Met Office

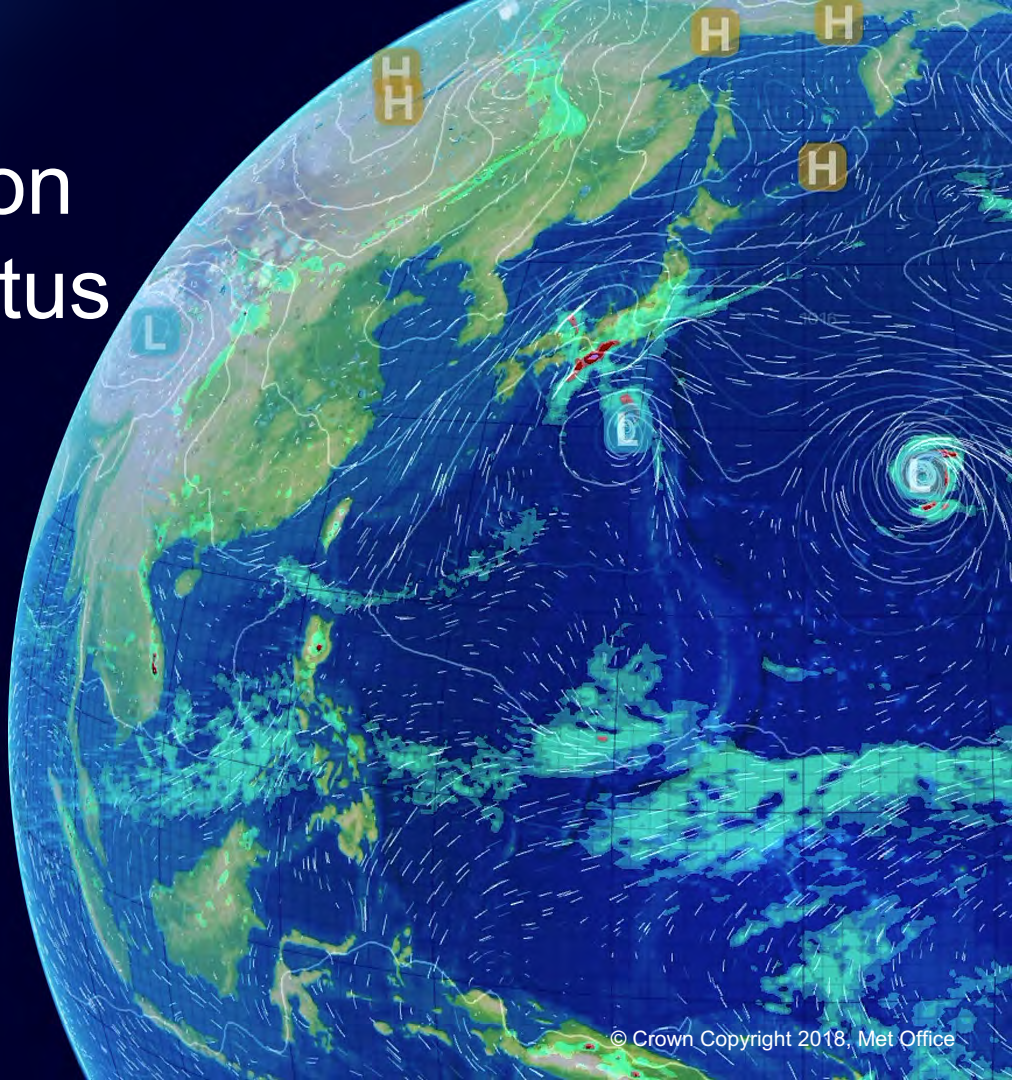
The UK ocean prediction community, current status and future directions

Forum for Operational Oceanography,

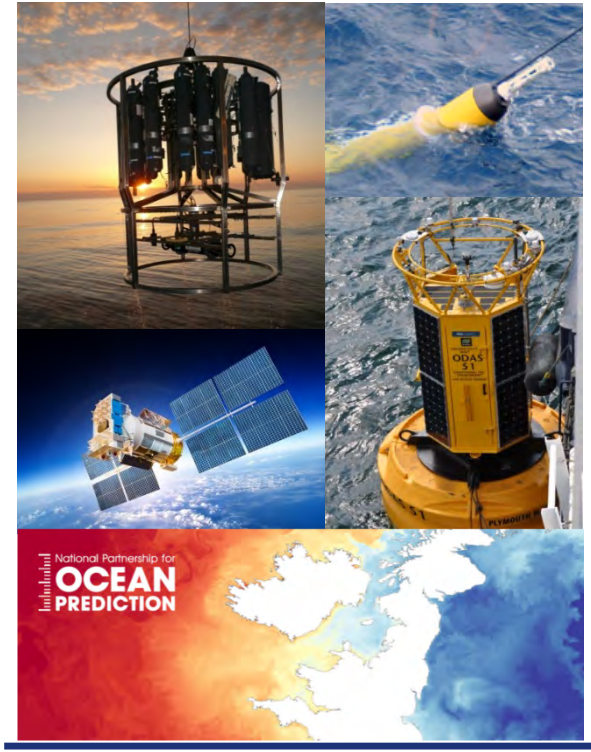
Melbourne, October 2019

John Siddorn
Met Office Head Ocean Forecasting R&D
National Partnership for Ocean Prediction Co-Chair

With thanks to many at Met Office and elsewhere in the UK Ocean Prediction community



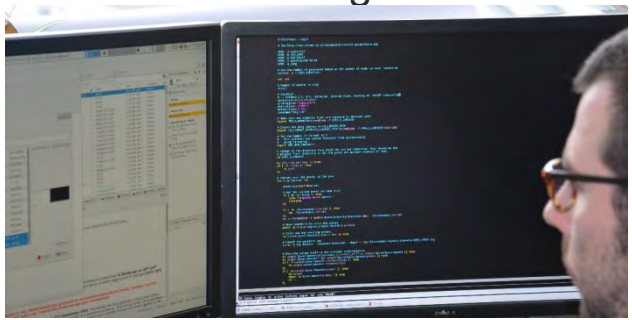
National Partnership for Ocean Prediction

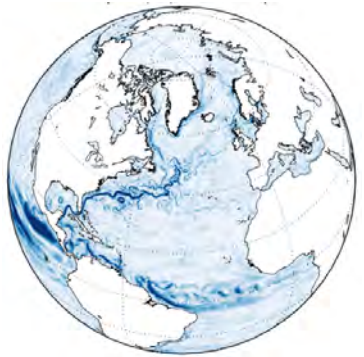


… the UK's partnership underpinning ocean prediction services for national and public benefit

We aim to develop and promote marine products and services, with a focus on national and public benefit

Our focus is on the integration of models, observations and scientific understanding.





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National Partnership for OCEAN PREDICTION

UK National Capability

- Focus across groups on the same National Capability tools*
  - NEMO ocean model
  - NEMOVAR ocean data assimilation
  - ERSEM / Medusa ocean biogeochemistry
- Partnership creates a framework where this coming together has happened
- Partnership plays a significant role in ensuring horizon scanning for next generation capability, understanding needs across forecasting, climate and research, to find the sweet spot.

* Where appropriate. Diversity can play a role too

National Partnership for OCEAN PREDICTION

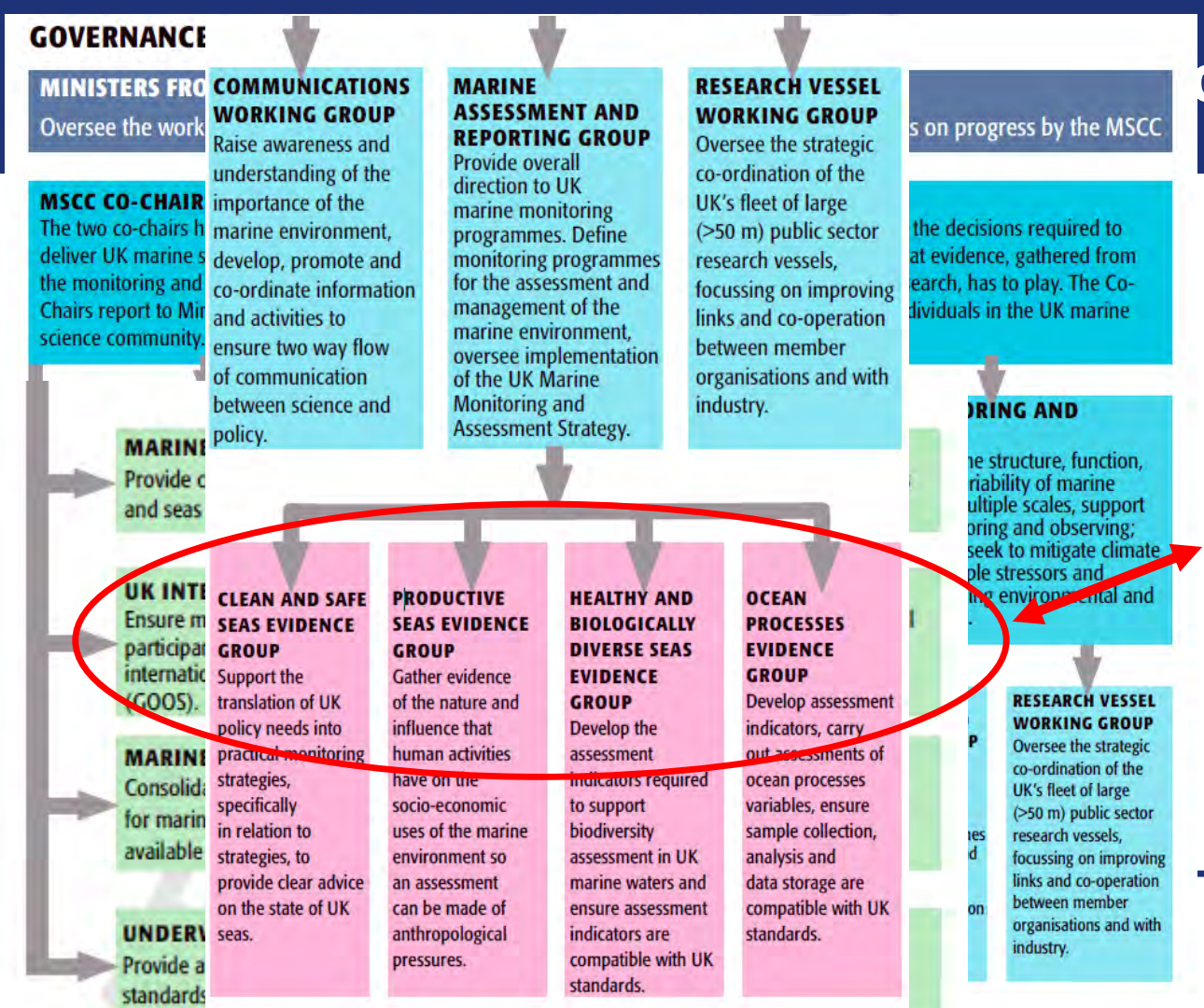
Summary of Activities

Activity Groups:

- Coastal Processes
- Marine Data Assimilation
- Marine Prediction on Seasonal to Centennial Timescales
- Marine Biogeochemistry Modelling
- Observational Datasets: Gaps and Requirements
- Surface Waves
- Next Generation Modelling

Plus Stakeholder Engagement and Communications Activities:

ce in the UK - II



National Partnership for OCEAN PREDICTION

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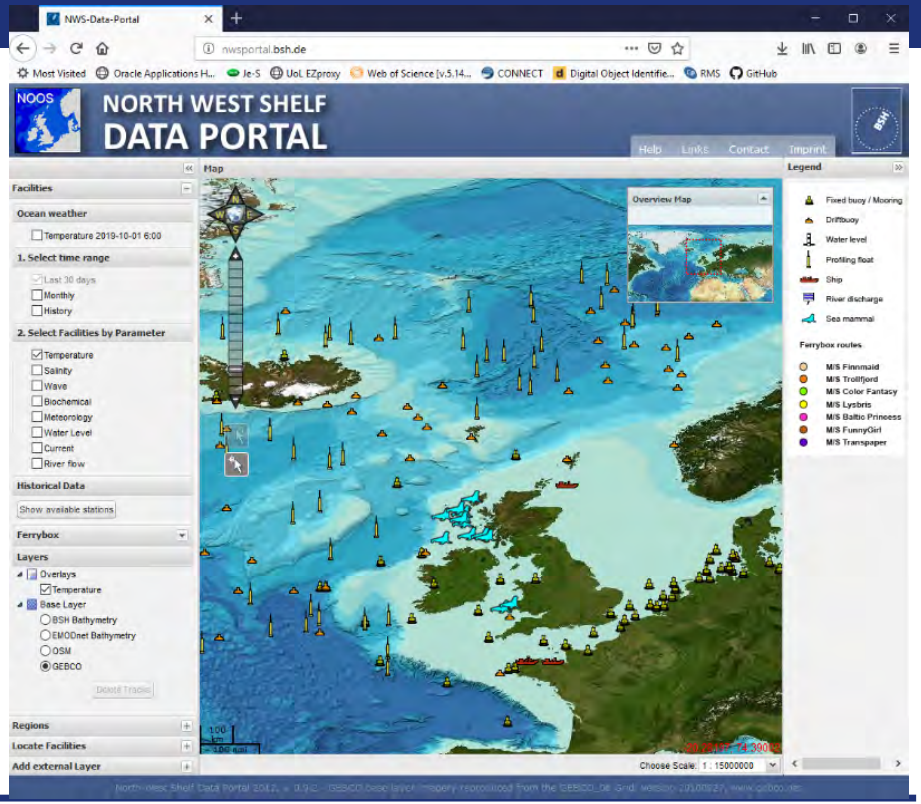
National Partnership for OCEAN PREDICTION

Observational Datasets: Gaps and Requirements

- Building links between *in-situ* and remote sensing observational and modelling communities
- Link to UK-IMON, GOOS, OceanObs19
- Models and modelling needs inform observational network design



