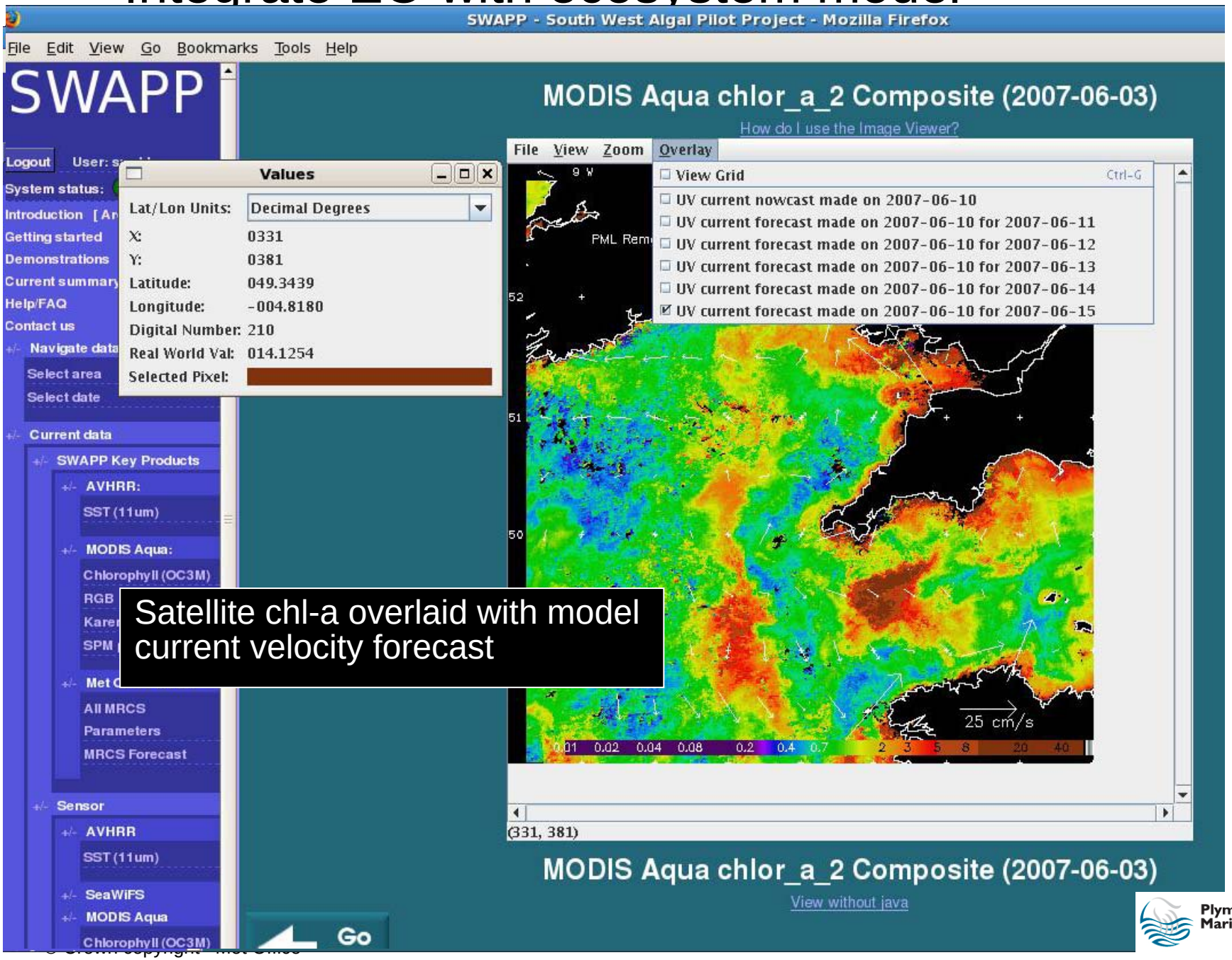
Surface nutrients in 5 days

Surface nutrients 5 days ago

Used by Environment Agency to assess prediction of nuisance bloom events on beaches

