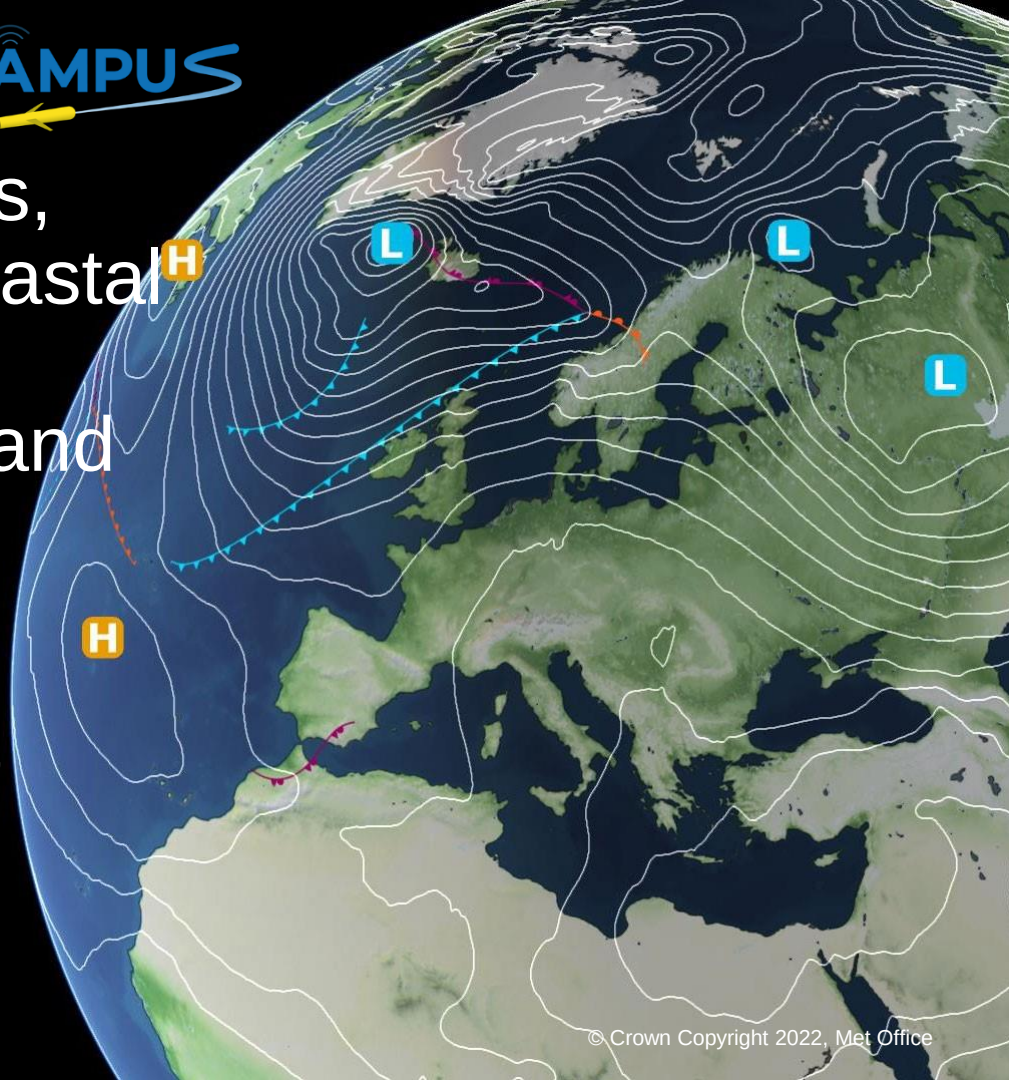
A solution for autonomous, adaptive monitoring of coastal ocean ecosystems: integrating ocean robots and operational forecasts



David Ford[1], Shenan Grossberg[2], Gianmario Rinaldi[2], Prathyush Menon[2], Matthew Palmer[3], Jozef Skákala[4], Tim Smyth[4], Charlotte Williams[3], Alvaro Lorenzo Lopez[3], Stefano Ciavatta[4]

[1]Met Office, [2]University of Exeter, [3]NOC, [4]PML

SynObs Kickoff, 17th November 2022

Met Office

Contents

- Concept and motivation
- “Smart system”
  - Glider
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  - Stochastic prediction model and path planning
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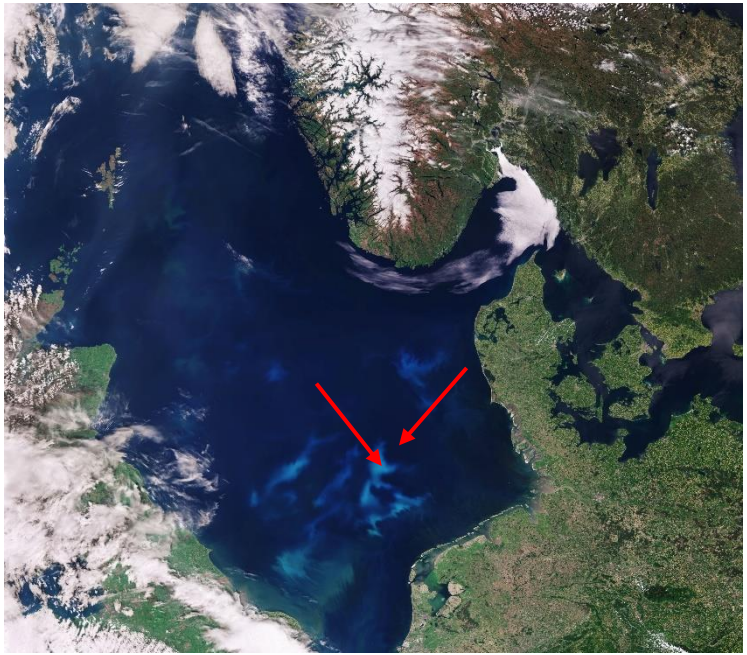
- Summary and future challenges