AG Leads
(in situ / IMON) matthew.palmer@noc.ac.uk
(EO) chris.banks@noc.ac.uk

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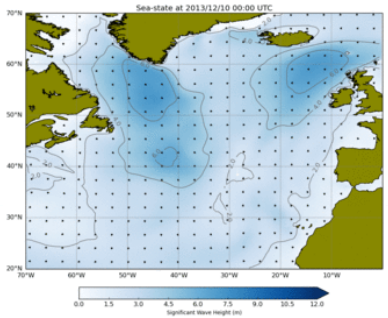
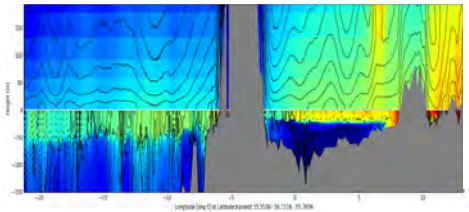
Met Office

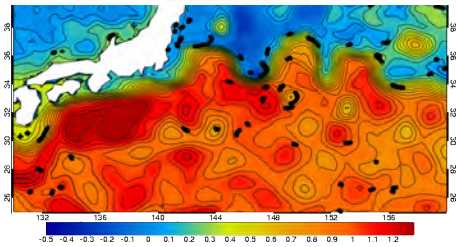
Met Office

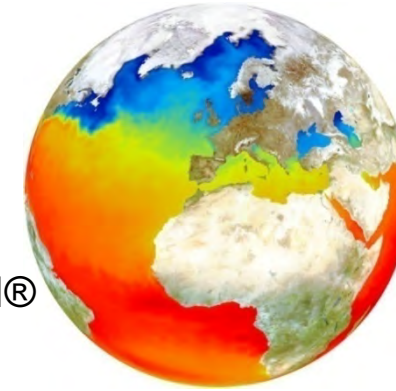
The Met Office is the UK’s national weather service

Forecast Models and Systems









- SST & sea-ice satellite and in situ obs. analysis (OSTIA)
  - foundation SST and diurnal temperature
- Surface waves based on NCEP's WAVEWATCH III®
  - Runs 4 x daily, including an ensemble
- Storm surge based on POLCOMS (moving to NEMO)
  - Runs 4 x daily, including an ensemble
- Ocean (FOAM) using NEMO-CICE with NEMOVAR data assimilation
  - 3D monitoring and prediction, including biogeochemistry
- Coupled Atmosphere-Ocean-Wave-Ice-Land research systems

Met Office

NERC SCIENCE OF THE ENVIRONMENT

Joint Weather & Climate Research Programme

Joint Marine Modelling Programme (JMMP)

Coordinates **configurations** of the global ocean, sea ice and north-west shelf using the **NEMO** model.

responsible for providing **national capability modelling infrastructure** and configurations to support the UK's scientific research and operational prediction systems for **ocean, weather and climate**.

includes **operational oceanography**, **coupled NWP**, **monthly to decadal** forecasting and **climate** projections.

JMMP is led by a management group represent the **Met Office, National Oceanography Centre (NOC)** and **British Antarctic Survey (BAS)** and is overseen by a governance group who can allocate resources to JMMP.

Helene Hewitt, Head of JMMP, Met Office,helene.hewitt@metoffice.gov.uk

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

National Oceanography Centre
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National Oceanography Centre
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National Oceanography Centre

“The National Oceanography Centre is the UK’s centre of excellence for oceanographic sciences. We have a remit to provide national capability and leadership for big ocean science.”

NOC Science Program Model Data Sets

UK Earth System Modelling (Joint with Met Office)

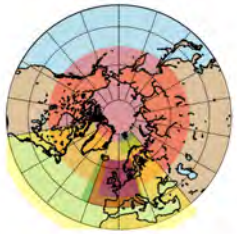
Develop Ocean and BGC models

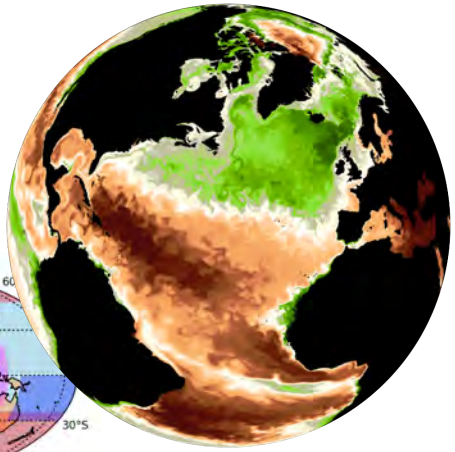
- Not limited to operational products
- Many global and regional model data sets among the partners available for community use

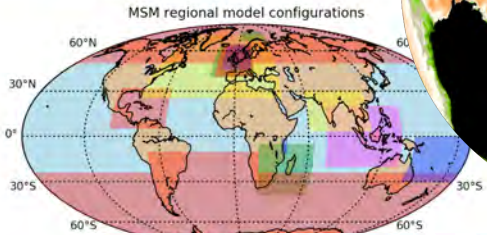
e.g.

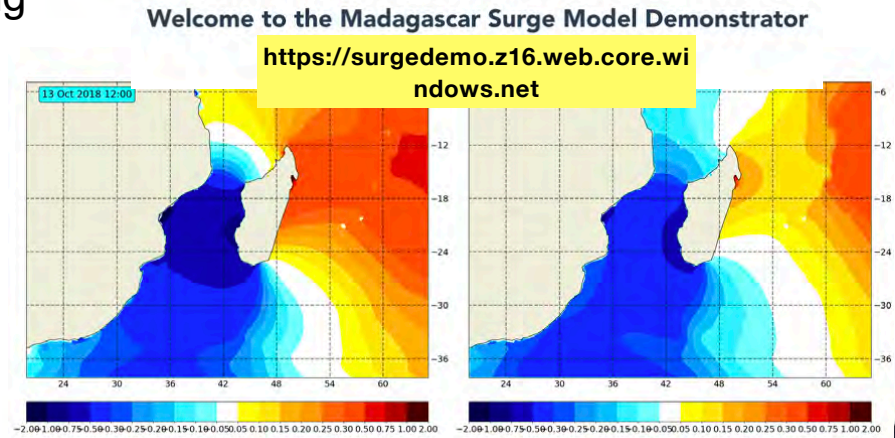
NEMO-MEDUSA 1/12 deg

Next run: climate forced -> 2100







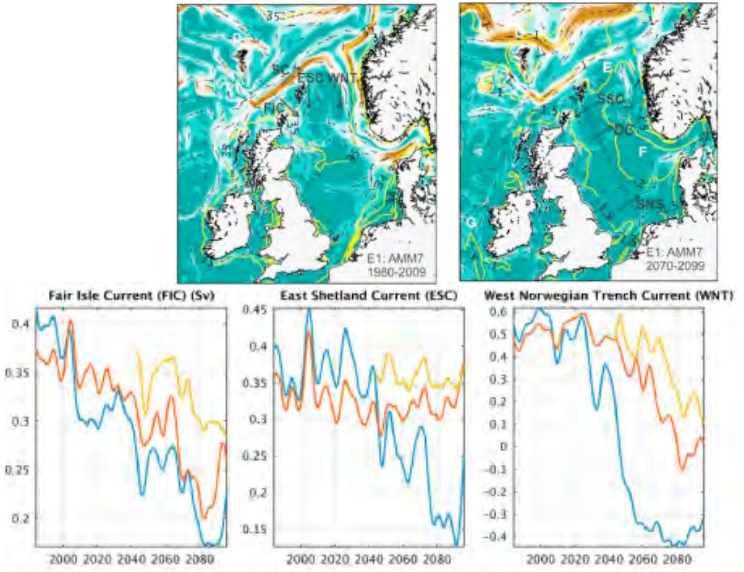


National Partnership for OCEAN PREDICTION

Marine Prediction on Seasonal to Centennial Timescales

- Provides a focal point for scientific discussion on shelf seas and coastal forecasts and projections from months to 100 years ahead
- Links to UKCP and MCCIP
- How to does marine community benefit from improved seasonal forecast skill?

Future Change in Circulation:



Holt et al 2018 GRL

Led by Richard Wood: richard.wood@metoffice.gov.uk

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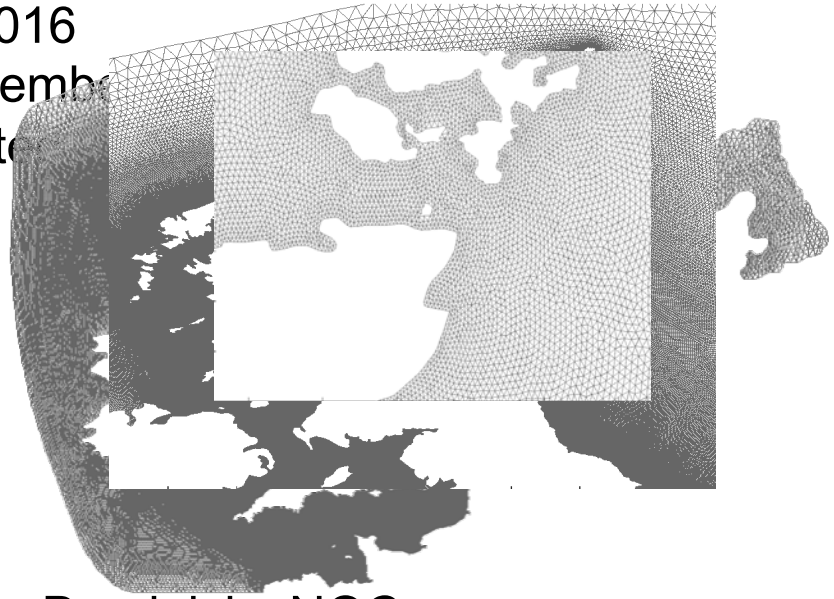
Marine Scotland

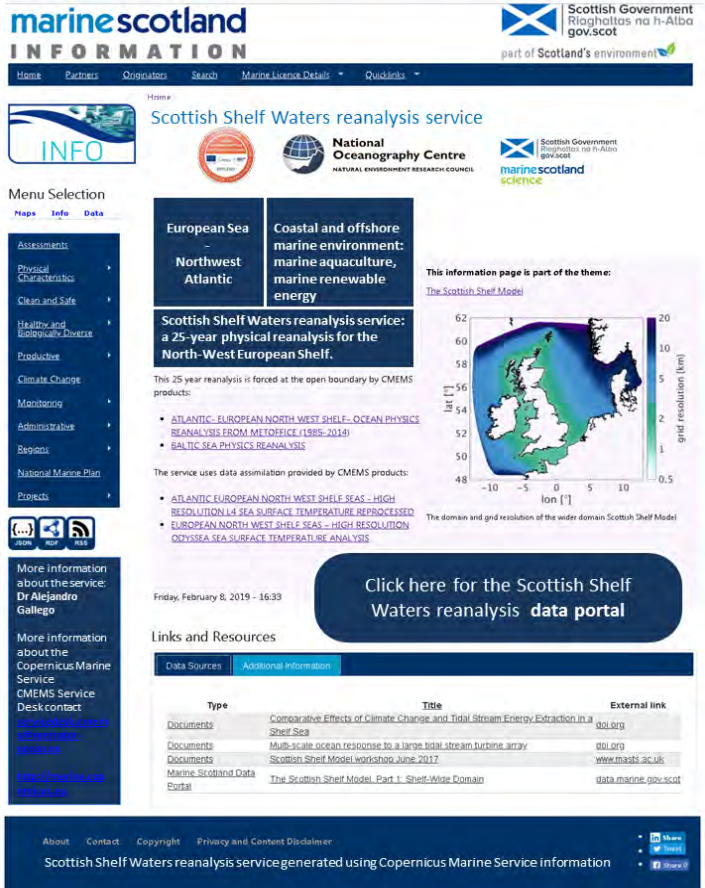
“Marine Scotland is a civil service directorate within the Scottish Government,

responsible for leading the protection of Scotland’s coastal waters and seas, to both build sustainable economic growth from Scotland’s marine assets, and to safeguard its valuable marine ecosystems.”