Plymouth Marine Laboratory

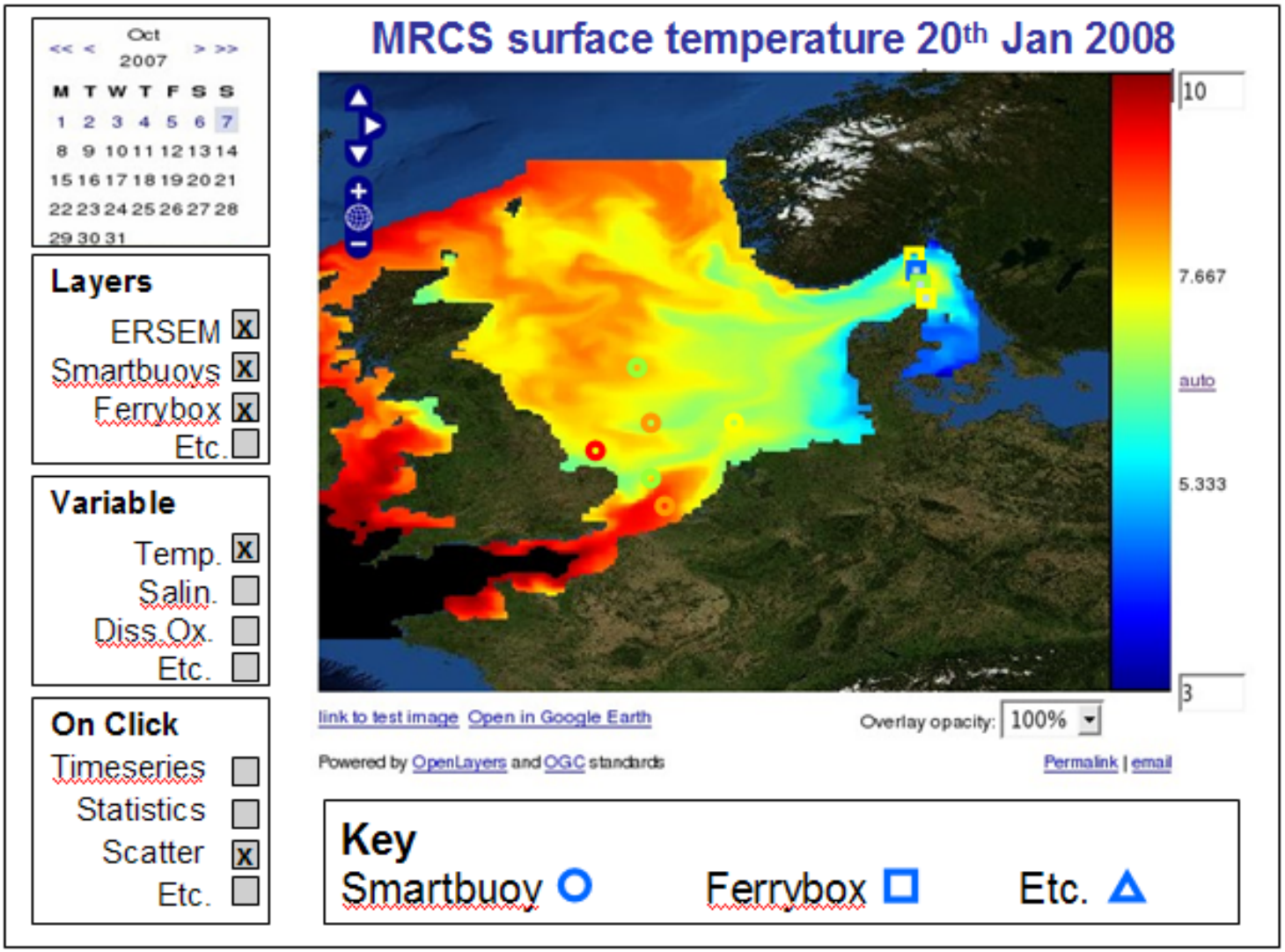
Integrate EO with ecosystem model



Plymouth Marine Laboratory

ECOOP (European COastal-shelf sea OPerational Observing and forecasting system Integrated Project)

