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Autonomous, adaptive monitoring integrating ocean robots and operational forecasts

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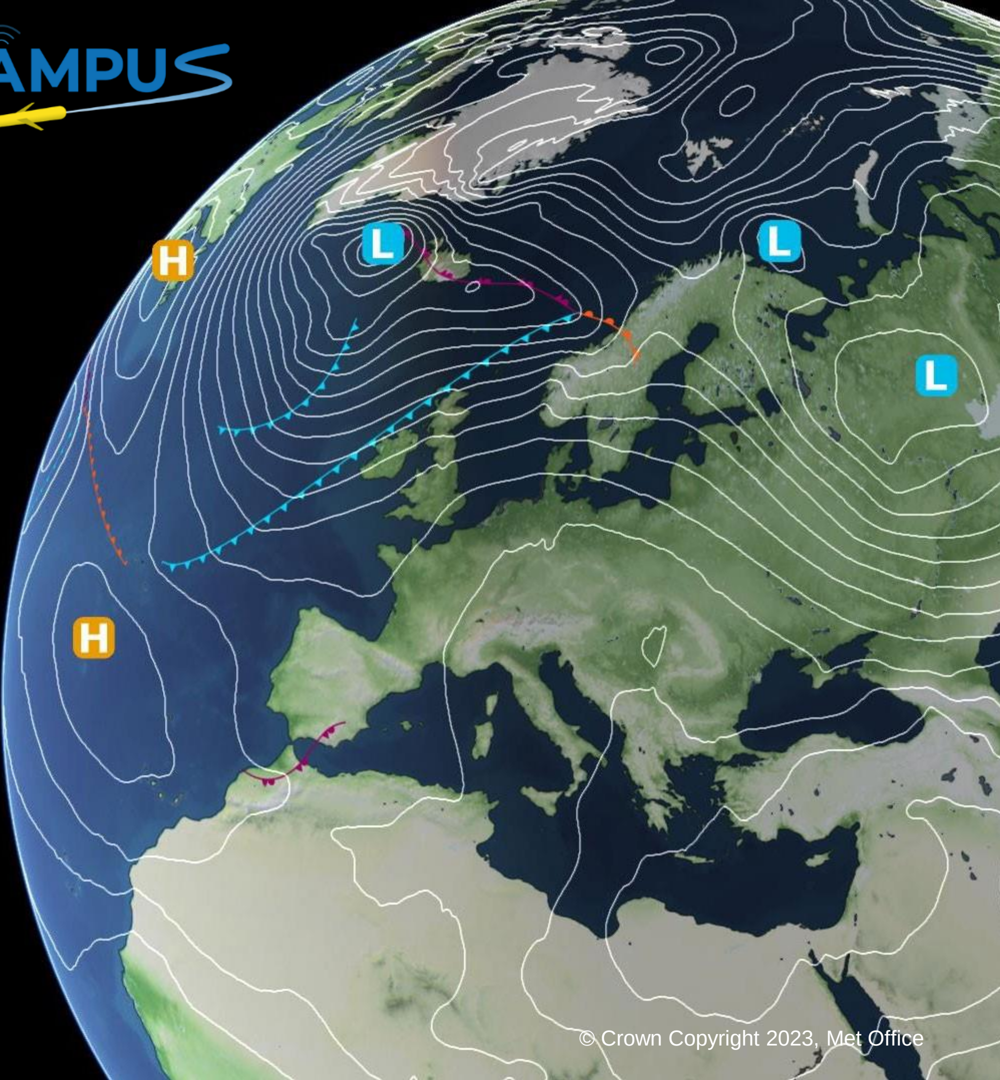
OceanPredict MEAP-TT, 3rd May 2023