Scottish Shelf Waters Model

- NOC and Marine Science Scotland
- Unstructured mesh, physics
- Currently 1-year climatology
- New reanalysis under production: 1992-2016
- By Novembr
- Integrat



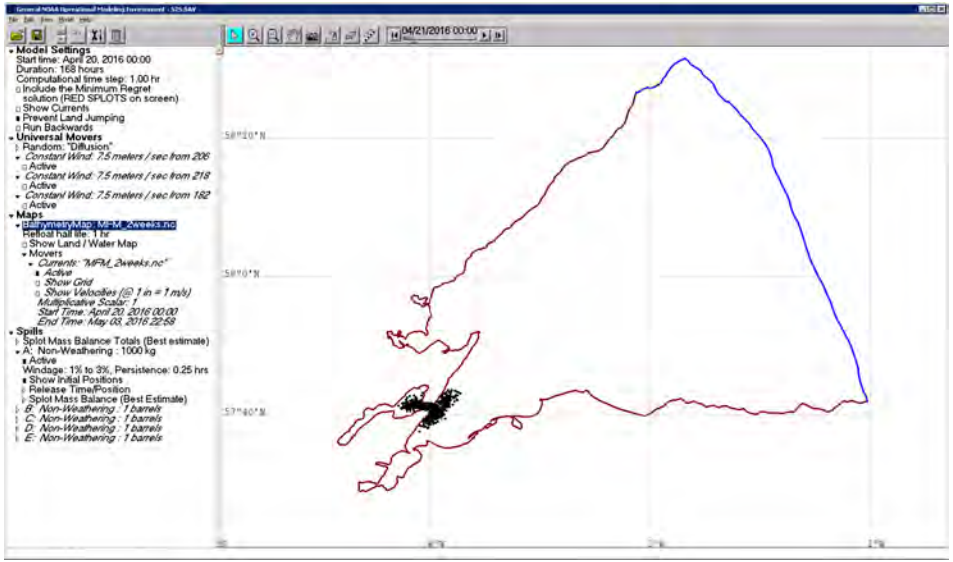


Michela de Dominicis, NOC
Alejandro Gallego, MSS

MSS Emergency Response – oil spills mainly

marinescotland science

- GNOME 2D oil trajectory modelling
- Relies on UK operational model output AMM7/AMM15
  - 6 day forecast
  - Hindcast data available
  - Ca. 7/1.5 km resolution
- Using Scottish Shelf Model currents:
  - Finer resolution, i.e. ~150 m
  - Represent our complex inshore circulation much better
  - Not yet operational so only used for contingency/spatial planning



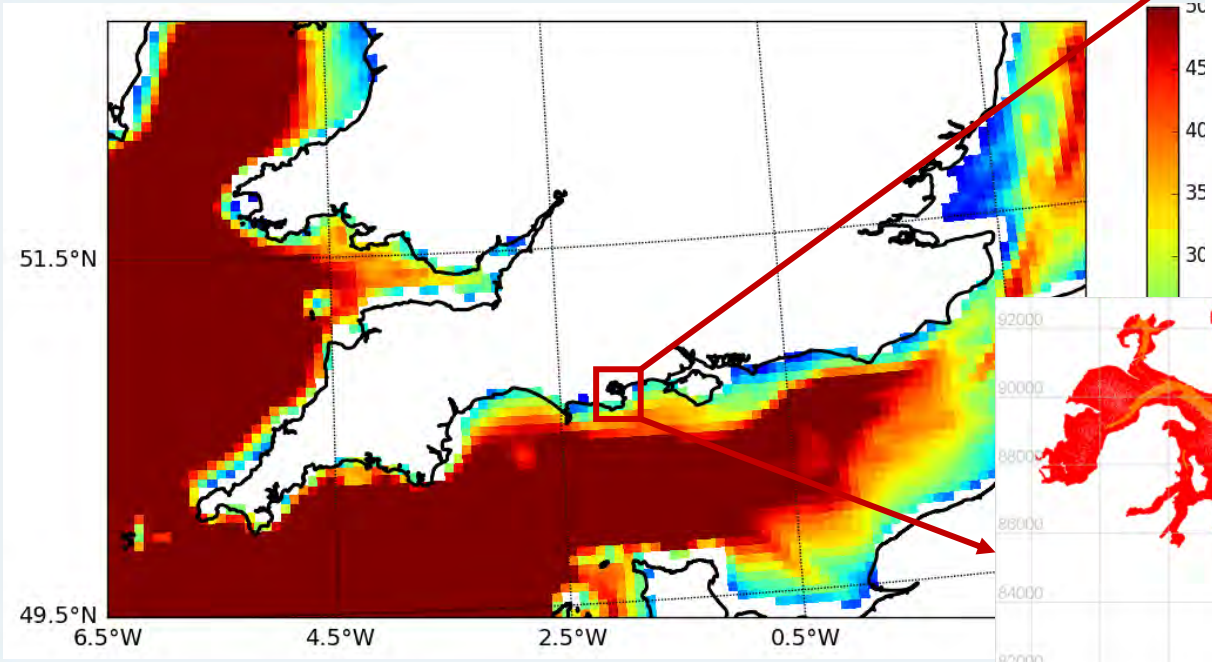
Centre for Environment, Fisheries and Aquaculture Science

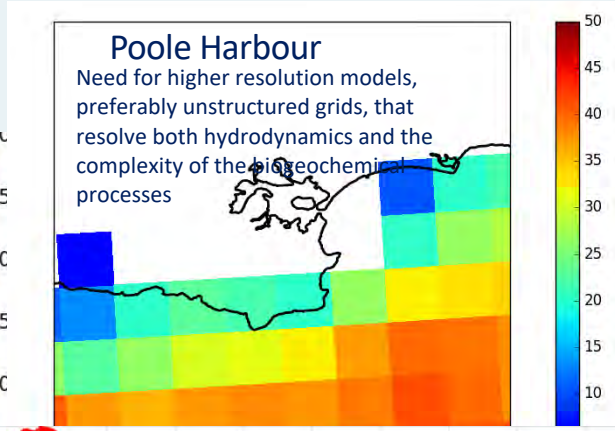
Is an executive agency of the United Kingdom government Department for Environment, Food and Rural Affairs.

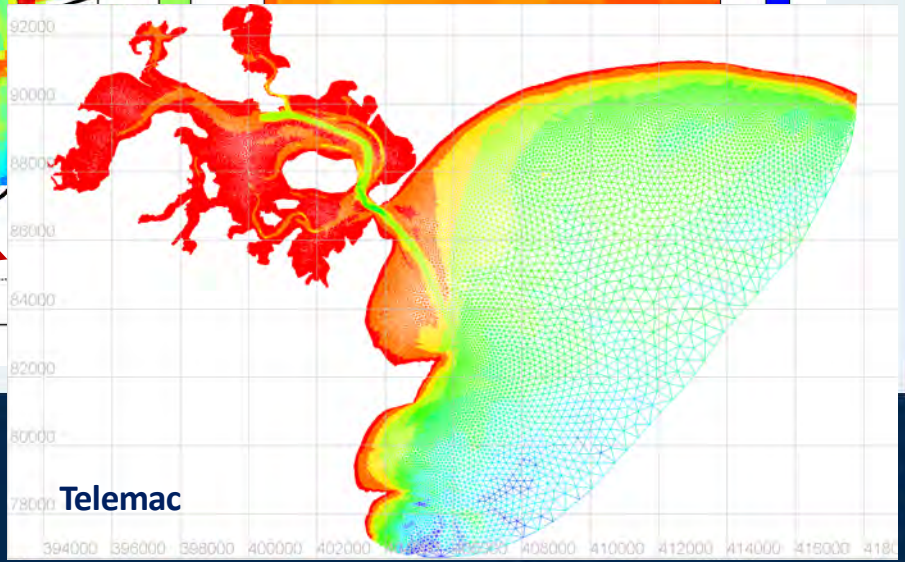
Cefas is a world leader in marine science and technology, providing innovative solutions for the aquatic environment, biodiversity and food security.

Water Quality Modelling - From regional to coastal applications

Regional models are too coarse to investigate water quality issues at finer scales (estuaries, harbours, etc.)



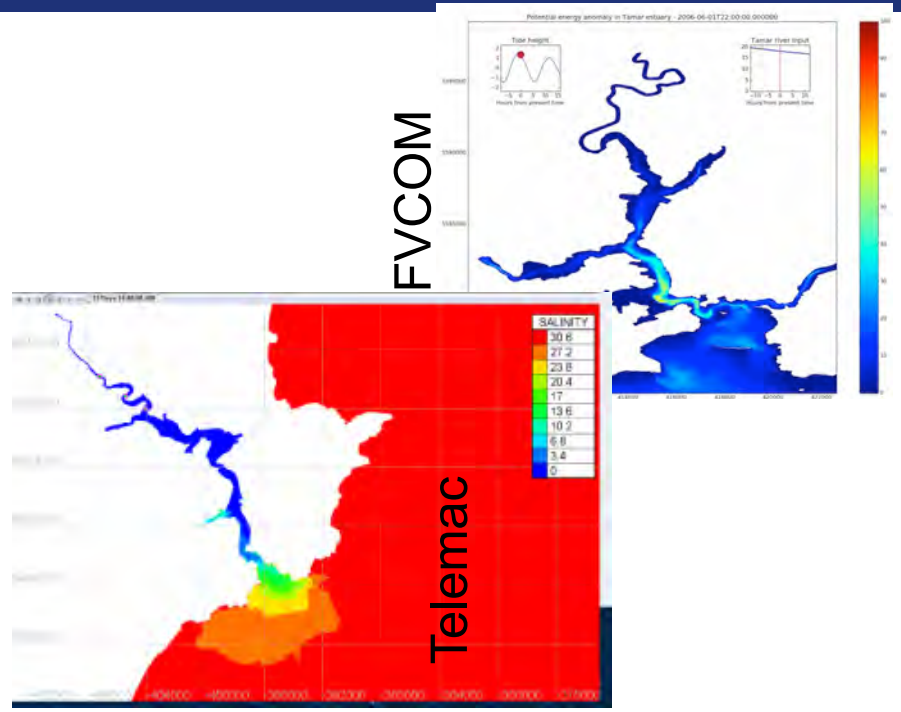




Ocean Prediction Coastal Processes Activity Group

- How to fill the gap of high resolution hydrodynamic and biogeochemical/water quality models in coastal areas at a UK wide scale?
- To create synergies between the diverse approaches at these fine scales
- To link land and ocean
- To understand estuarine -> coastal scale processes

AG Lead: luz.garcia@cefas.co.uk



PML | Plymouth Marine Laboratory

Plymouth Marine Laboratory

Research activity at PML broadly investigates global-scale issues of climate change and sustainability, centred around **biogeochemistry** and systems science, **ecosystem health** and human health, and **sustainable development and biodiversity**.

NCEO provides the UK's Natural Environment Research Council with national capability in **Earth observation science** – monitoring the health of our planet through **satellite instruments** and more.

National Centre for Earth Observation

National Centre for Earth Observation
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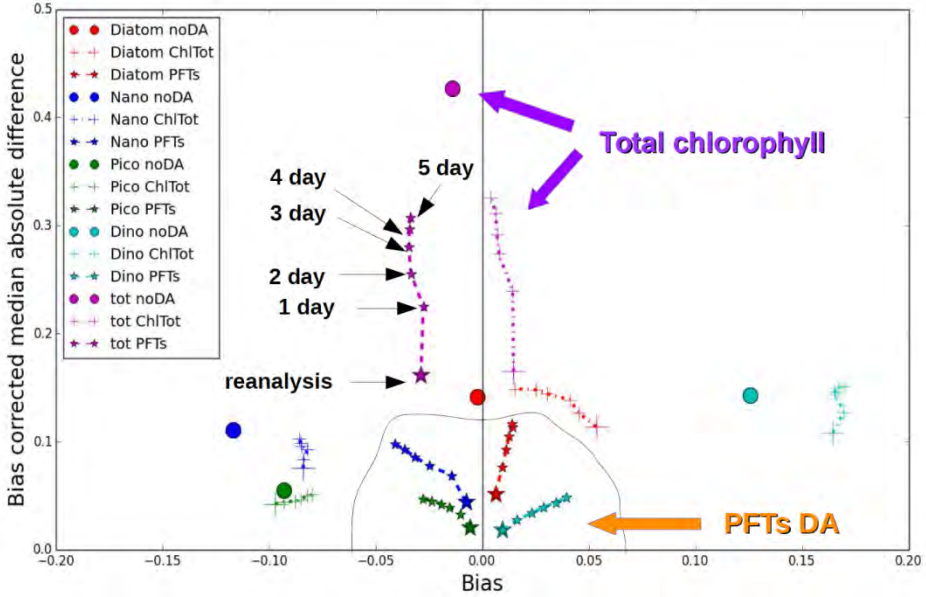
Assimilation of Plankton Functional Type



Assimilating Plankton Functional Type chlorophyll significantly reduces errors in the community composition, and the improvement is still significant after 5 days forecast

Copernicus Marine Service

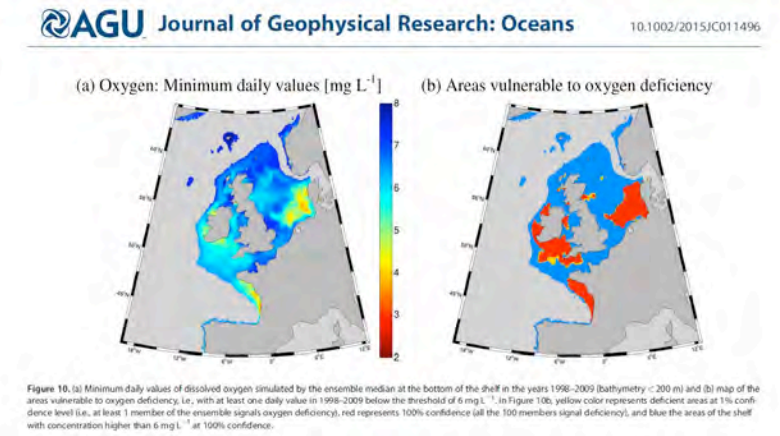
National Partnership for OCEAN PREDICTION

Marine Data Assimilation Activity Group

- Innovative, **stakeholder-oriented** data assimilation approaches
- Reanalyses and forecasts
- Hydrodynamics and BGC
- Engage with multiple communities
- Regular workshops

AG Lead Stefano Ciavatta
avab@pml.ac.uk

Oxygen deficiency in reanalysis simulation



Ciavatta et al 2016 *JGR*

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Challenges and future directions

Future directions / challenges

	Research	R2O*
• Environmental Prediction systems (Earth Systems for the short-range)	✓	✓
• Ensemble / probabilistic ocean forecasts	✓	✓
• Advanced verification (esp. Hi-Res systems)	✓	✓
• Next Gen systems (computational layers / new science)	✓	✓
• Scalable complexity biogeochemistry models	✓	✓
• Couple to statistical models to go beyond model variables	✓	✓
• Post-processing ocean parameters	✓	✓
• Machine Learning and Artificial Intelligence	✓	✓

To do these things we need:

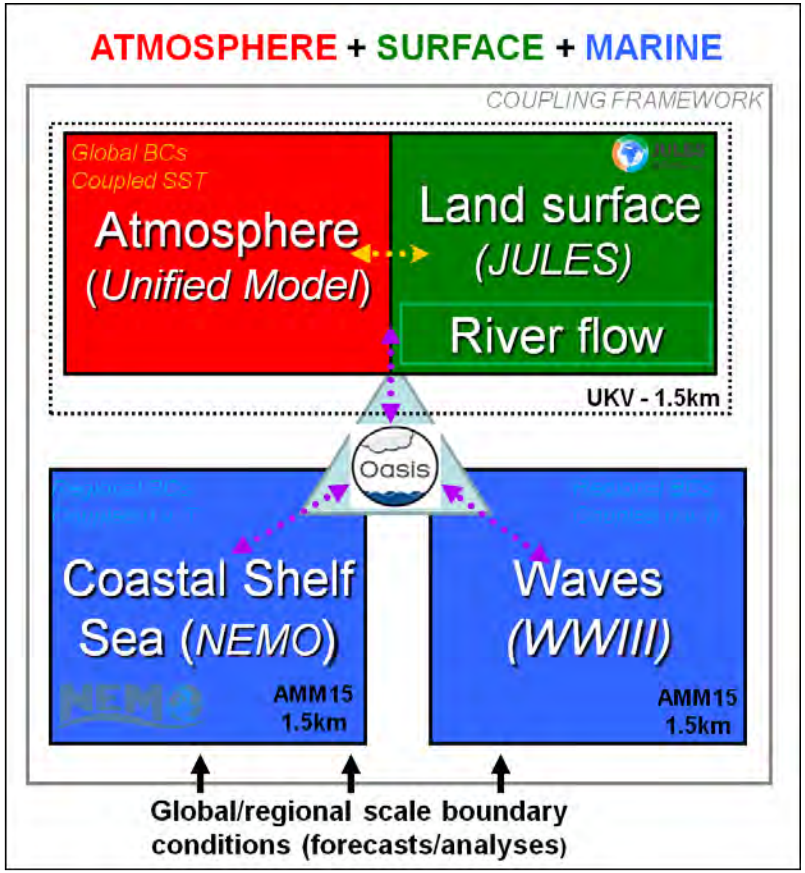
• Adapted, use-orientated, fit-for-purpose ocean observing networks	✓	✓

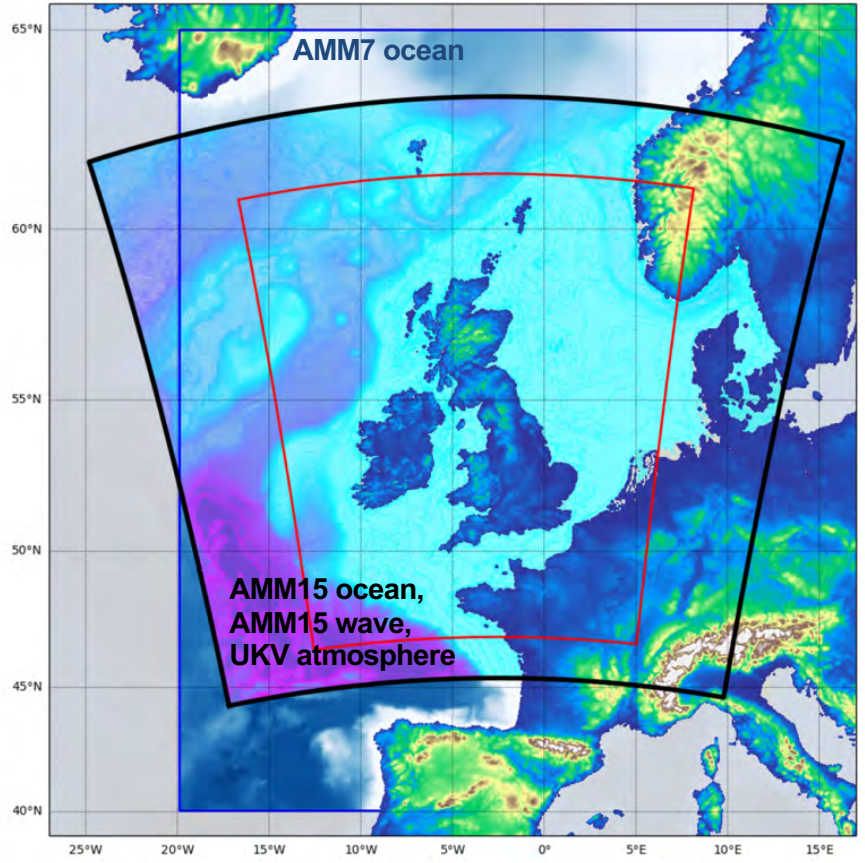
*Route to operations clear for forecast products

Met Office

Ensemble coupled prediction

Regional coupled prediction system





Lewis et al., 2018 (GMD)

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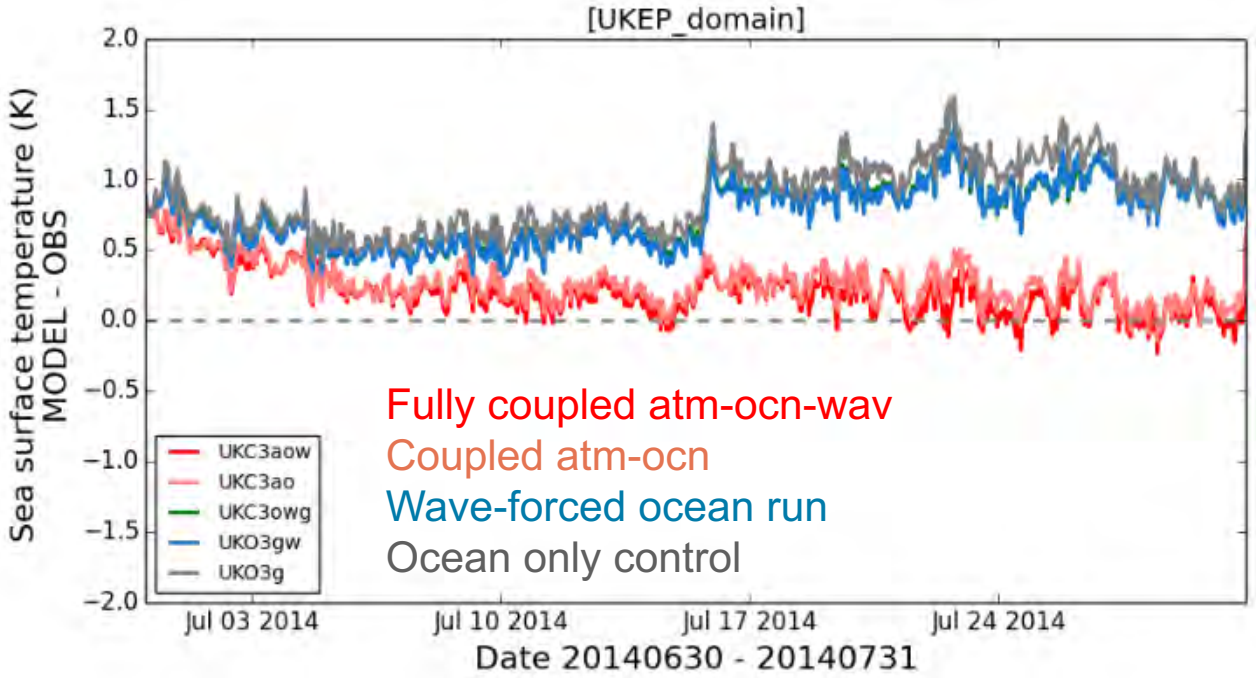
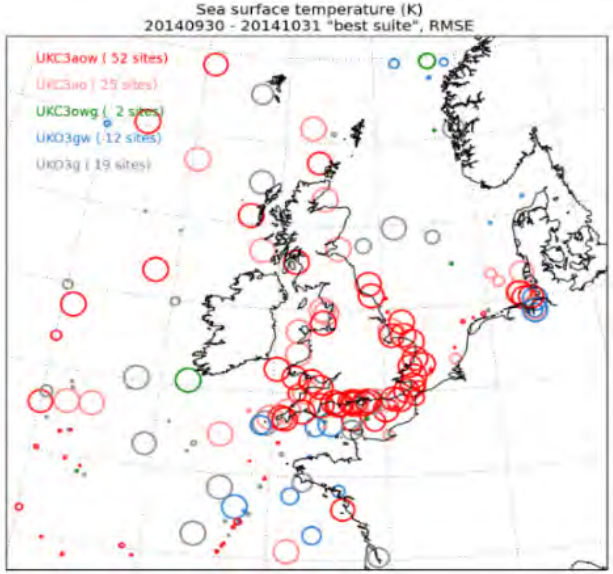
Results



Mean MODEL – OBS SST difference against in-situ observations, July 2014:

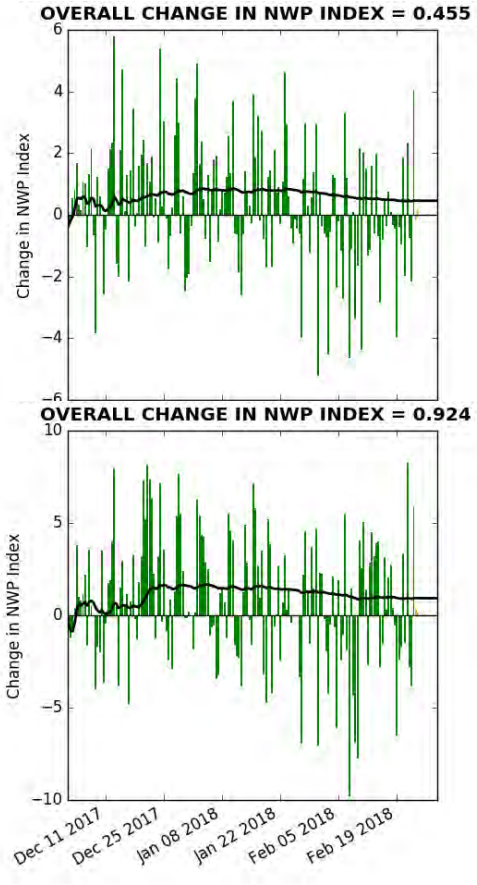
Wave coupling and atm coupling improve results, particularly near-coast



Evaluating Coupled NWP on Weather

vs Obs

vs Anal



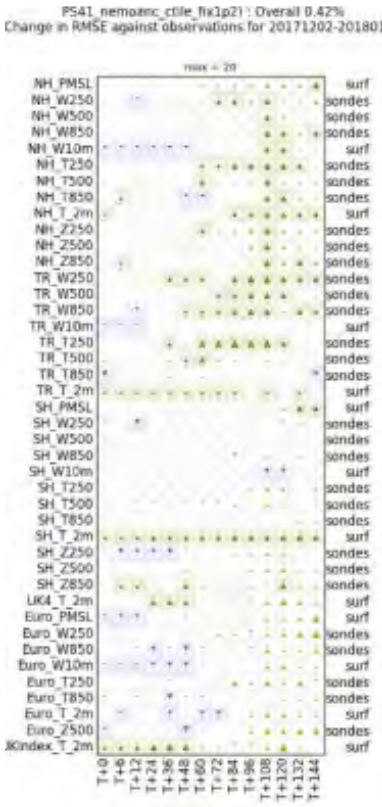
N640 winter trial

NWP Index:
Basket of measures, largely positive

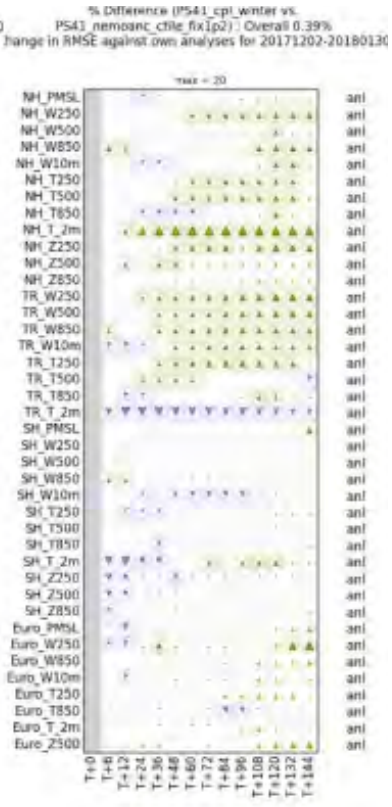
Net positives for all trials (~0.5 – 0.9 NWP increase)

TC track also improved (not shown)

vs Obs



vs Anal



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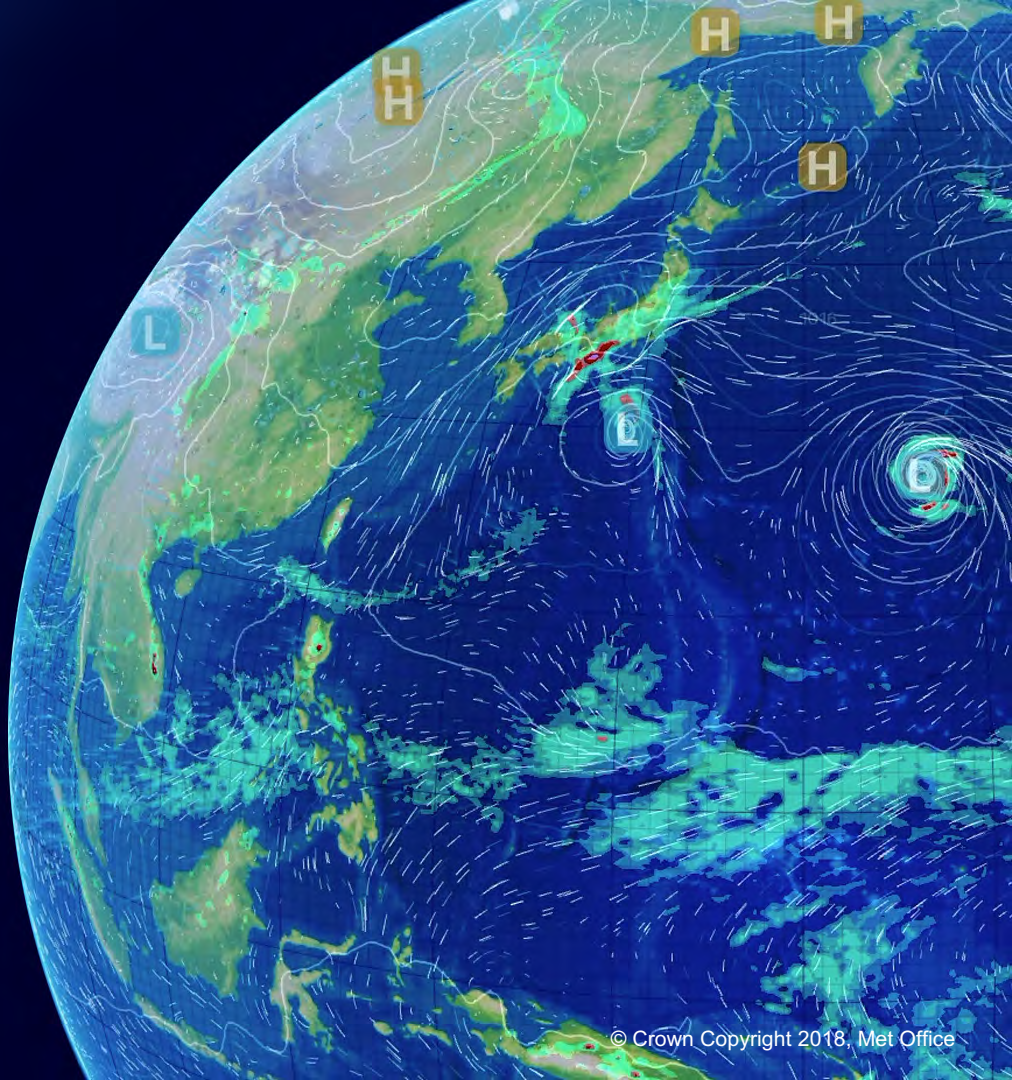
Thank you