Ecosystem Health in the North Sea



Environmental Status Support to North Sea Fisheries Assessment

Met Office

Ecoop

NATURAL ENVIRONMENT RESEARCH COUNCIL
ENVIRONMENTAL SYSTEMS SCIENCE CENTRE

Variable:

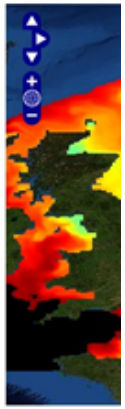
MRCS bottom temp [x]
IBTS bottom temp [ ]
MRCS – IBTS [ ]
MRCS - WOA [ ]

Start Month:

Oct 2007

M	T	W	T	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

Select re



Plot

Variable:

MRCS bottom temp [x]
IBTS bottom temp [ ]
MRCS – IBTS [ ]
MRCS - WOA [ ]

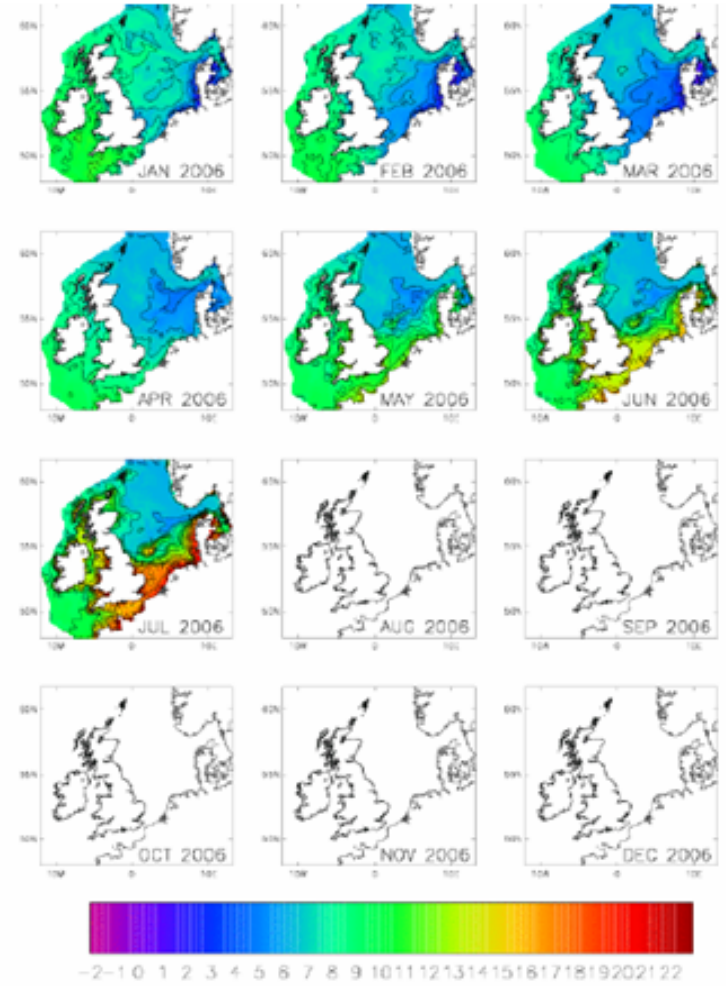
Fisheries info:

Cod spawning [x]
Cod breeding [ ]
Herring spawning [ ]
Etc. [ ]

New Region

3 mnths **3 mnths**

Monthly mean near-bed temperature
Met Office MRCS-ERSEM



Statistics for region?

Conclusions

- Successful demonstration of a pre-operational, fully coupled, physical-biogeochemical modelling system, FOAM-HadOCC, for the open ocean.
- Development of a novel biological data assimilation scheme, which applies balancing increments to all biogeochemical tracers.
- The biological assimilation scheme is effective at controlling the chlorophyll field and seem to improve the representation of air-sea fluxes of CO_2.
- A number of applications have been developed using Met Office physical-biogeochemical operational models for the global ocean and the shelf-seas.
- This include:
    - MCS/MyOcean.
    - Monitoring of ocean pCO_2.
    - Pre-operational warning system for detection of nuisance blooms linked to WFD (EA)
    - Environmental (physical & biological) information for fisheries management in the North Sea (ICES)

Any questions?

What will be doing next?