Concept and motivation

Motivation

- Observations are necessary but expensive
- Want to simultaneously reduce costs and maximise impact
- Make best use of all available information (Observations! Models! Statistics!)
- Adaptive monitoring could automatically direct a robot toward a likely feature of interest (e.g. an algal bloom)



https://www.esa.int/var/esa/storage/images/esa_multimedia/images/2018/09/north_sea_bloom/17675390-1-eng-GB/North_Sea_bloom.jpg

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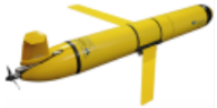


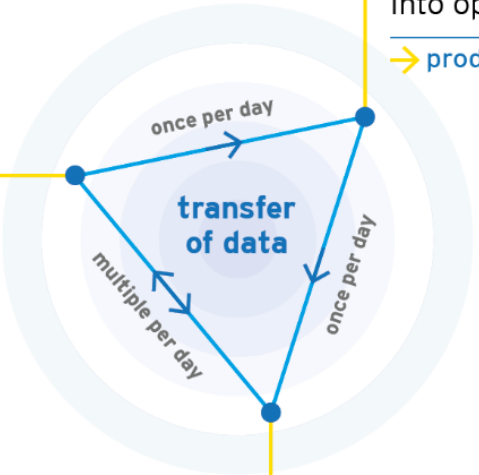
Glider

Navigated by the stochastic model

Operational forecast model

Assimilate glider data into operational model

→ produce 2-day forecast

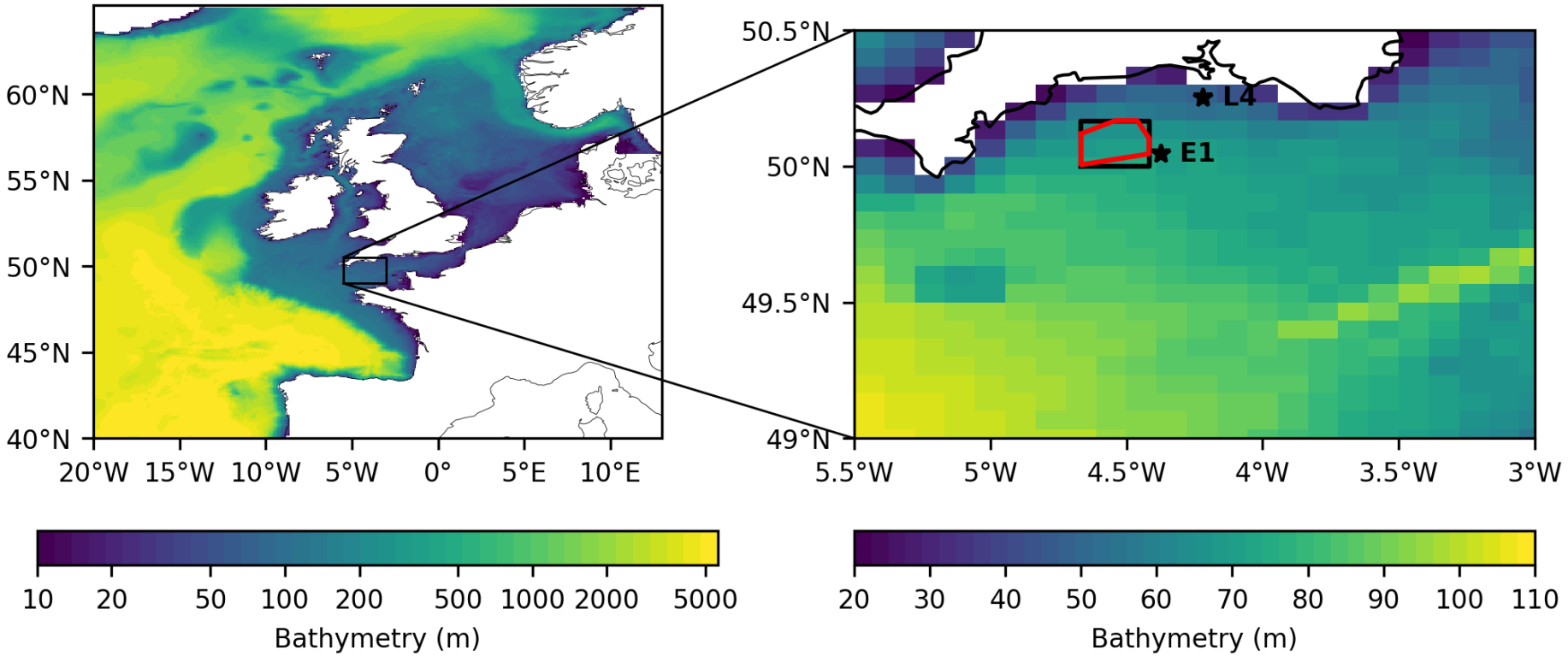


Stochastic prediction model