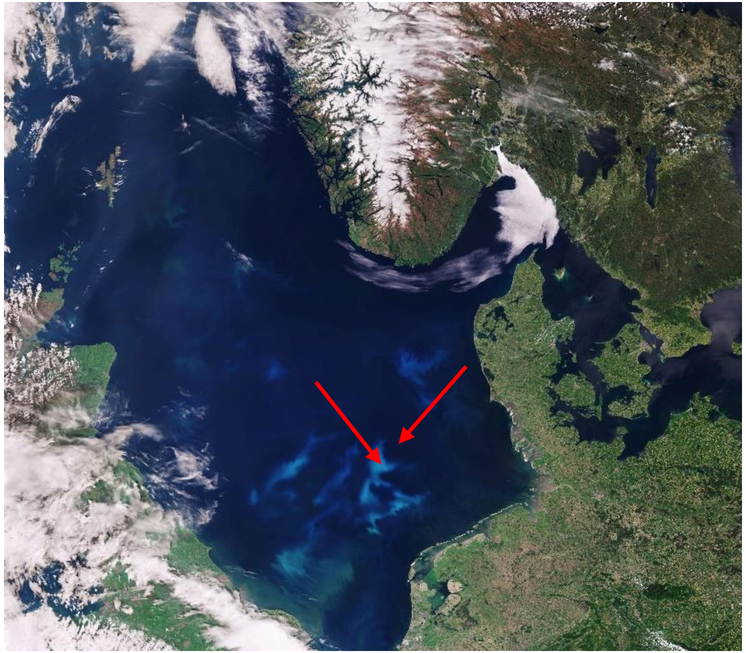
Contents

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

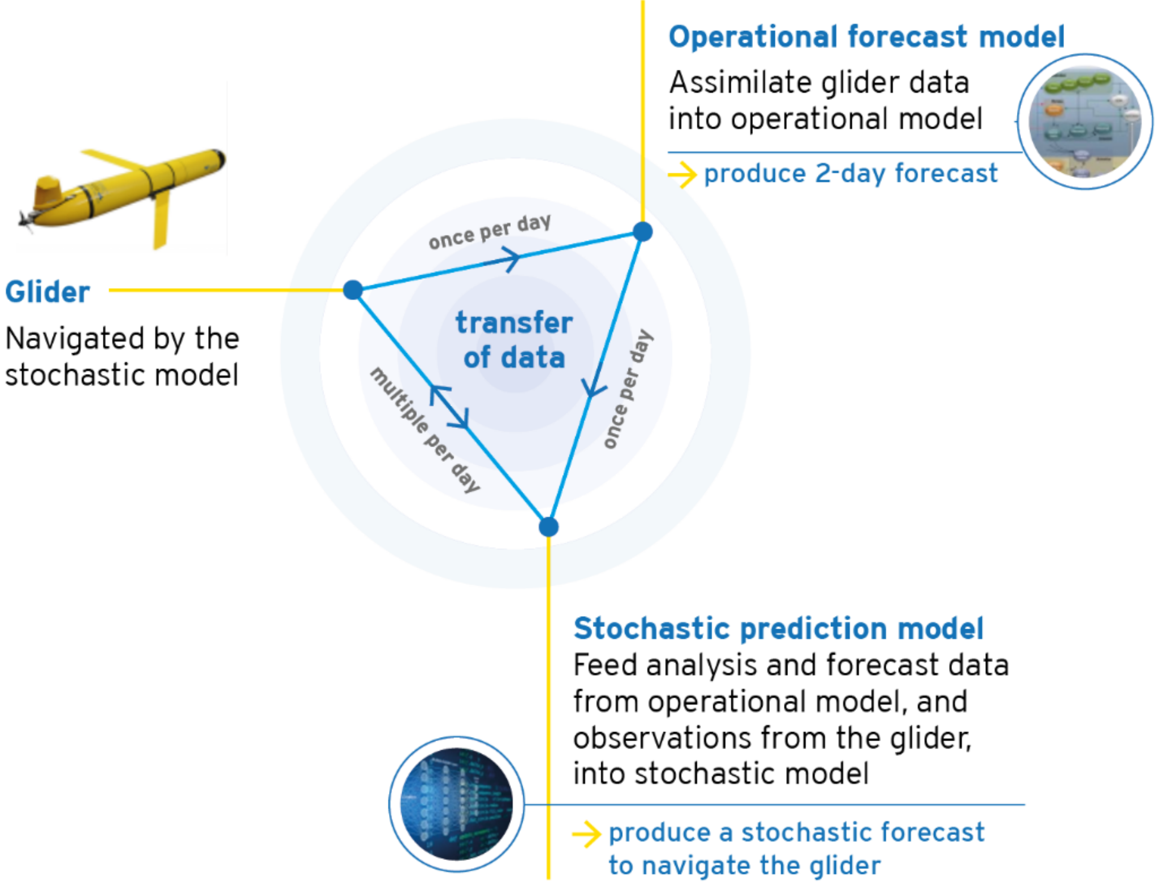
Concept and motivation

Motivation

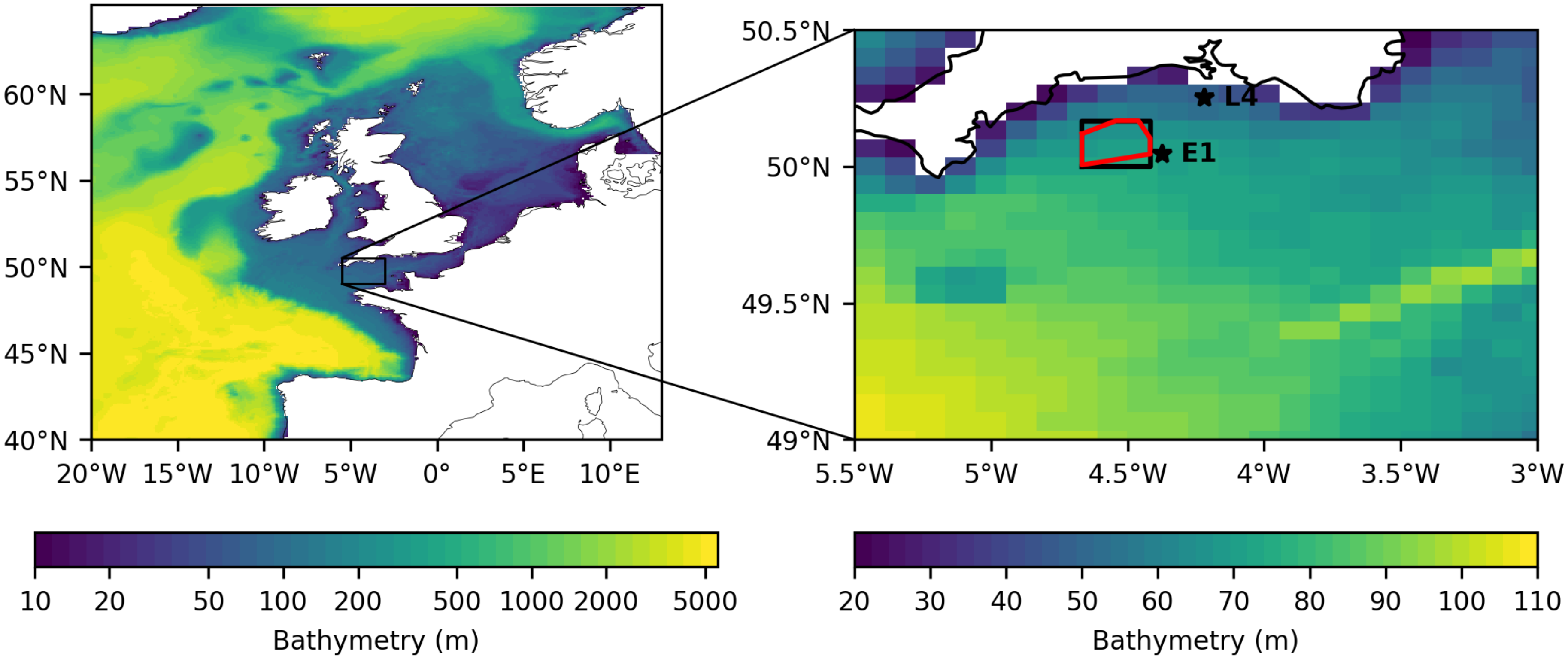
- Observations are necessary but expensive
- Want to simultaneously reduce costs and maximise impact
- Make best use of all available information (Observations! Models! Statistics!)
- Adaptive monitoring could automatically direct a robot toward a likely feature of interest (e.g. an algal bloom)