National Partnership for OCEAN PREDICTION

EuroGOOS and NOOS

The European Context is, and has always, been important to us

EuroGOOS coordinates European Operational Oceanography

NOOS is regional alliance that does practical implementation around UK and neighbours waters:

- Critical mass of like-minded experts for advocacy and visibility
- Sharing of observations
- Sharing of expertise

EuroGOOS
European Global Ocean Observing System

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CMCC (Italy)

Met Office (UK)

Puertos de Estados (Spain)

BSH (Germany)

NERSC (Norway)

MERCATOR OCEAN INTERNATIONAL

CNR (Italy)

SHOM (France)

MeteoFr (France)

Ifremer (France)

CNRS (France)

IRD (France)

GODAE OceanView / OceanPredict

GODAE OceanView continues the legacy of GODAE in providing coordination and leadership in consolidating and improving global and regional ocean analysis and forecasting systems.

GODAE OceanView Principle Sponsors

GOV provides international science leadership for operational ocean forecasting

The Met Office Ocean Forecasting group provides a number of experts to this international consortium

- we lead two of the six international task teams
- we are on both the Science Team and the Patrons Group
- the GOV project office is led from the Ocean Forecasting team

Met Office

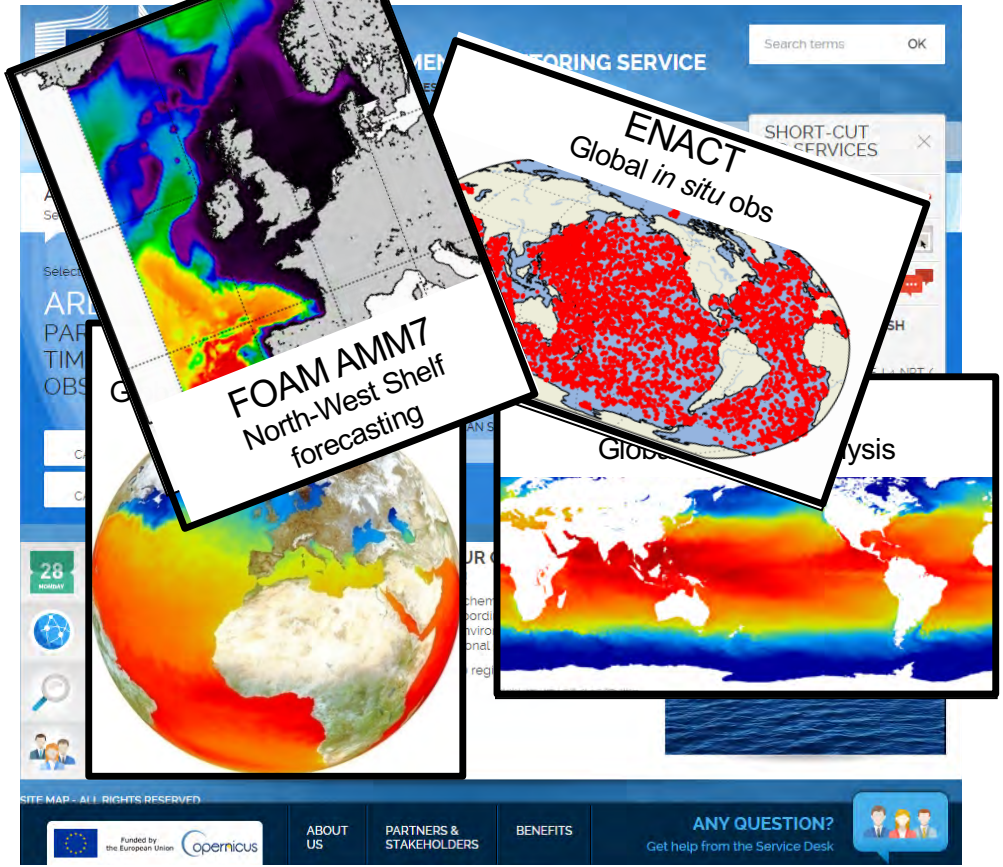
European Commission

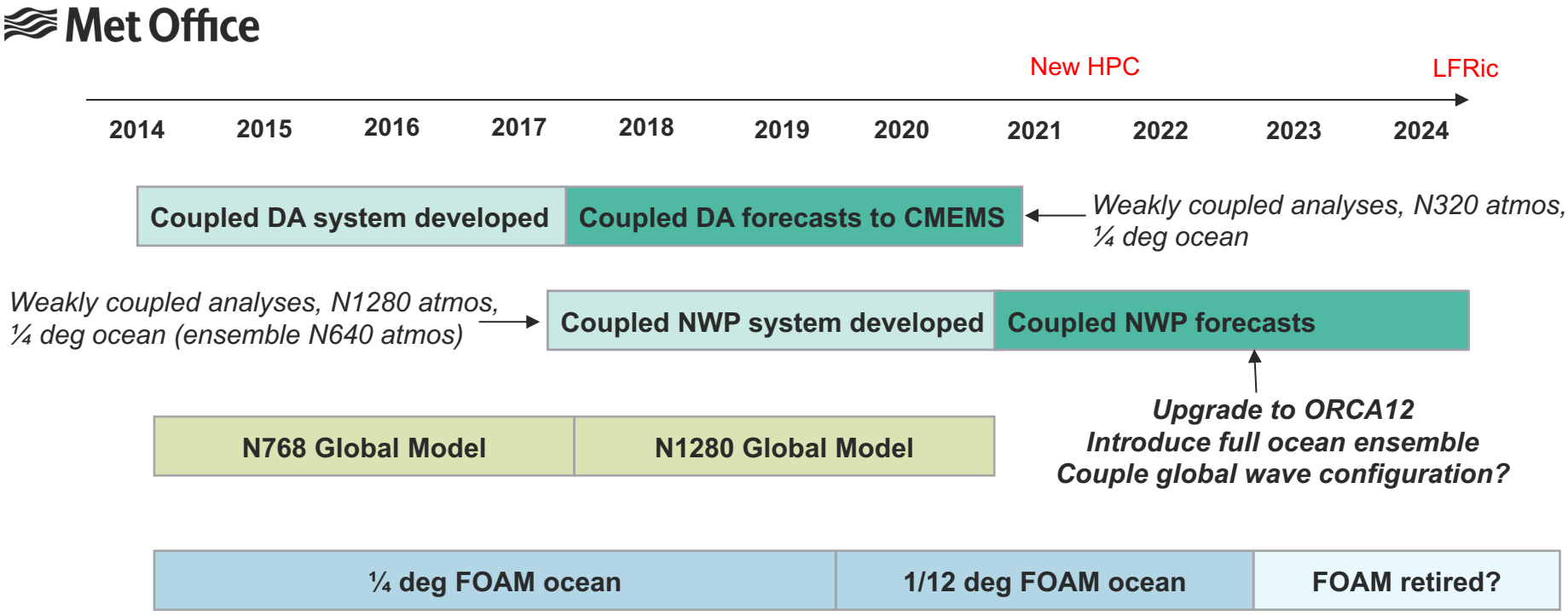
Copernicus Marine Environmental Monitoring Service

Copernicus Europe's eyes on Earth

Successfully operating:

- *North-West Shelf*
- *Global SST/Ice*
- *Global In Situ*
- *Coupled global*



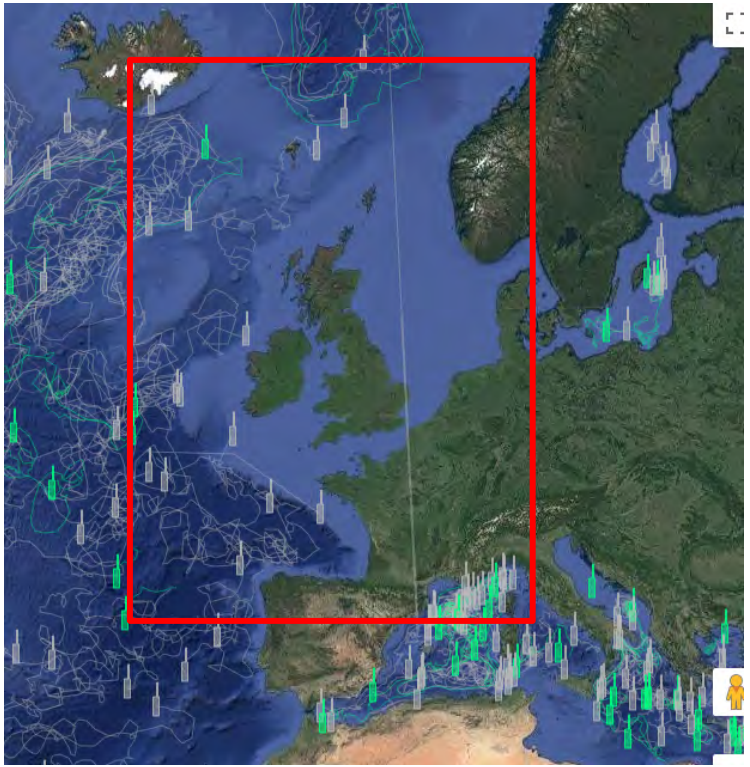


- Coupled NWP project is trialling NWP operational systems with PS41 N1280 and lower resolution versions
- Aim for implementation at PS46 (go live early 2021) to replace NWP deterministic and MOGREPS-G
- A coupled system will result in retiring ocean, and potentially, wave only forecast systems, and facilitate coupled ensembles

Challenges: lack of in situ data

Match-ups to in situ data for 1998-2010:

temperature	745641
salinity	738288
chlorophyll	56740
pH	11322



Very limited Bio-ARGO data

Surface Waves

- Improving the up take of wave information by developing a network across a diverse range of stakeholder.

Palmer…Bricheno… et al 2018

Future wave projections:

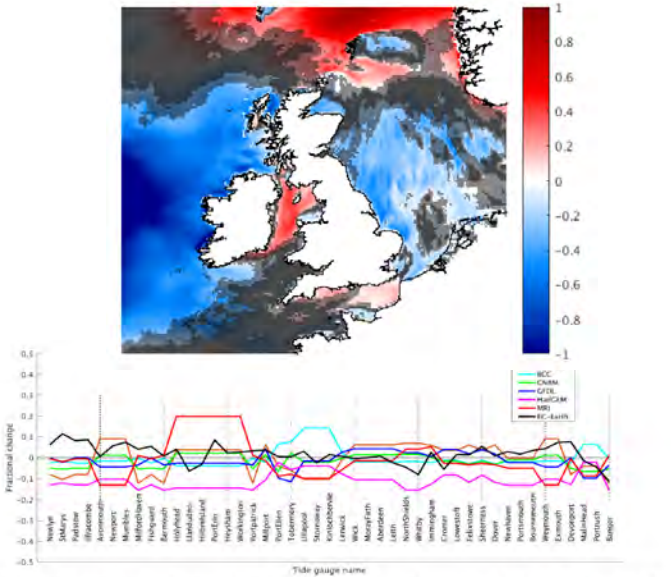
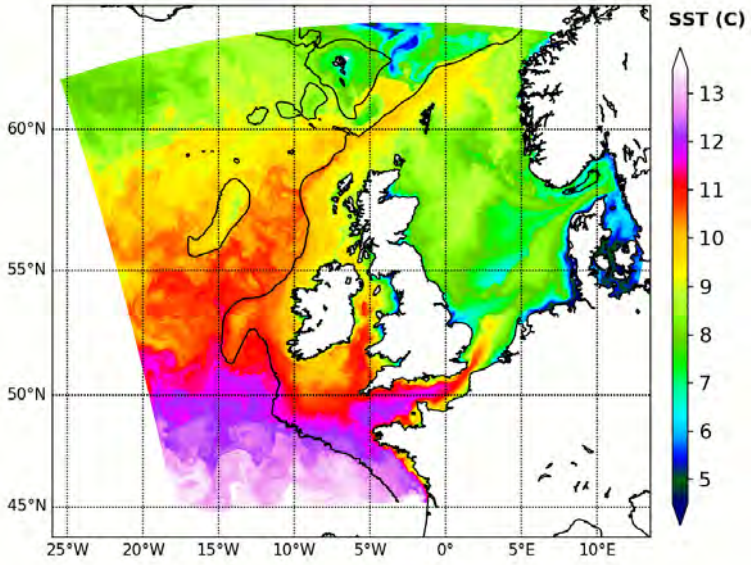