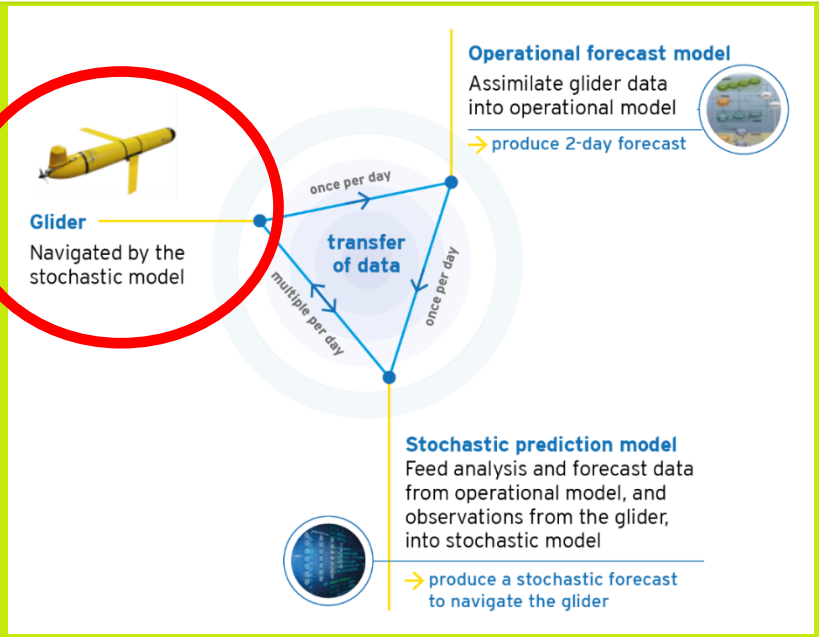
Feed analysis and forecast data from operational model, and observations from the glider, into stochastic model

→ produce a stochastic forecast to navigate the glider

22 March – 8 June 2021



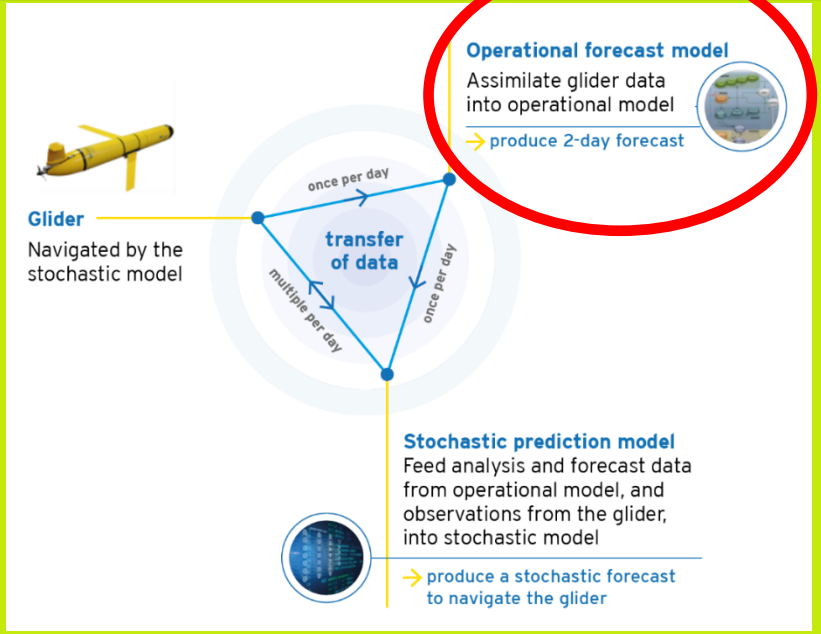
Glider



Glider horizontal speed:	1.20 km/h
Glider depth range:	from 1 to 50 metres from the surface
Surface time interval	Every 3 hrs during daytime
Glider sensor sampling frequency:	10 seconds
Glider yo angle:	26 deg up and dow
Number of dives per waypoints	3
Surfacing time interval for communication	20 min

- CTD: temperature and salinity
- Fluorescence: chlorophyll
- Oxygen

Assimilation and forecast model



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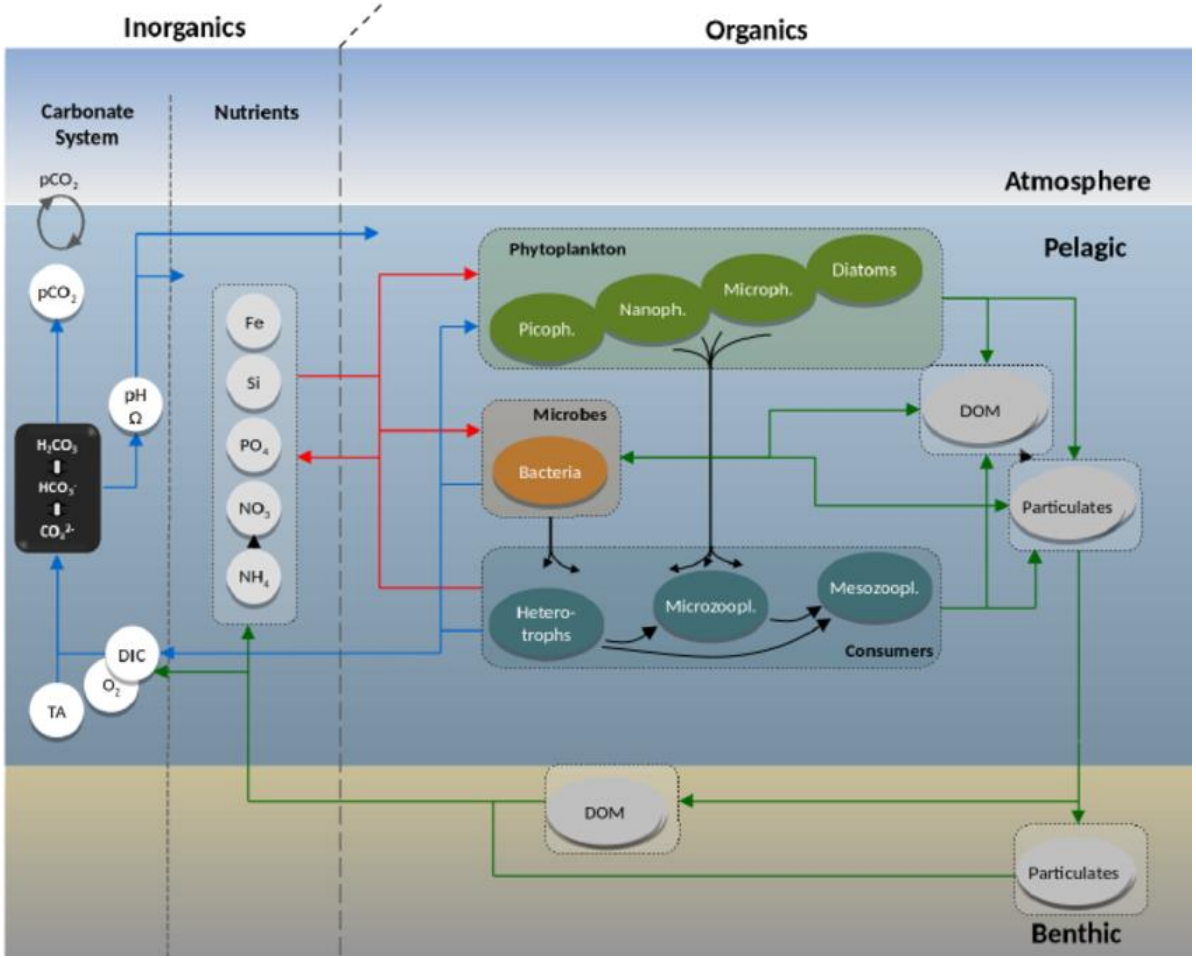
NEMO