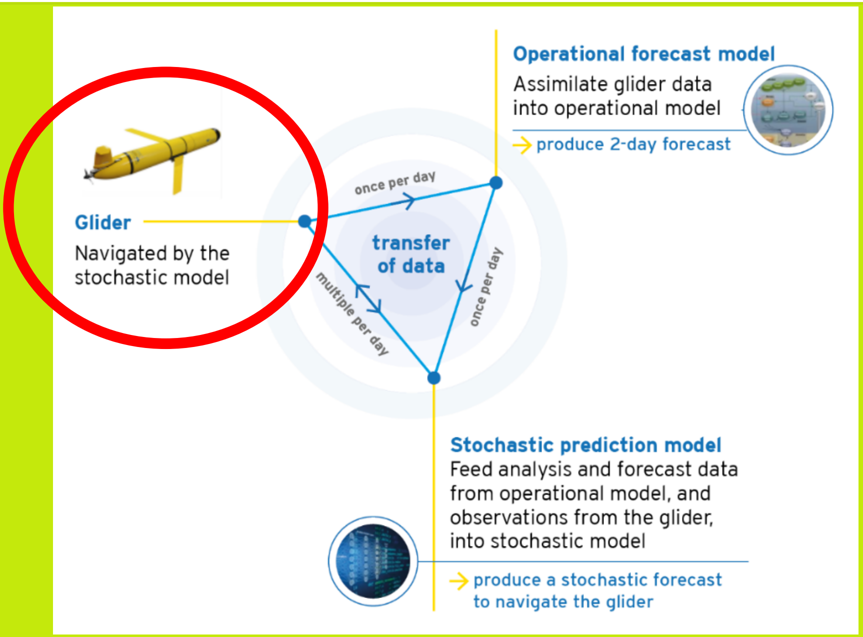
https://www.esa.int/var/esa/storage/images/esa_multimedia/images/2018/09/north_sea_bloom/17675390-1-eng-GB/North_Sea_bloom.jpg


Operational forecast model
Assimilate glider data into operational model
produce 2-day forecast
Glider
Navigated by the stochastic model
once per day
transfer of data
once per day
multiple per day
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



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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

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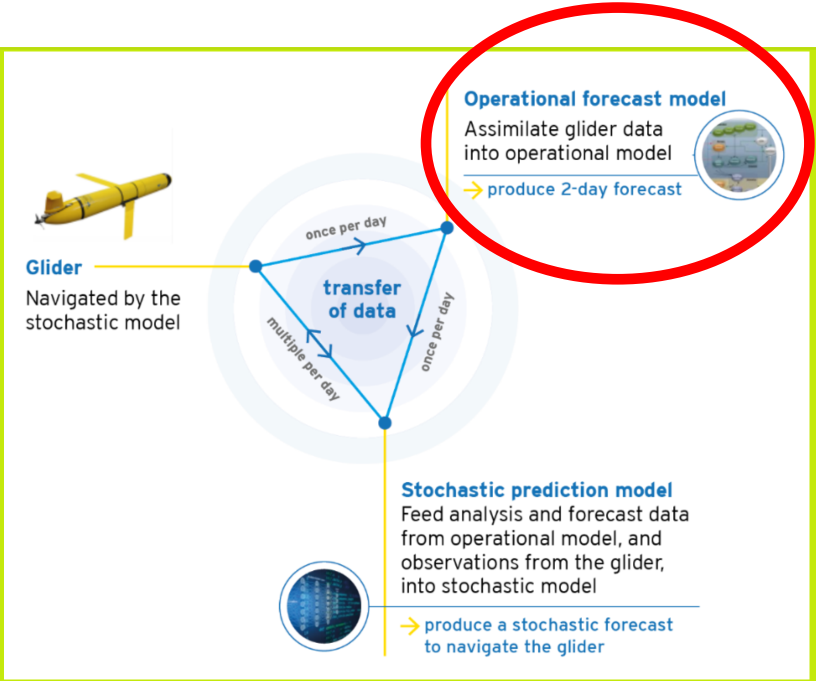
Assimilation and forecast model