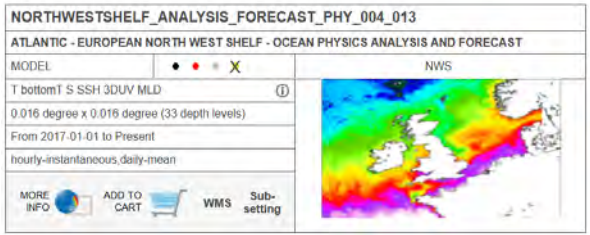
Figure 3.3.1. Fractional change in mean significant wave height (SWH, upper panel) and annual maximum wave height (AnnMax, lower panel) for class A tide gauge locations around the UK. The change is computed as the 2070-2099 average for RCP8.5 minus the 1980-2005 average from the historical simulation. Colours correspond to different CMIP5 climate models as indicated in the figure legend.

john.bacon@cefas.co.uk

Copernicus Products: Ocean Physics, Waves and Biogeochemistry 6-day forecast

- AMM15 1.5km resolution
- AMM7 7km for BGC
- Assimilates SST, profiles, sea level
- Hourly and daily mean data, 33 levels
- From 01-01-2017
- Run at Met Office





http://marine.copernicus.eu/services-portfolio/access-to-products/

Copernicus Products: Ocean Physics and Biogeochemistry Reanalysis

- AMM7 7km resolution
- Assimilates SST, Profiles, Sea level
- Hourly and daily mean data, 33 levels
- From 01-01-1992 physics
- From 01-01-1998 BGC
- Run at Met Office

Extensive quality assessment and validation

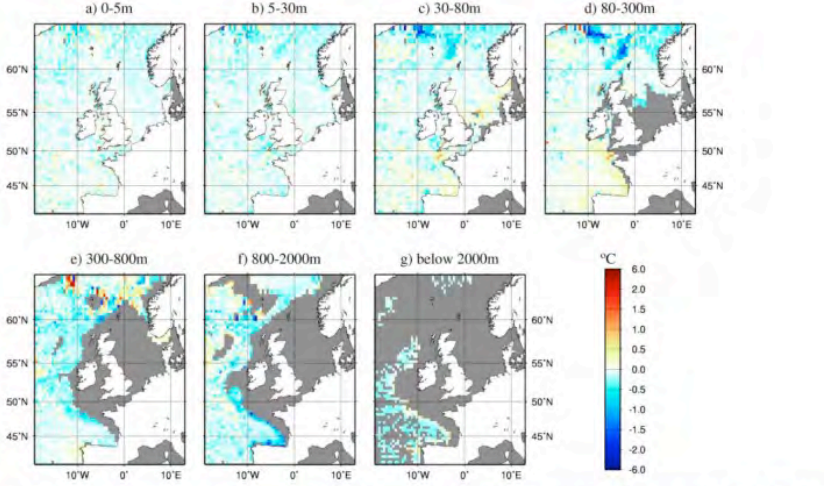


Figure 6: Mean biases between co-located V4 temperatures and WOD13 observations in different layers for 1992-2016.

http://resources.marine.copernicus.eu/documents/QUID/CMEMS-NWS-QUID-004-009.pdf

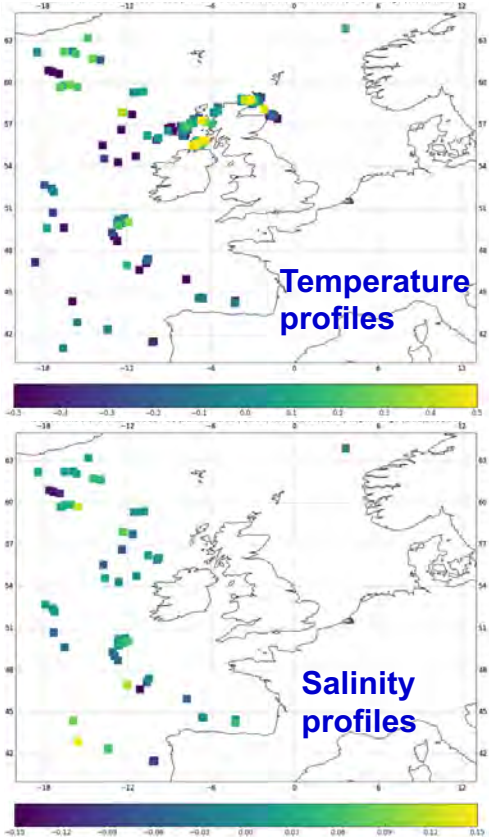
http://marine.copernicus.eu/services-portfolio/access-to-products/

Met Office

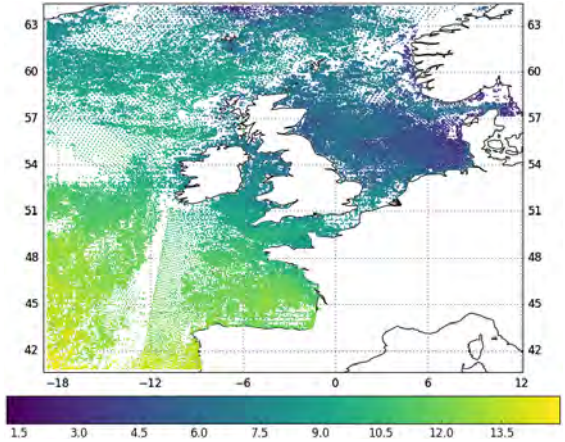
Assimilation

Ensembles
SMOS
SWOT
Gliders

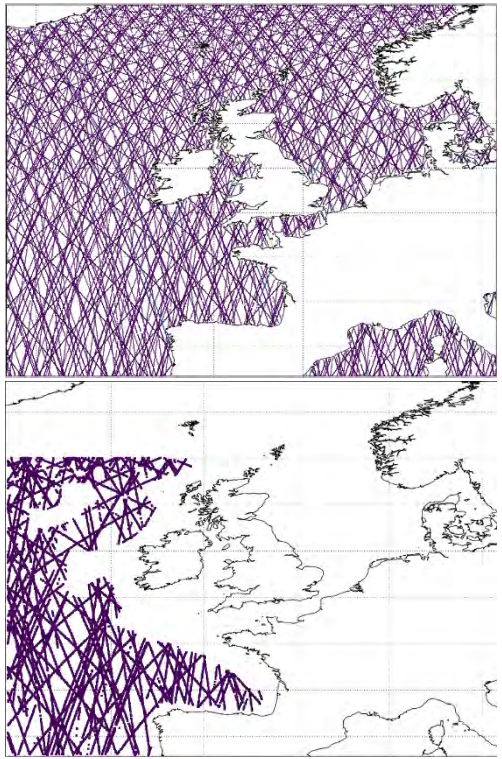
Observations Assimilated on Shelf Region



Example monthly coverage of T/S



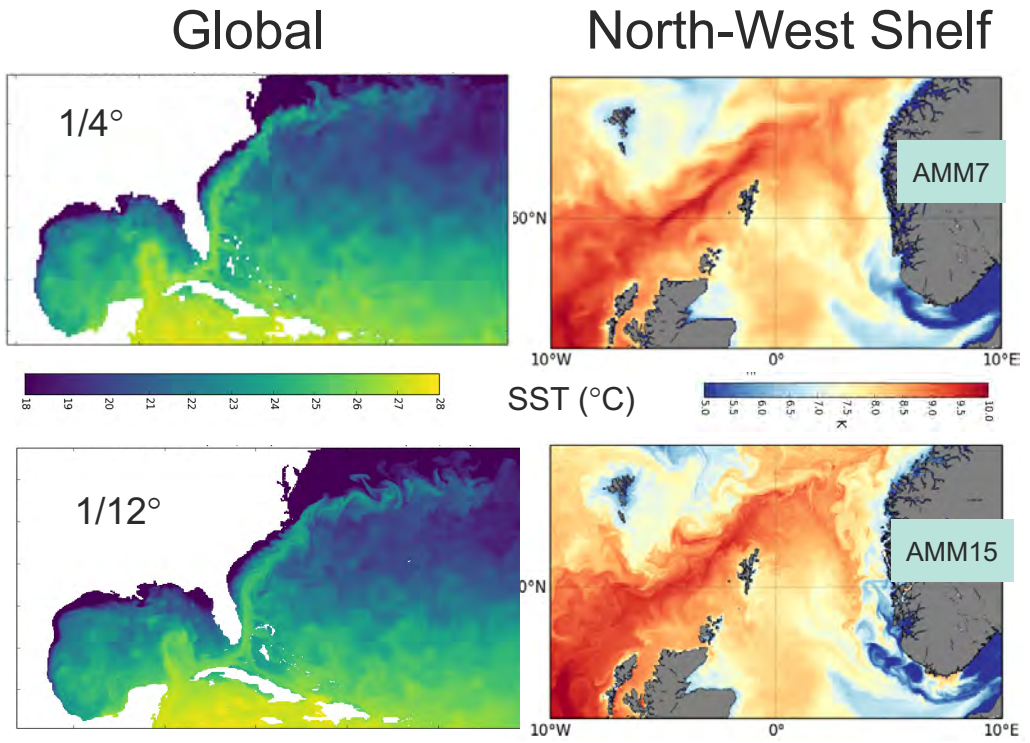
Example daily coverage of SST obs



Example coverage of satellite altimeter observations for 1-month from Sentinal-3, Jason-3, Cryosat and AltiKa (top) and those assimilated (bottom).

Data assimilation in High Resolution models

- Assimilation of **satellite** and **in situ SST** data, satellite **altimeter SLA** data (in the deep part of the domain), and **in situ temperature/salinity profiles** has been implemented in **AMM15 and ORCA12**.
- First implementation of DA in AMM15 gives **similar accuracy** to AMM7, while **maintaining** the **high resolution** model information.
- Further tuning needed **for high resolution satellite** and e.g. **glider** observations.
- **Computational efficiency** of the data assimilation in the high resolution is an isse.



Assimilation and Biogeochemistry

Status

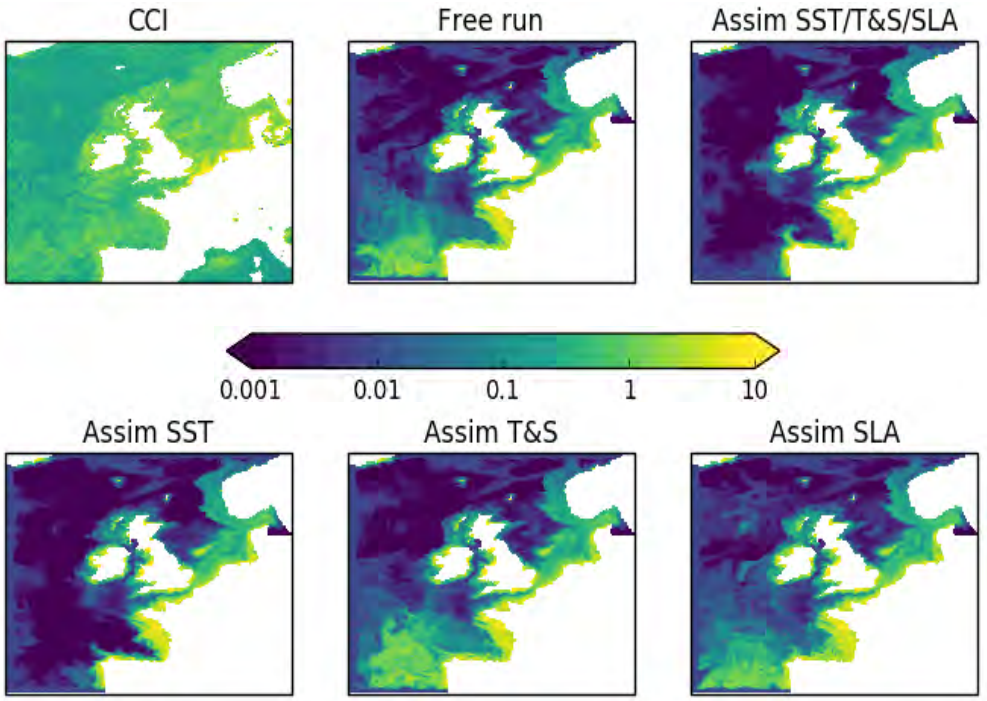
- Surface chlorophyll-a implemented in reanalysis
- Soon to be implemented in forecasts
- Results really promising

Next steps

- Plankton Functional Type from EO
- Gliders and other profiles

Challenges:

- The effect of physics DA on BGC
- Poor obs quality, quantity and timeliness
- Balancing increments

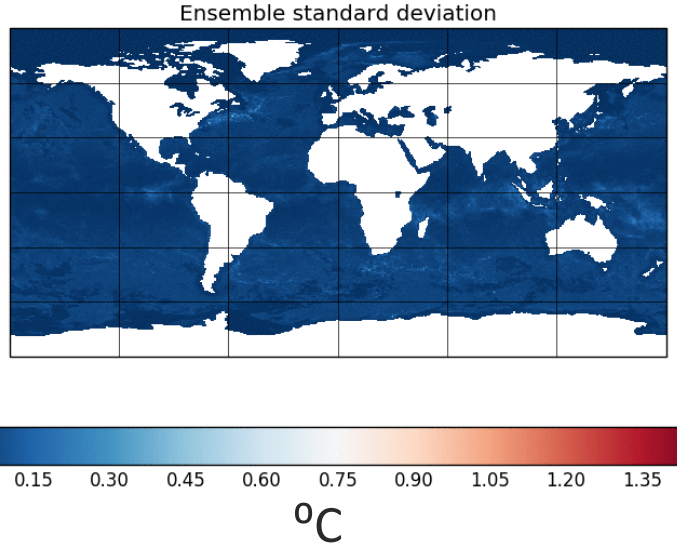


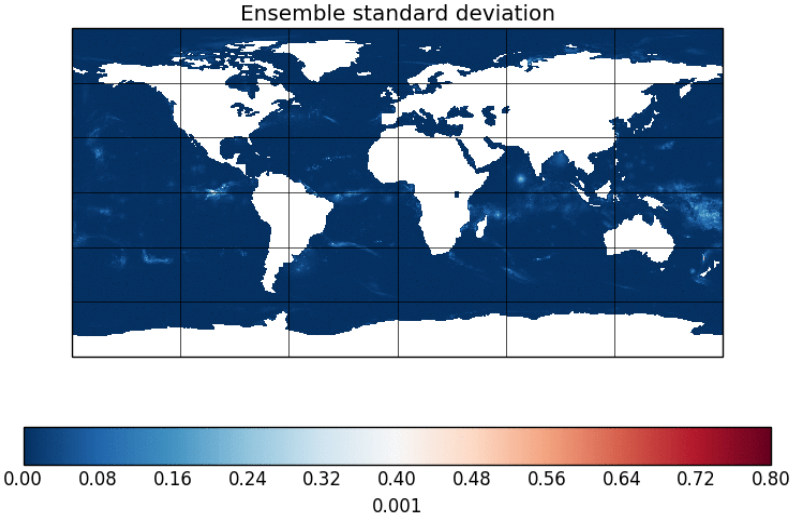
Global Ensemble Development

- Flux perturbed from NWP Ensemble
- Obs value perturbed
- Obs location perturbed

- Spin-up clearly visible
- As are day to day variations in the spread (errors of the day).