+

European **R**egional **S**eas **E**cosystem **M**odel (**ERSEM**)

+

NEMOVAR
(3D-Var assimilation)



7km resolution

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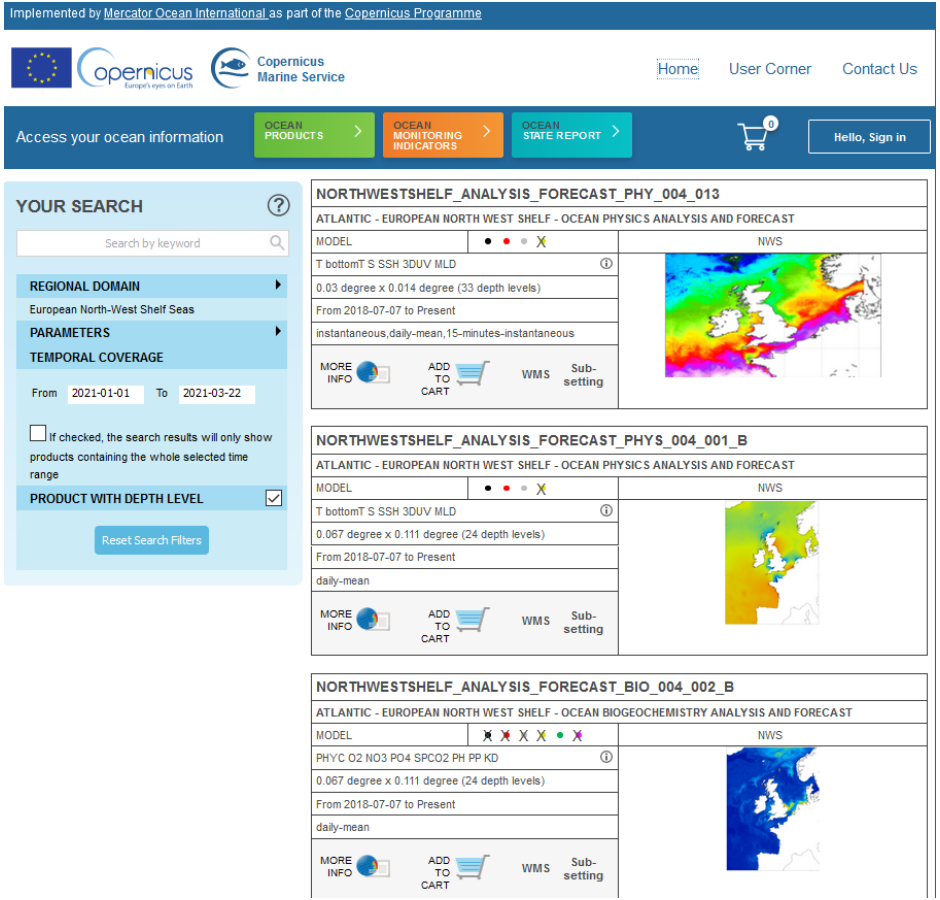
- Operational forecasts
  - Analysis and six-day forecast available from CMEMS
  - Updated daily
- Physics assimilation:
  - Satellite and in situ SST
  - In situ temperature and salinity
  - Satellite altimetry
- Biogeochemistry assimilation:
  - Chlorophyll from satellite ocean colour



https://marine.copernicus.eu/

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JGR Oceans

Research Article | Open Access

Towards a Multi-Platform Assimilative System for North Sea Biogeochemistry

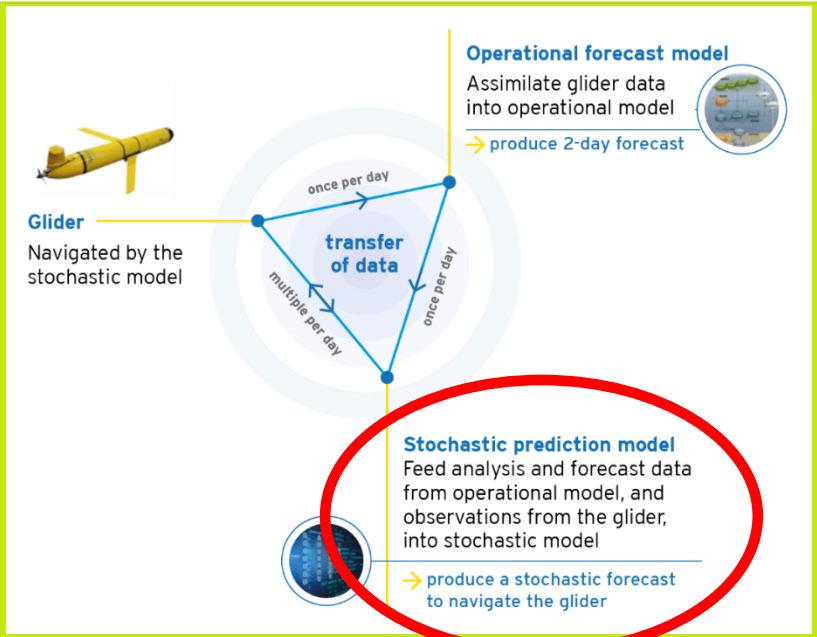
Jozef Skákala, David Ford, Jorn Bruggeman, Tom Hull, Jan Kaiser, Robert R. King, Benjamin Loveday, Matthew R. Palmer, Tim Smyth, Charlotte A. J. Williams, Stefano Ciavatta

