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

OCEAN PREDICTION 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.





Cefas







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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

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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:











MINISTERS FRO Oversee the work MSCC CO-CHAIR The two co-chairs h deliver UK marine the monitoring and Chairs report to Mi science community	COMMUNICATIONS WORKING GROUP Raise awareness and understanding of the importance of the marine environment, develop, promote and co-ordinate informatio and activities to ensure two way flow of communication between science and policy.	 MARINE ASSESSMENT AND REPORTING GROUP Provide overall direction to UK marine monitoring programmes. Define monitoring programmes for the assessment and management of the marine environment, oversee implementation of the UK Marine Monitoring and Assessment Strategy. 	RESEARCH VESSEL WORKING GROUP Oversee the strategic co-ordination of the UK's fleet of large (>50 m) public sector research vessels, focussing on improving links and co-operation between member organisations and with industry.	s on progress by the MSCC the decisions required to at evidence, gathered from earch, has to play. The Co- dividuals in the UK marine	ce in the UK - II
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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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The Met Office is the UK's national weather service

www.metoffice.gov.uk

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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





SCIENCE OF THE

NERC

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







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National Oceanography Centre

NATURAL ENVIRONMENT RESEARCH COUNCIL

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

nocrac:

e.g.

NEMO-MEDUSA 1/12 deg

Next run: climate forced -> 2100





National Oceanography Centre



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?



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Holt et al 2018 GRL

efas

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











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 Novembrand
- Integrate

Michela de Dominicis, NOC Alejandro Gallego, MSS

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Scottish Shelf Waters reanalysis service generated using Copernicus Marine Service information

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MSS Emergency Response – oil spills mainly

marine scotland 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





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









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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



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



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PML



Marine Data Assimilation Activity Group

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

Oxygen deficiency in reanalysis simulation



AG Lead Stefano Ciavatta avab@pml.ac.uk

Figure 10.1 Minimum day values of discolved oxygen initialized by the exempte median at the bottom of the eff in the years 10% room bank primery - 200 mi and (b) may of the meric valuerable to soggen deficiency, curved that bas not not dely value in 10% room block with the interval of d ng u⁻¹. In Figure 10, yellow color represents delecter assault 15% confidence level is, at least 1 member of the ensemble signals asygen deficiency, not represents 100% confidence (all the 100 members signal deficiency), and base the areas of the shelf with concentration indipler than 6 mg 1⁻¹ at 100% confidence.

Ciavatta et al 2016 JGR







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Challenges and future directions

Met Office Future directions / challenges

- 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



Research

R2O*

*Route to operations clear for forecast products

Ensemble coupled prediction

^{See Met Office} Regional coupled prediction system



Lewis et al., 2018 (GMD)



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

Results

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



Met Office Evaluating Coupled NWP on Weather



N640 winter trial

NWP Index: Basket of measures, largely positive

Net positives for all trials $(\sim 0.5 - 0.9 \text{ NWP increase})$

TC track also improved (not shown)

vs Obs

PS41_nemoznc_ctile_fix1p2) : Overall 0.42% Change in RMSE against observations for 20171202-20180130

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vs Anal

% Difference (PS41 cpl writer vs PS41 nemoanc ctile fix1p2) Overall 0.39% in RMSE against own analyses for 20171202-20180130

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Thank you



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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



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)

mercator-ocean.eu/marine.copernicus.eu

Met Office GODAE OceanView / OceanPredict

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

GODAE OceanView Principle Sponsors



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

GOV provides international science leadership for operational ocean forecasting

Successfully operating:

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

28



European Commission



Met Office New HPC LFRic 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 Weakly coupled analyses, N320 atmos, Coupled DA system developed **Coupled DA forecasts to CMEMS** 1/4 deg ocean Weakly coupled analyses, N1280 atmos, Coupled NWP system developed **Coupled NWP forecasts** 1/4 deg ocean (ensemble N640 atmos) Upgrade to ORCA12 Introduce full ocean ensemble N768 Global Model N1280 Global Model Couple global wave configuration? ¹/₄ deg FOAM ocean 1/12 deg FOAM ocean **FOAM retired?**

- 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





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 CMIPS climate models as indicated in the figure legend.

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National Centre for Earth Observation

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

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- 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





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





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National Partnership for OCEAN PREDICTION

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.

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

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





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Assimilation

Ensembles SMOS SWOT Gliders

Met Office Observations Assimilated on Shelf Region







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

Example monthly coverage of T/S

Met Office 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

Met Office

- 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



Met Office Global Ensemble Development

- Flux perturbed from NWP Ensemble •
- Obs value perturbed ٠
- Obs location perturbed •

Spin-up clearly visible

0.30

0.15

0.00

0.45

0.60

- 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.

Ensemble standard deviation



0.75

0.90

1.05

1.20

1.35

1.50





Met Office 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.

SST SSS 0 - 0.2K 0 - 0.05 PSU 0.060,14 012 0.05

Ensemble standard deviation over first month

How important is the extra resolution?

AMM7 20 mins per day



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

AMM15 110 mins per day



-2.0 -1.7 -1.4 -1.1 -0.8 -0.5 -0.2 0.1 0.4 0.7

1.0

Cefas Emergency Response Modelling Oil and Chemical Spills



Centre for Environment Fisheries & Aquaculture Science



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)

noclac uk

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





National Oceanography Centre

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

- 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



Hyder et al 2015

Yuri Artioli yuti@pml.ac.uk







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The Scottish Shelf Model and CMEMS

marine scotland science

- 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?



Wide domain and sub-domains



Present-day and 2050's climatologies



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)



Resolutions

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- Eddy-resolving at the **global scale**?
- With tides at 1/25°?

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 at 1/12° nominal resolution global system replacement will be

- 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-AMM1

Surface currents

65°N +12 02-10-2018 60°N MAMM7 55°N [m/s] Surface current 50°N 45°N Scottish coastal current Norwegian coastal current 56N European slope current AMM15 0F Velocity magnitude [m/s] 40°N 0.0 0.2 0.3 0.5 0.8 0.6 25°W 20°W 15°W 10°W 5°W 0° 5°E 10°E 15°E 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

	Assimilation techniques and supporting observations
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