The key next steps are:

- further quantitatively validation to initial FOAM-HadOCC integrations.
- further refinement of biological assimilation scheme.
- parameter tuning (required to improve performance).
- 10-year re-analysis of FOAM-HadOCC with ocean colour and physical assimilation (1º global).
- on-line coupling to NEMO.

What is NCOF ?

- The National Centre for Ocean Forecasting is a strategic consortium involving the Met Office …

Plymouth Marine Laboratory

Proudman Oceanographic Laboratory
NATURAL ENVIRONMENT RESEARCH COUNCIL

National Oceanography Centre, Southampton
UNIVERSITY OF SOUTHAMPTON AND NATURAL ENVIRONMENT RESEARCH COUNCIL

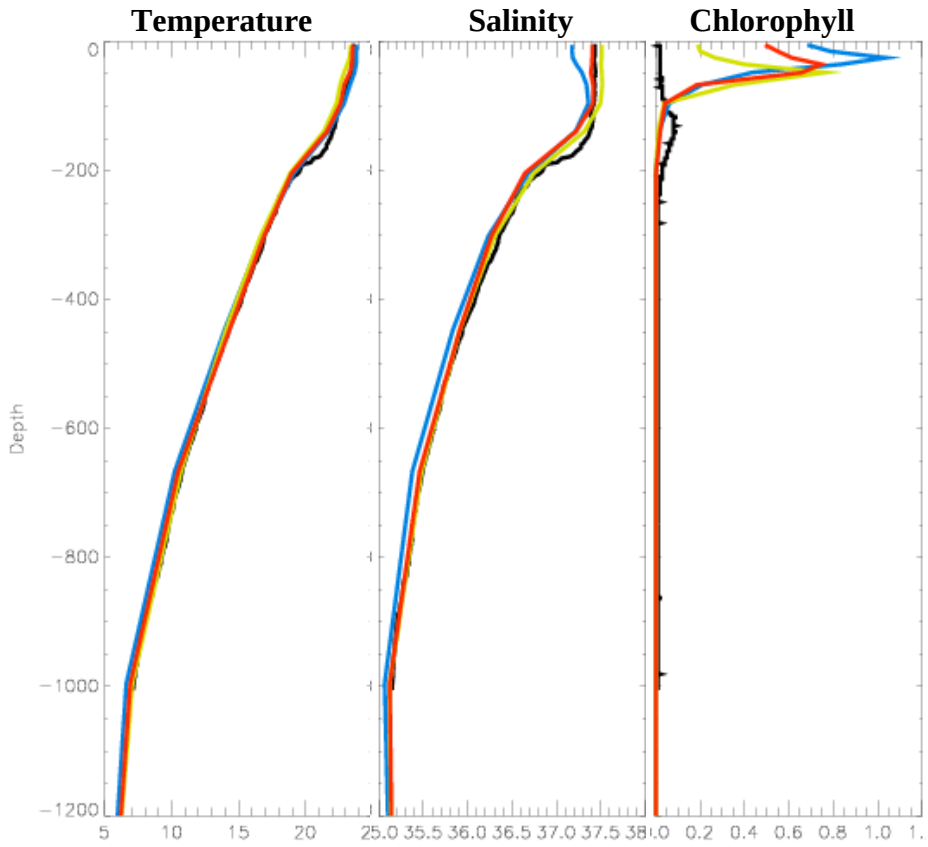
NATURAL ENVIRONMENT RESEARCH COUNCIL
ENVIRONMENTAL SYSTEMS SCIENCE CENTRE

- Mission is “To establish ocean forecasting as part of the national infrastructure, based on world-class research and development.”