First published: 20 February 2021 | https://doi.org/10.1029/2020JC016649 | Citations: 3

Pseudo-operational forecasts

- Run daily at 09:00 UTC
- Identical to operational suite but assimilating the glider chlorophyll and oxygen data
- Hourly mean chlorophyll and temperature for past five days (analysis) and next six days (forecast) processed for glider region and placed on FTP

Stochastic model and path planning



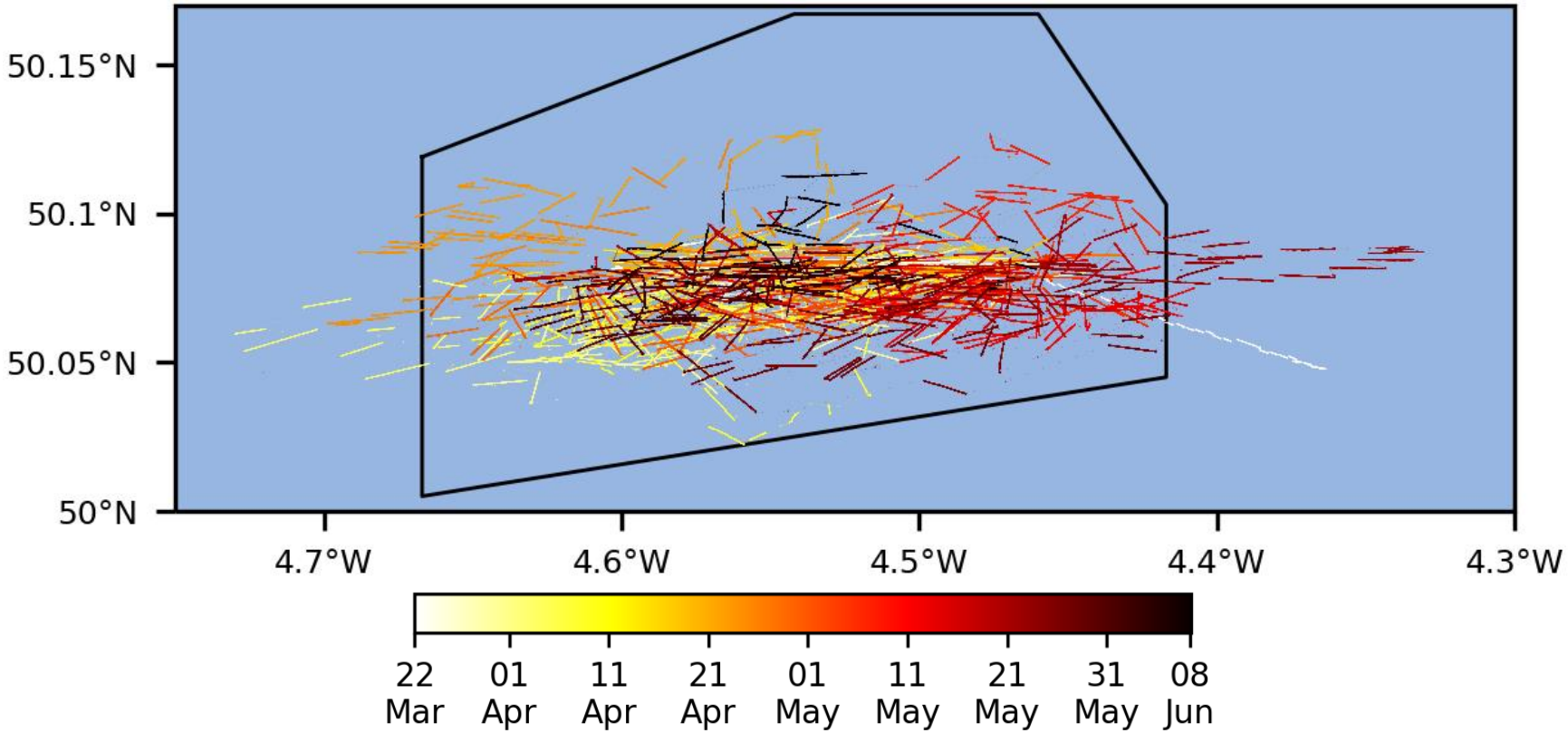
Stochastic prediction model

- Developed and run at University of Exeter
- Uses the integrated nested Laplace approximation (INLA) to approximate Bayesian inference (www.r-inla.org)
- Inputs:
  - Glider chlorophyll
  - Model chlorophyll and temperature
- Outputs:
  - High-resolution (0.0014° x 0.0009°) 24-hour chlorophyll forecast
  - Sets of waypoints for the glider, automatically emailed to pilot, based on location of forecasted chlorophyll maximum