- Also seen are weather effects which would not be present if we just perturbed the forcing.



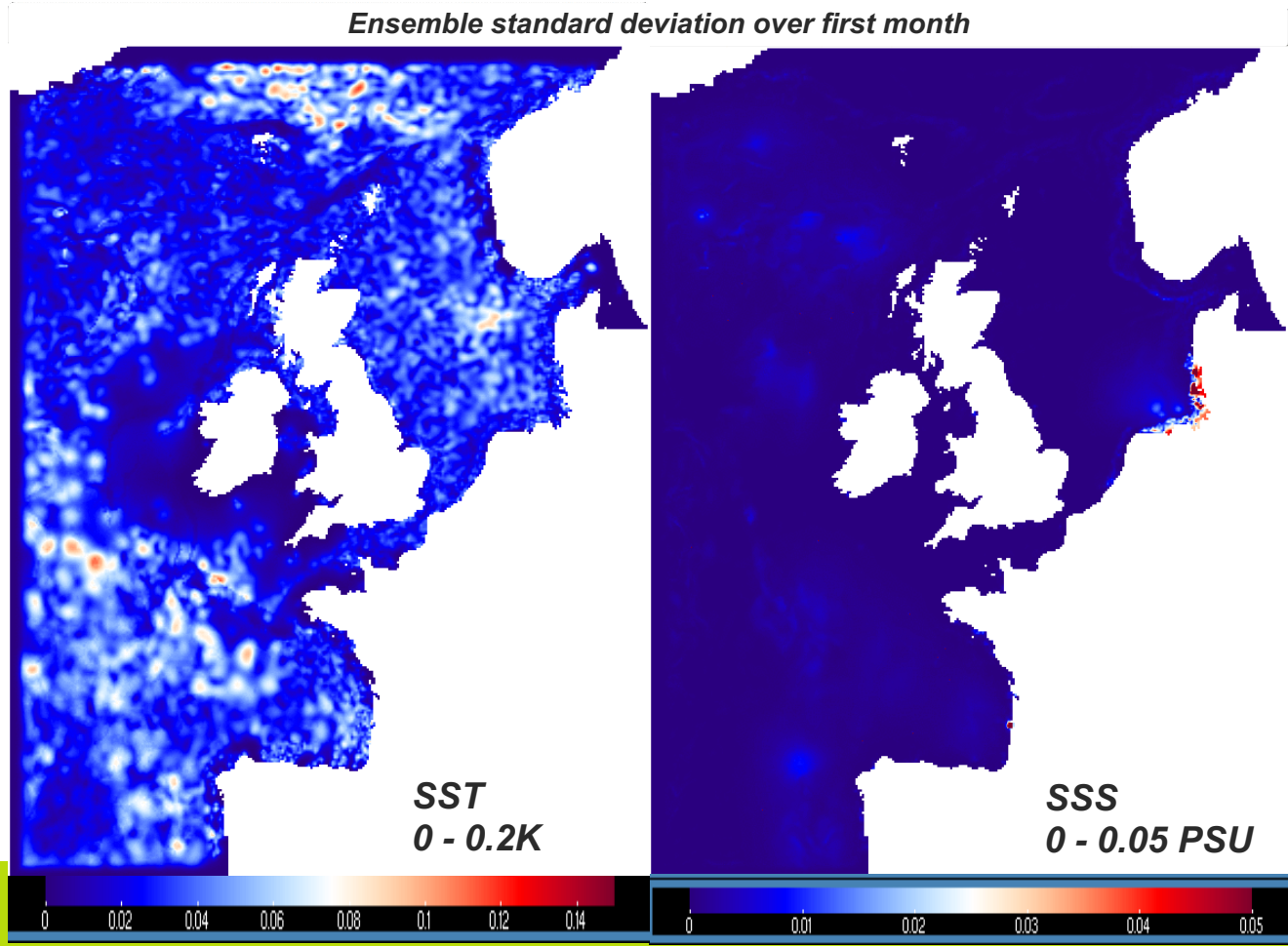


Developing the shelf seas ensemble

Currently only perturbing observations, so dominated by perturbations from SST and off-shelf profiles/altimeter.

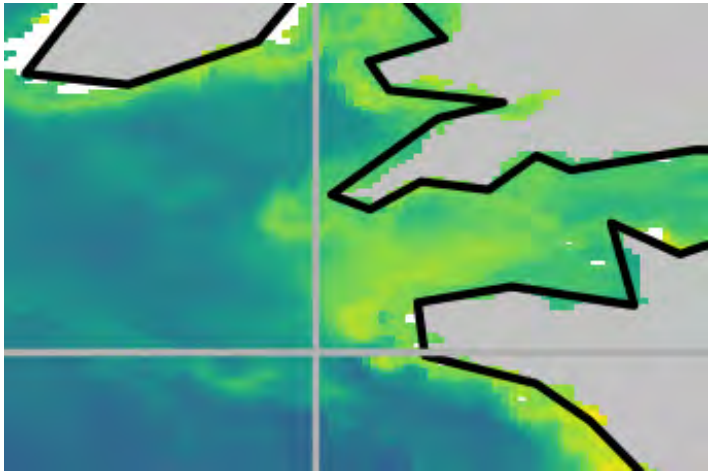
Other aspects required to introduce spread below ML.

Need work to understand if spread from these perturbations is realistic/sufficient.

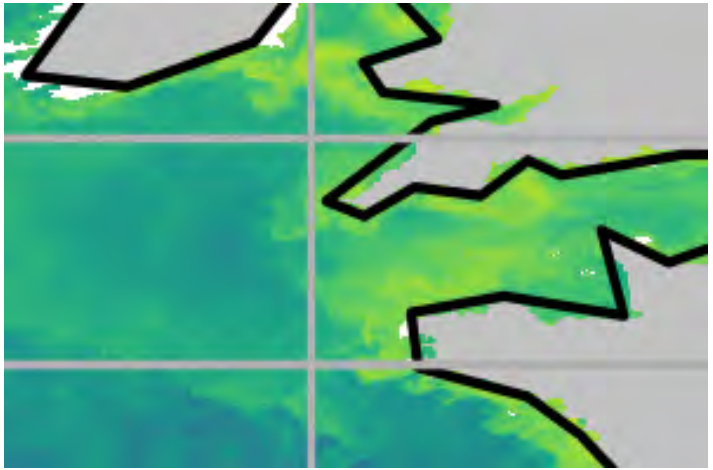


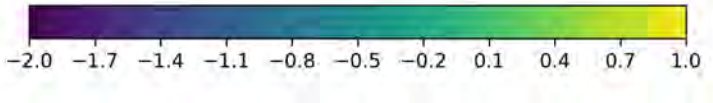
How important is the extra resolution?

AMM7 20 mins per day



AMM15 110 mins per day

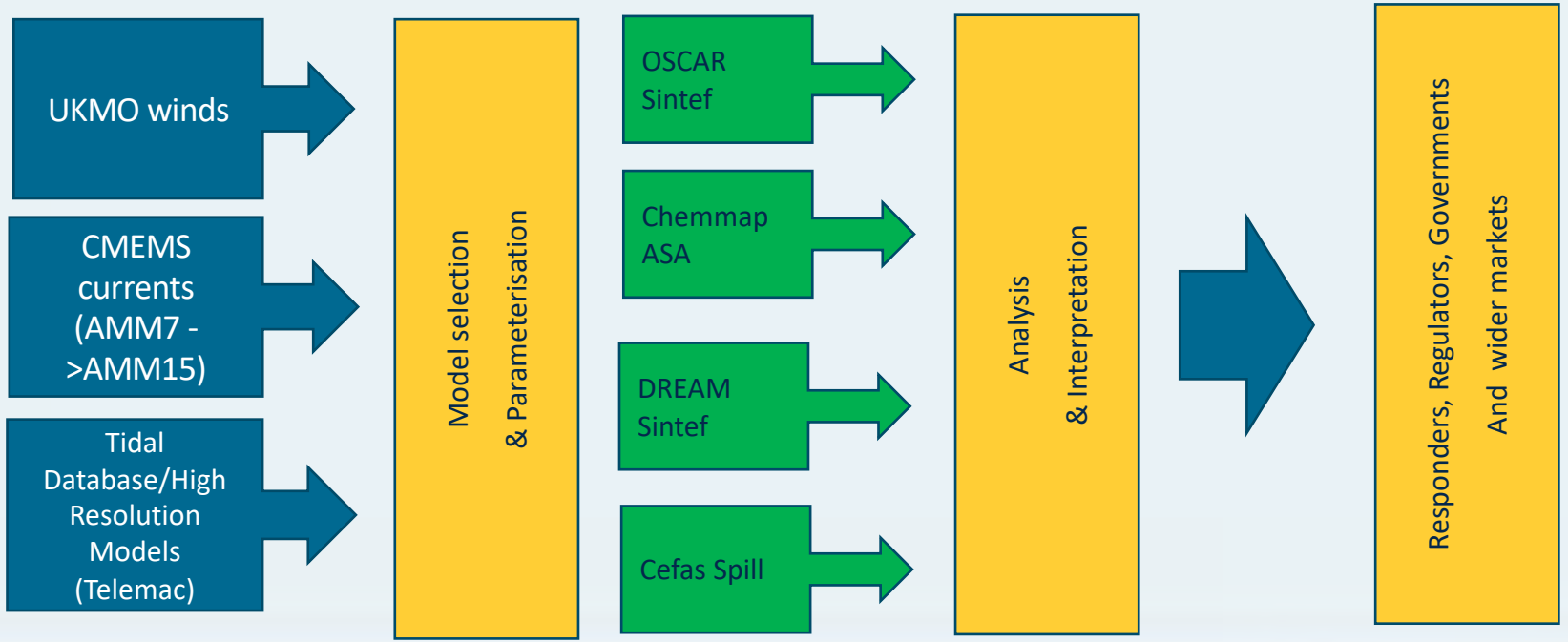




Sample output: surface log-chlorophyll for 2016-06-15

Cefas Emergency Response Modelling

Oil and Chemical Spills



C-RISC

Coastal Resilience to flooding Impact through relocatable Storm surge forecasting Capability for developing nations

Dr Jeff Polton (National Oceanography Centre)
Dr Simon Holgate (Sea Level Research Ltd)

Jason Holt, Christine Sams, Tom Prime, Anthony Wise, Kevin Horsburgh (NOC)

- Madagascar is exposed to cyclone risks, (~3-4 cyclones / year)
- 6000 km coastline & 1,250 fishing villages: marine activities important to Madagascar's social and economic life
- Coastal communities at risk from climate variability and change

Spécification idéale:

- contrôlé localement
- personnalisé localement
- résilience opérationnelle

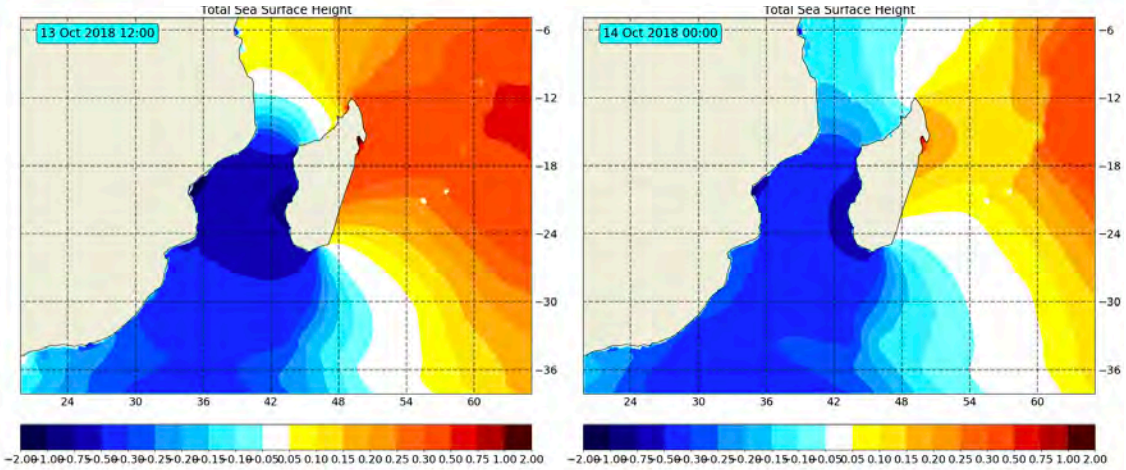
National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

SEA LEVEL RESEARCH

https://surgedemo.z16.web.core.windows.net

Welcome to the Madagascar Surge Model Demonstrator

Images from the latest model run: **2018-10-13 - 2018-10-18.**



Prototype Summary

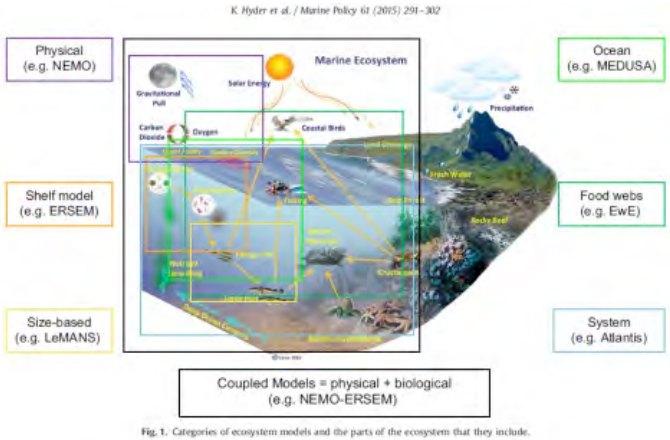
Meteorology: NCEP/NOAA (Global Forecast System) winds + sea level pressure (hourly, 1/4 deg)
Tides: FES2014
Ocean: NEMOv4
Output: 5 day forecast - hourly SSH (data / images)

Hosted on Azure cloud service (Micosoft)
Automated:

- meteorology download
- model run
- diagnostic processing

Marine Biogeochemistry Modelling

- To facilitate the pull-through of cutting-edge BGC model developments into operational systems and key applications
- To facilitate the uptake of stakeholder needs into model and product developments in order to promote the use of BGC product by stakeholders



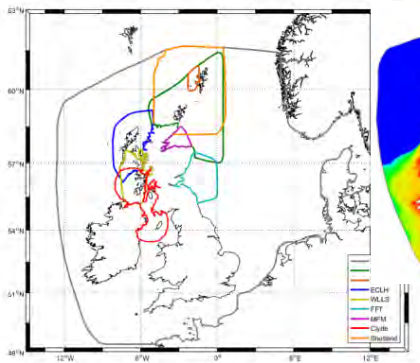
Making modelling count -….