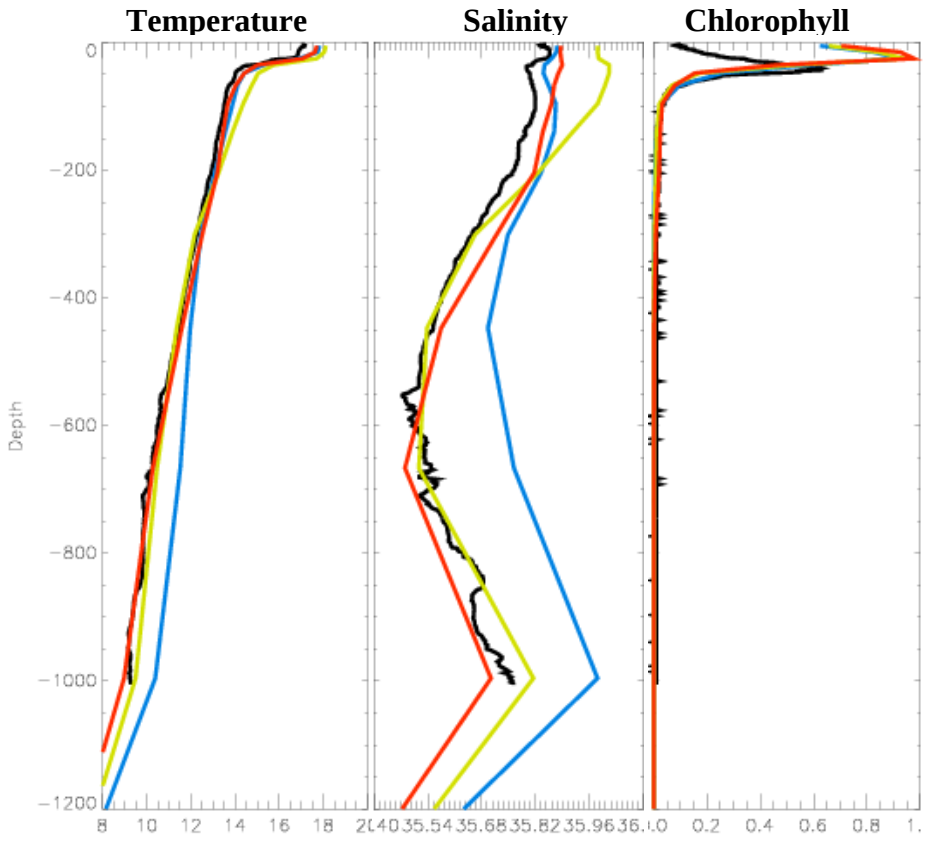
FOAM-HadOCC *versus* AMT

- Validation of subsurface structure *vs* AMT cruise data

32.6W, 24.3N, 6th June 2003



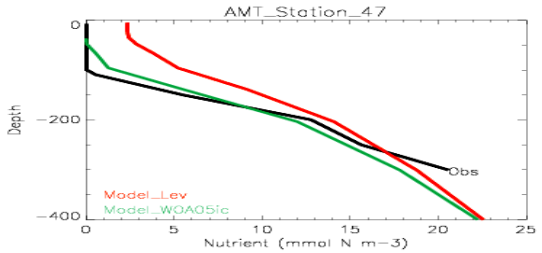
20.0W, 41.5N, 11th June 2003

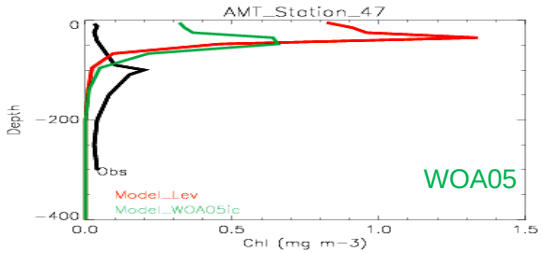


AMT obs
1/3º
1/9º
1º

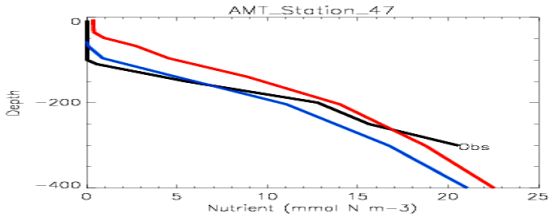
Improvements to the model

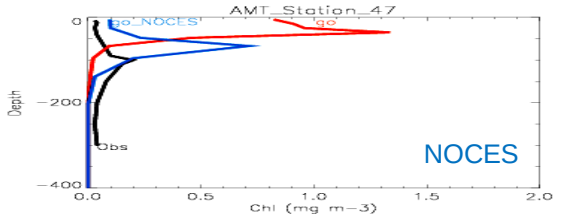
- WOA05 climatology



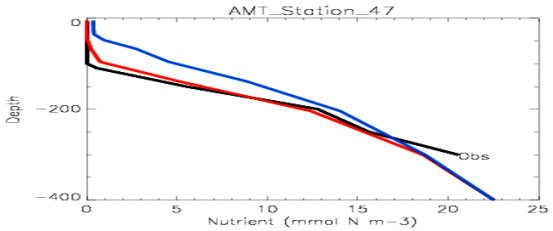


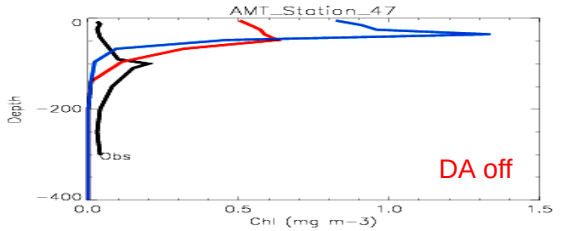
- Initial conditions





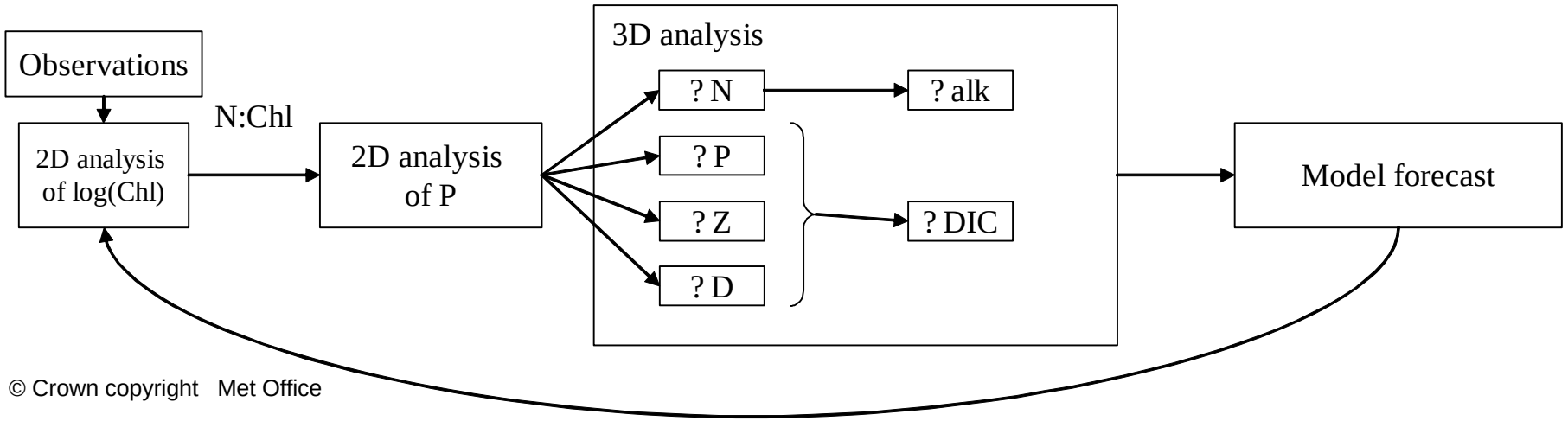
- Impact of physical data assimilation





Chlorophyll data assimilation scheme

- A 2D analysis of $\log_{10}$(Chl) is performed using the same method as for SST (OI-type scheme). This uses the error statistics described in the previous slide. The output from this is a field of surface $\log_{10}$(Chl) increments.
- These can then be converted into surface phytoplankton increments using the model's N:Chl ratio.
- In order to start the model from a "balanced" state, increments to the other ecosystem model variables are calculated using a scheme jointly developed by NOCS and Met Office (next slide).
- The analysed ecosystem model variables are then used directly as the starting conditions for the next model forecast.