Results

Observations

Glider trajectory



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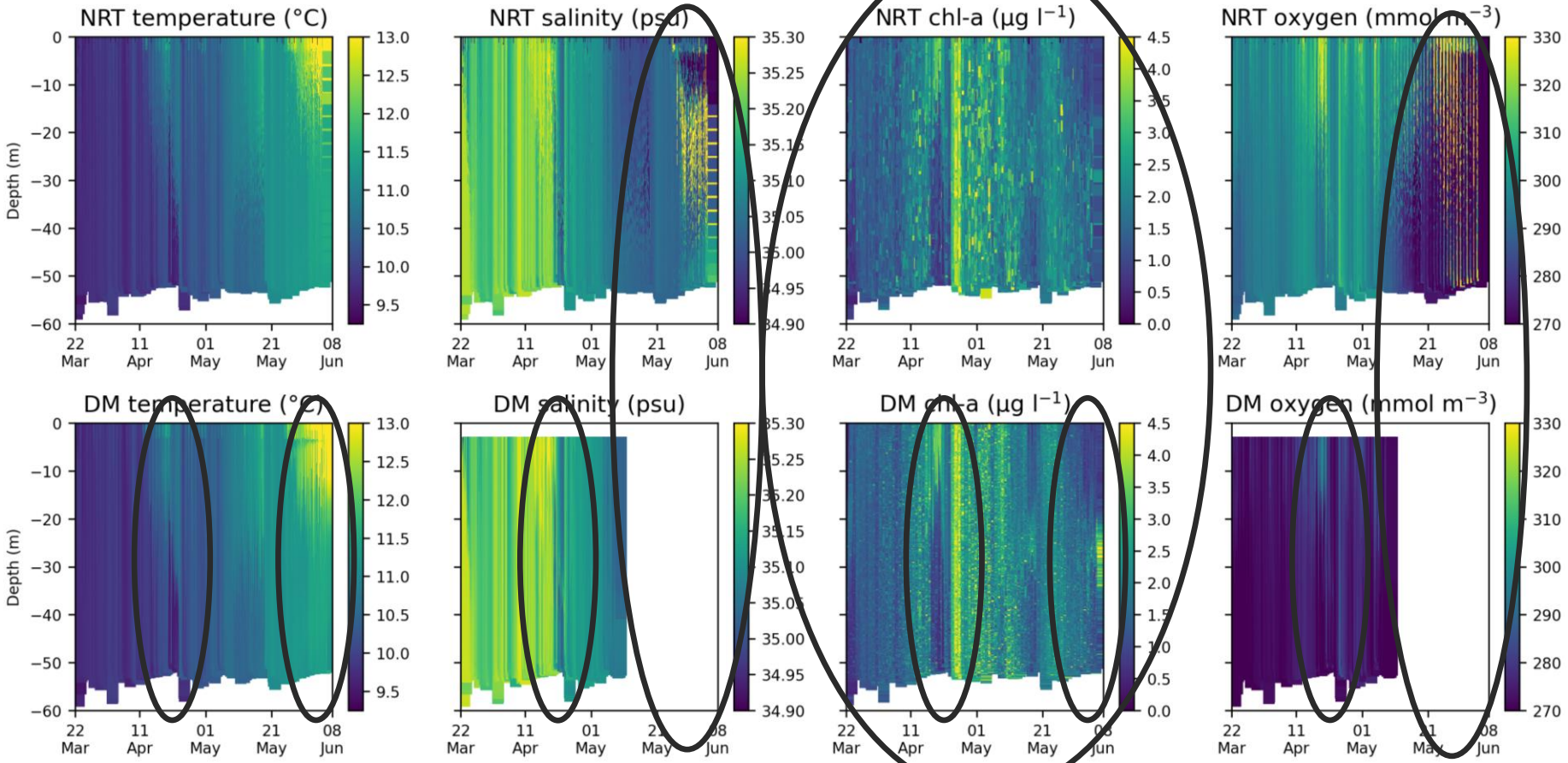

Results

Impact of glider assimilation on forecasts

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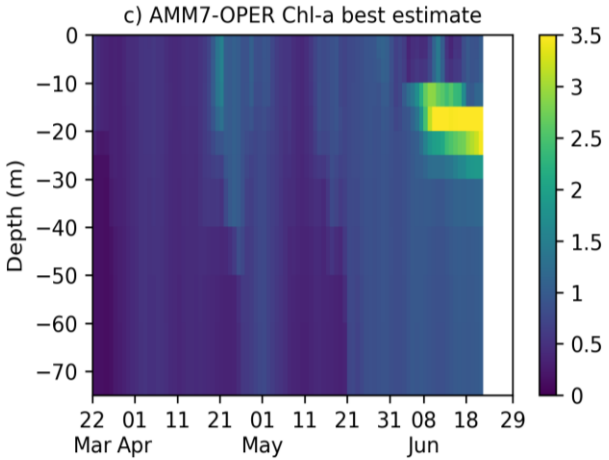
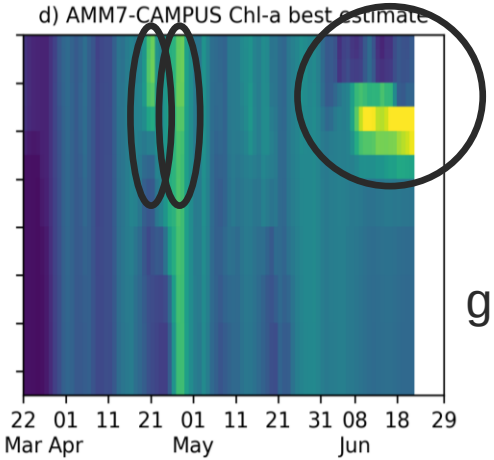
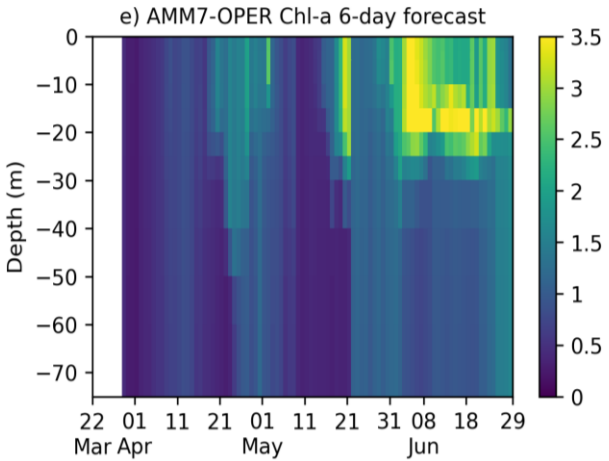
Chl-a analysis *without* glider assimilation