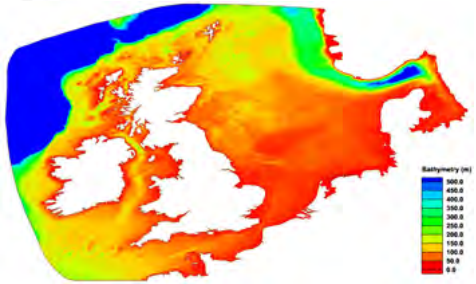
Hyder et al 2015

Yuri Artioli
yuti@pml.ac.uk

The Scottish Shelf Model and CMEMS

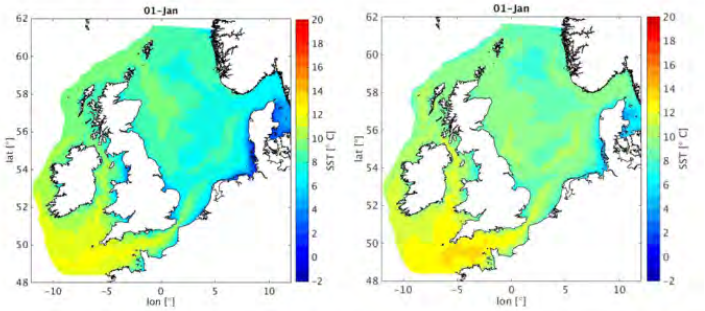
- FVCOM implementation
- One wider domain model and 8 (and growing) higher-resolution nested sub-domains
- FOAM AMM7 boundary forcing (moving to AMM15)
- Grid 2 Grid model climatology for freshwater
- ECMWF ERA-Interim data for atmospheric forcing
- Not (yet) operational but working on it
  - Finer resolution met forcing (UKV?)
  - Only for the higher resolution sub-models?





Bathymetry

Wide domain and sub-domains

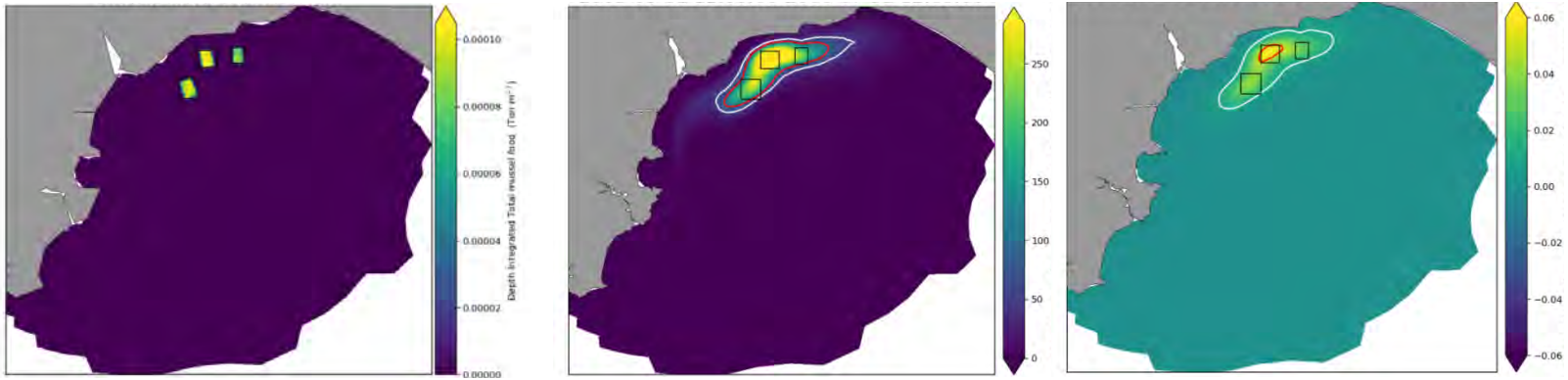


Present-day and 2050's climatologies

PML | Plymouth Marine Laboratory

Going beyond biogeochemistry

Coupling to Higher Trophic Level models to provide information for fishery, aquaculture, diversity, ecological status…



Aquaculture mussels production (left) and the impact on particle fluxes (mid) and benthic fauna (right)

NERC SCIENCE OF THE ENVIRONMENT

BBSRC bioscience for the future

Resolutions

What resolution is good enough

- Eddy-resolving at the **global scale**?
- With tides at 1/25^{o} ?

Eddy-resolving at the **shelf scale**?

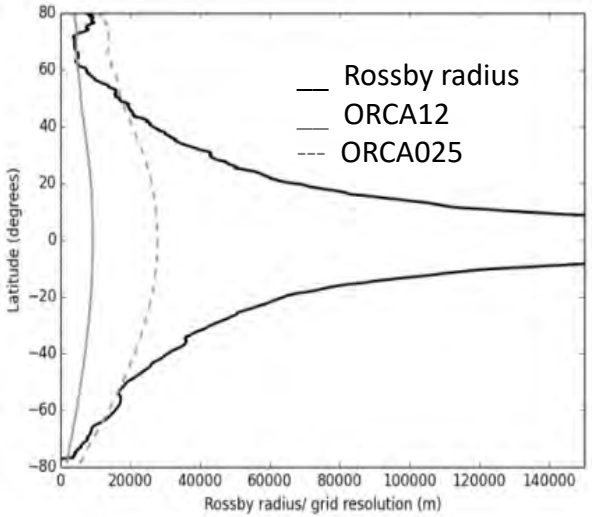
With unstructured grids for coastlines? At ~1 km?

Bridging the **land** and the ocean?

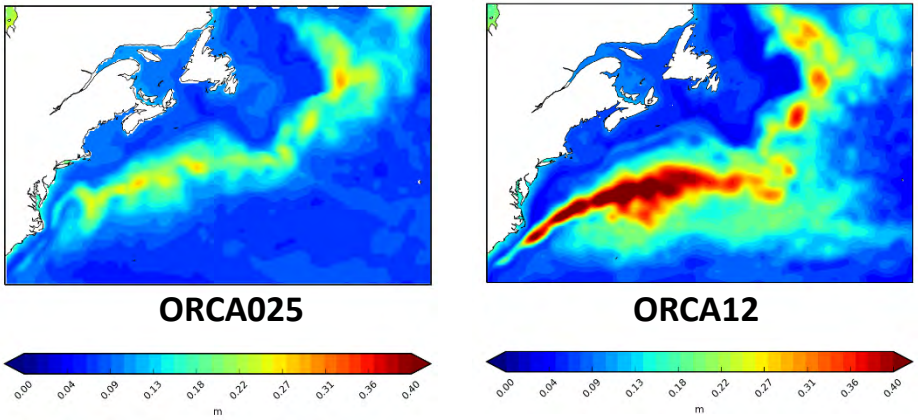
Estuarine scale interactions upscaling / downscaling from-to the shelf-wide solution?

FOAM-ORCA12

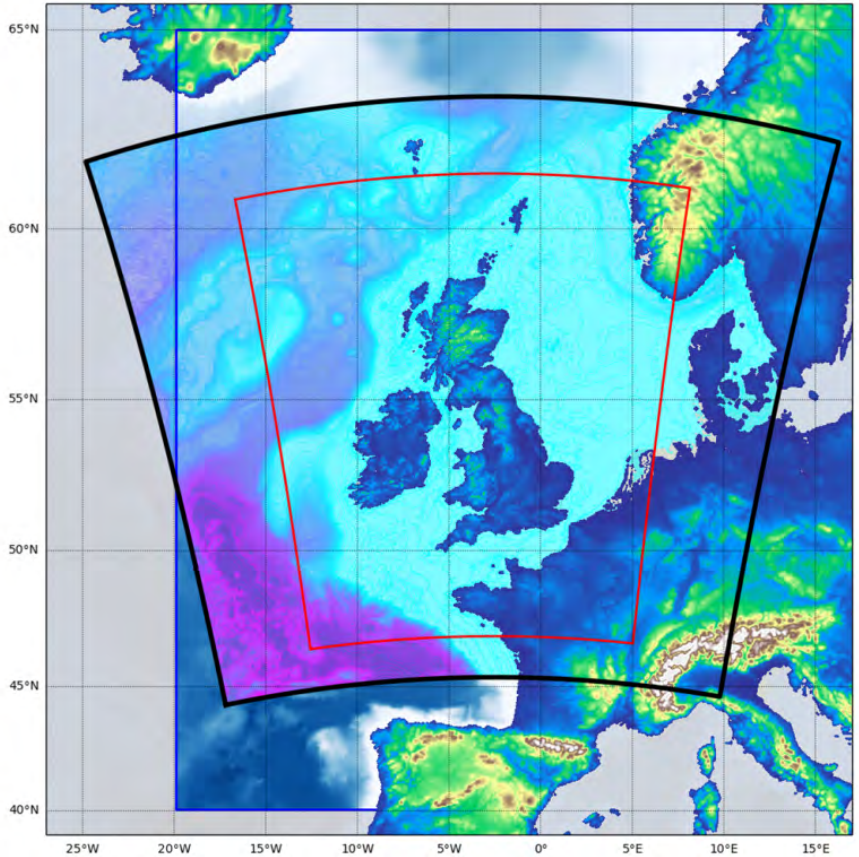
- The Met Office's global system replacement will be at 1/12° nominal resolution
- Co-developed with **National Oceanography Centre**, and aligned with DRAKKAR (FR) developments (Mercator etc.)
- Represents **dominant scales**, notably at high latitudes
- In process of final developments for operations **(R2O)**

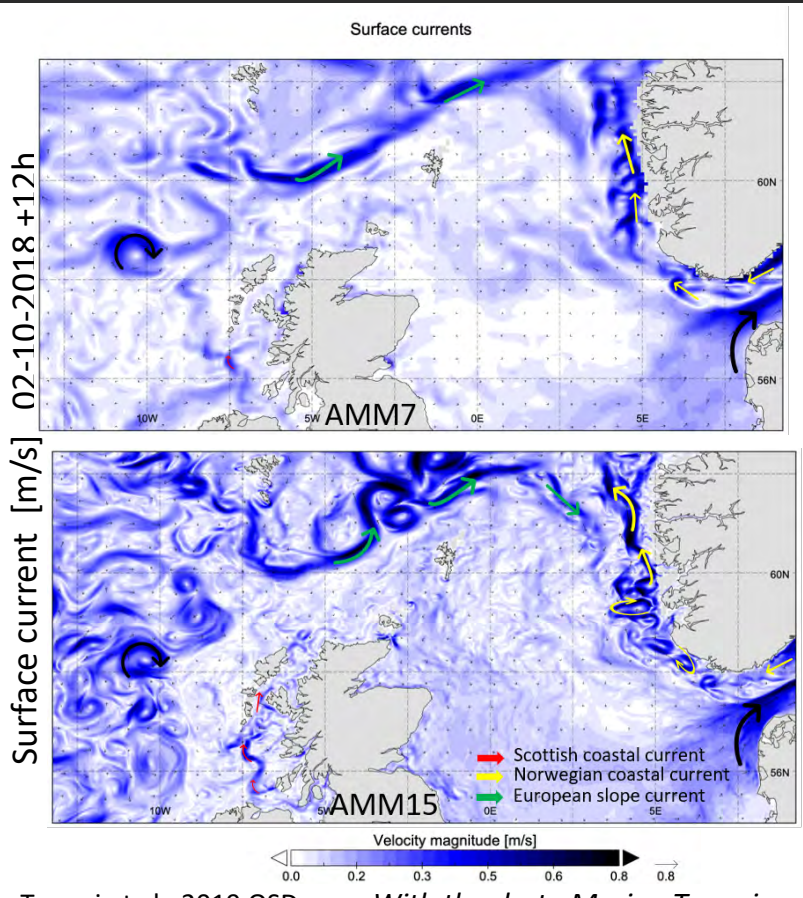


5 year SSH standard deviation from free model runs



FOAM-AMM15





Tonani et al., 2019 OSD

With thanks to Marina Tonani

Challenges

- Exascale, low-memory, high-processor environments
- Coupled weather / hazard prediction
- Machine learning and data-based solutions
- Post-processing
- Customer/user demands for more …
  - resolution
  - probabilistic information
  - earth system information
  - global reach
  - hazards and impacts information
  - tailored products
  - cost savings