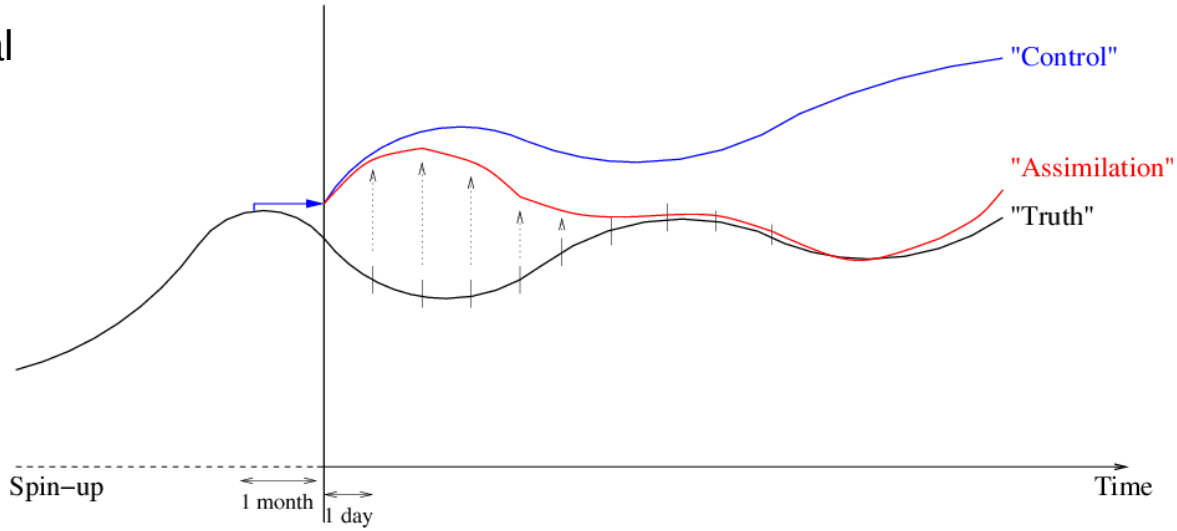
Experiments – identical twin set-up

- Start from a spun-up model state, then run the model forced by 6 hourly NWP fluxes for 1 year, with physical (T, S, SST) data assimilation. This is called the “true” run.

  Observations of Chl are taken from this “true” model state once a day.

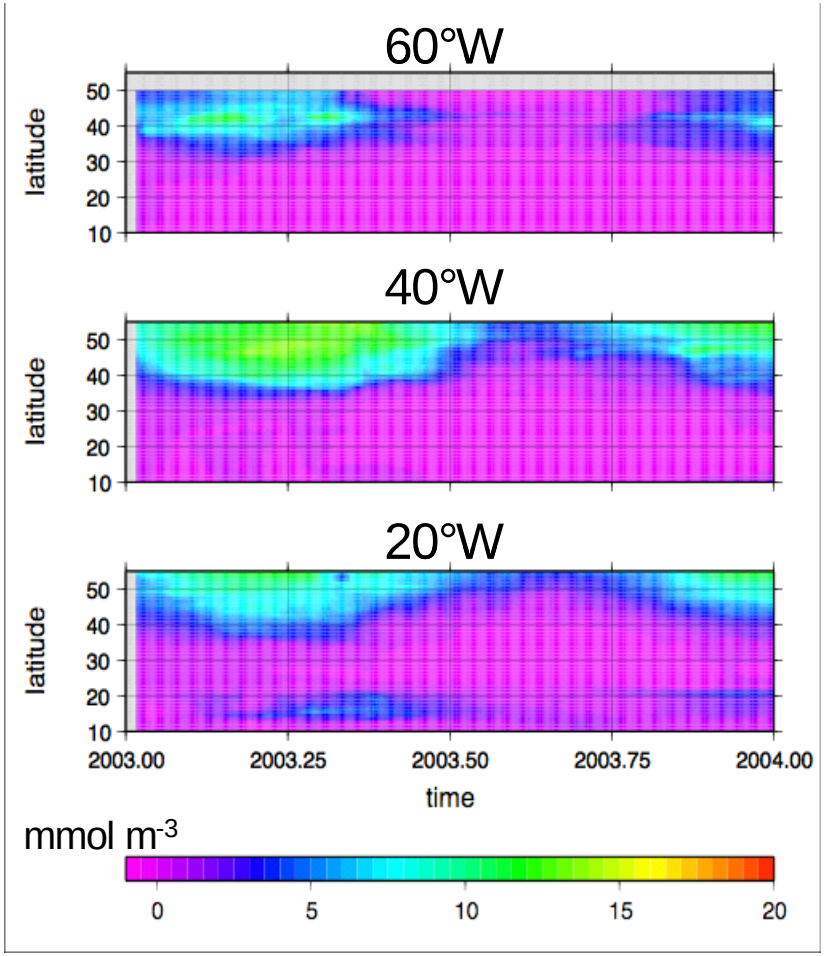
- The ecosystem model variables are initialised using the biological fields from March 2003, with the physical fields taken from the true run.