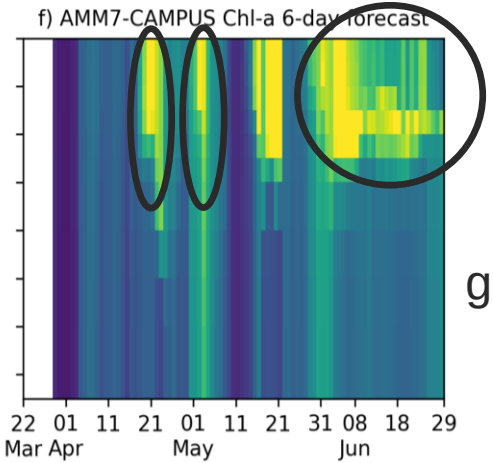




Chl-a analysis *with* glider assimilation

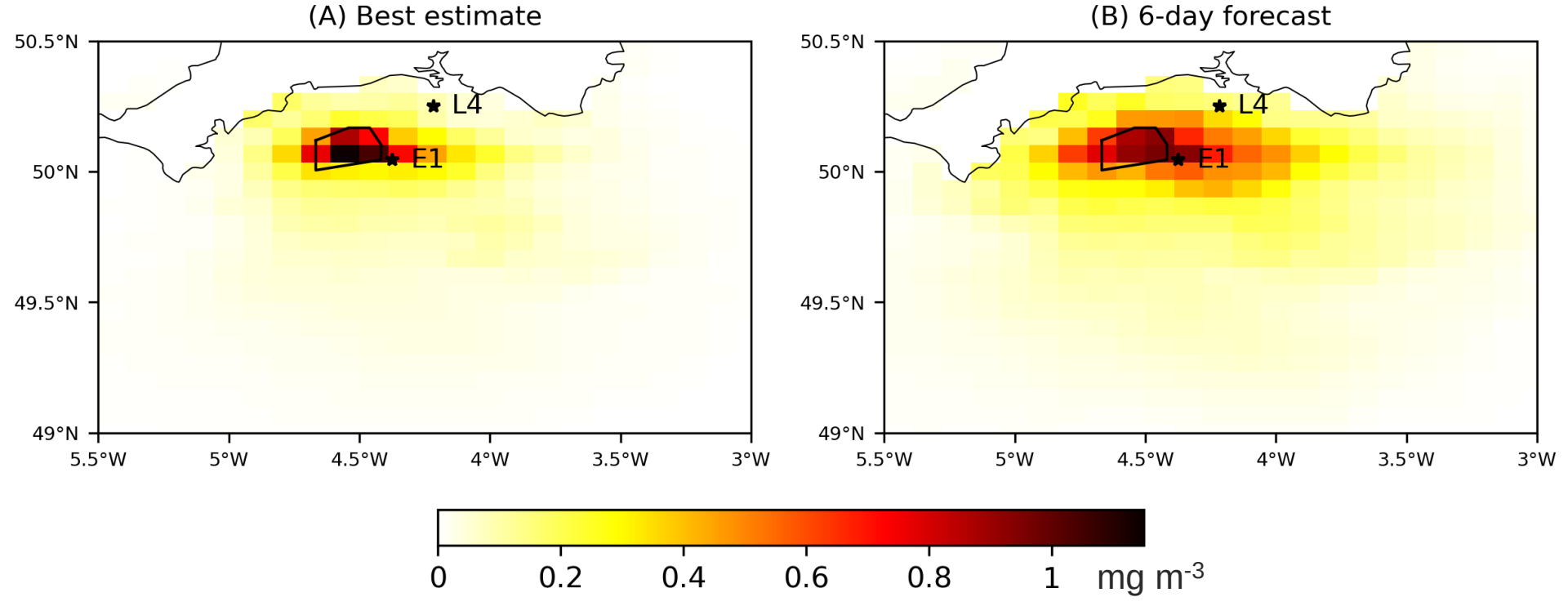
6-day forecast *without* glider assimilation