- Starting from these new initial conditions, the model is run from April 2003 without (“control”) and with (“assim”) the Chl observations assimilated.

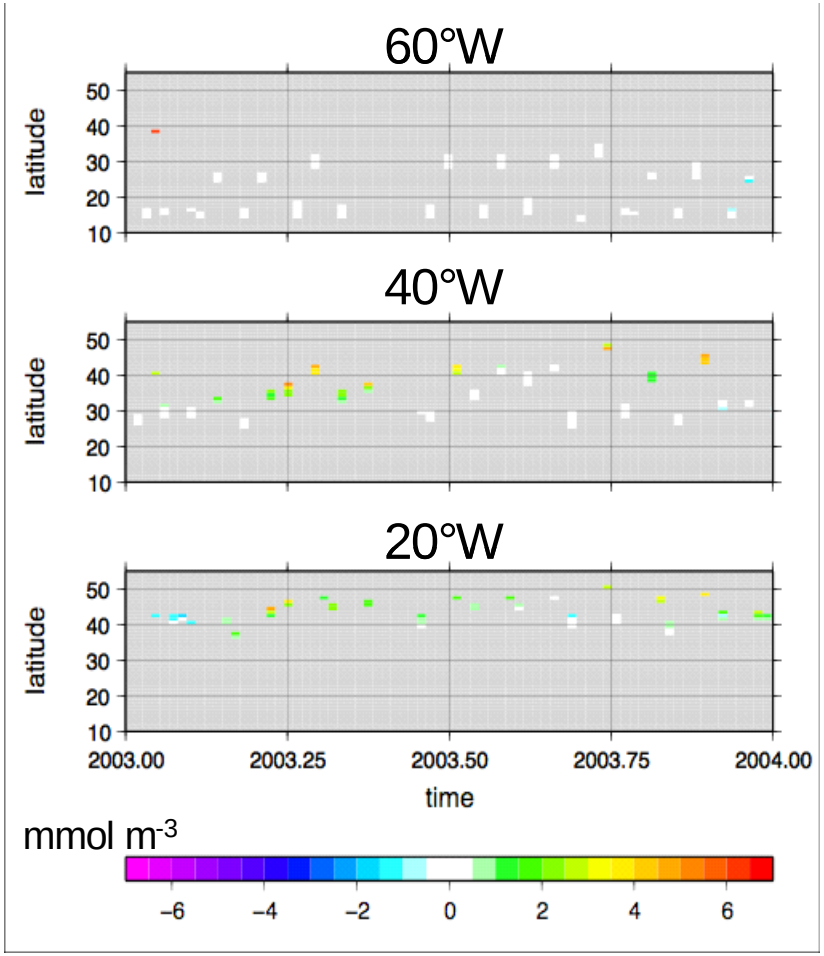


Surface nitrate

Model



Model - CAVASSOO



Conclusions from FOAM-HadOCC integrations

- The system appears to be effective at simulating the onset of the spring bloom
  - Good qualitative agreement with SeaWiFS, AMT and CAVASSOO data
  - Subsurface maxima larger than those seen in AMT data
- Higher resolution provides improved representation of advective processes in particular
  - Benefits masked by large scale errors
- Initial conditions from NOCES and nutrient relaxation to WOA05 improved the model's performance.
- Undesirable impact of physical data assimilation is potentially a complex issue.