6-day forecast *with* glider assimilation

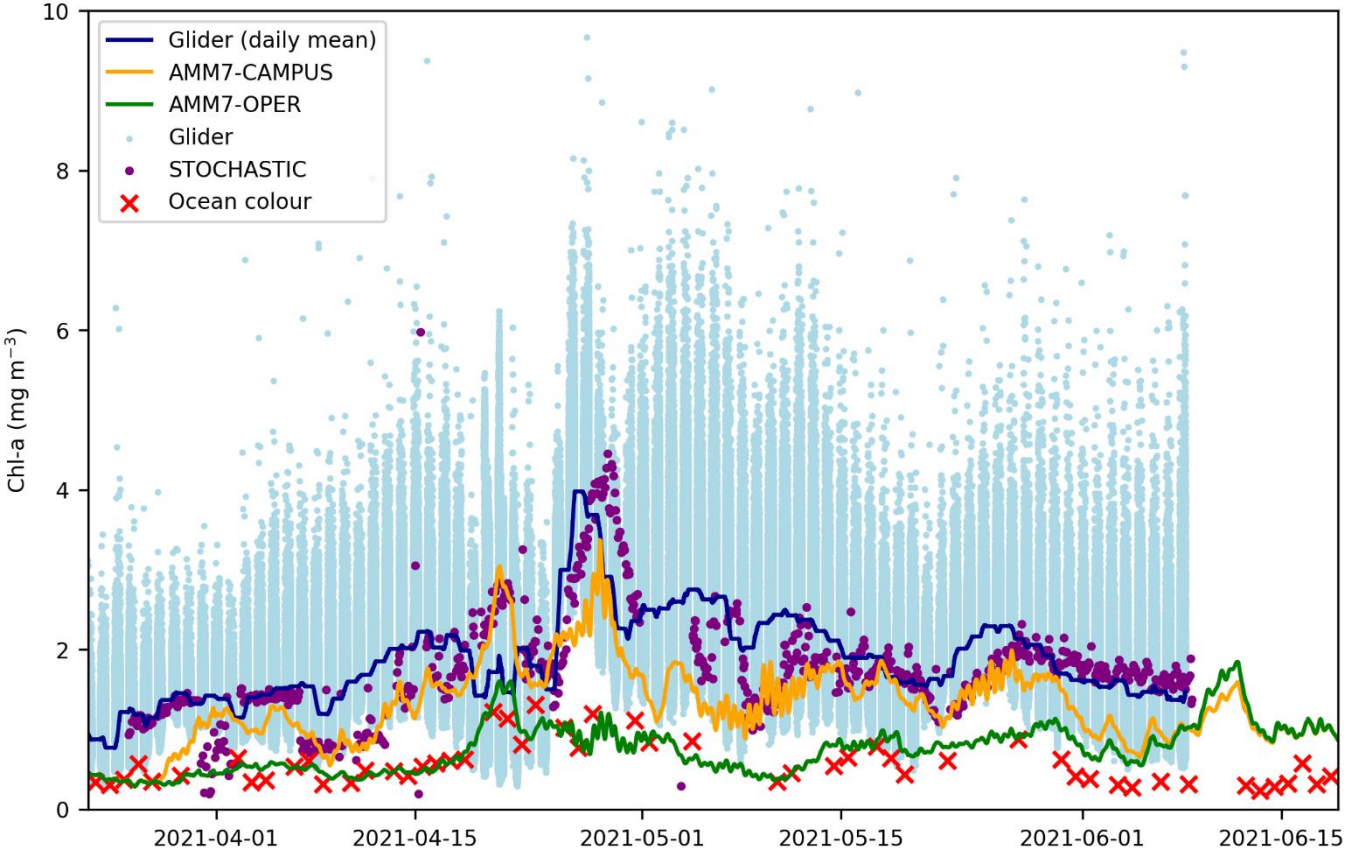
Mean absolute difference in surface chlorophyll with and without glider assimilation



Results

Intercomparison of observations and models

(Near-)surface chlorophyll

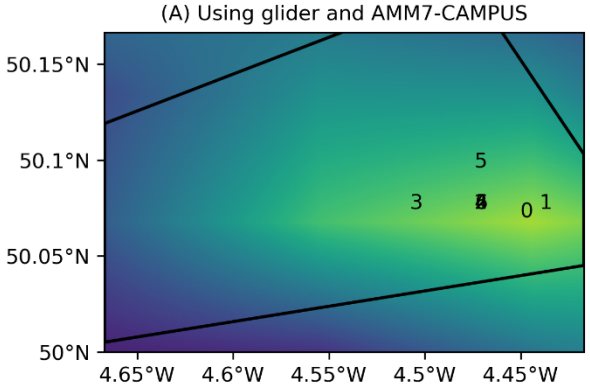


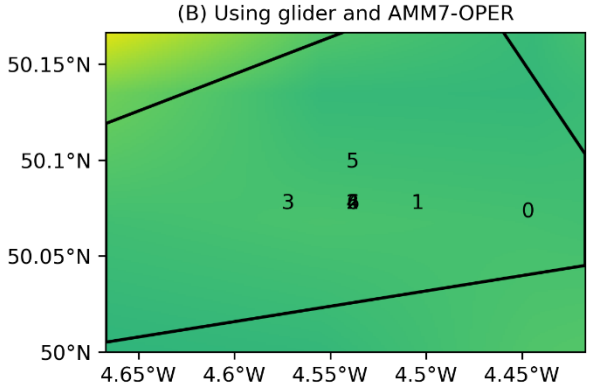
Results

Sensitivity of stochastic model to inputs

Stochastic model chlorophyll forecast and waypoints 14 May 2021

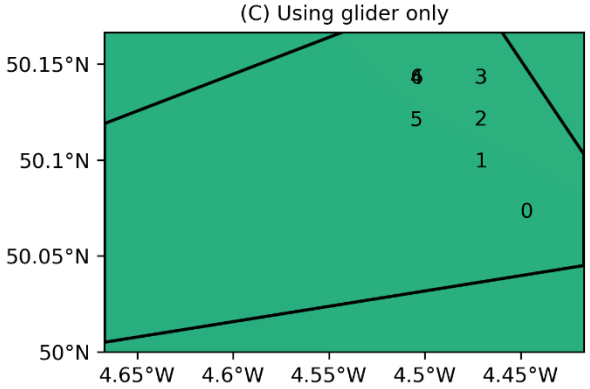
Using observations and model with glider assimilation

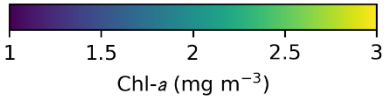




Using observations and model without glider assimilation

Using observations only





Summary and future challenges

Summary

- Successful proof-of-concept of an autonomous and adaptive “smart” observing system integrating models and gliders

- Observations improve models and models improve observations

Future challenges

- Biofouling!
- Near-real time QC
- Multiple gliders and larger area
- Accounting for currents
- Regulations (e.g. requiring a human pilot)
- Reconciling differences between satellite and in situ data
- Ensure biases don’t restrict trajectory
- Apply to other variables and observing platforms?

Questions?