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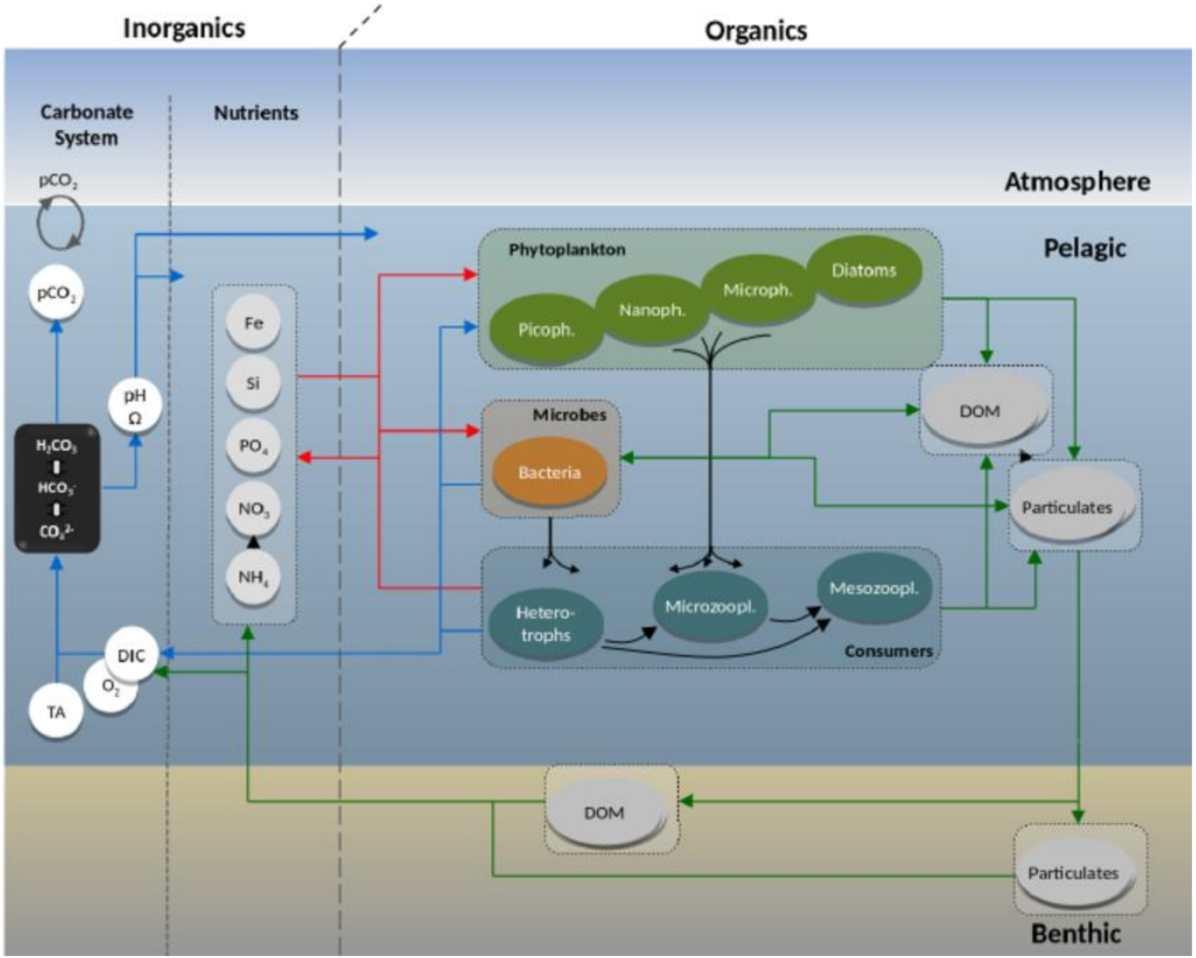
NEMO

+

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

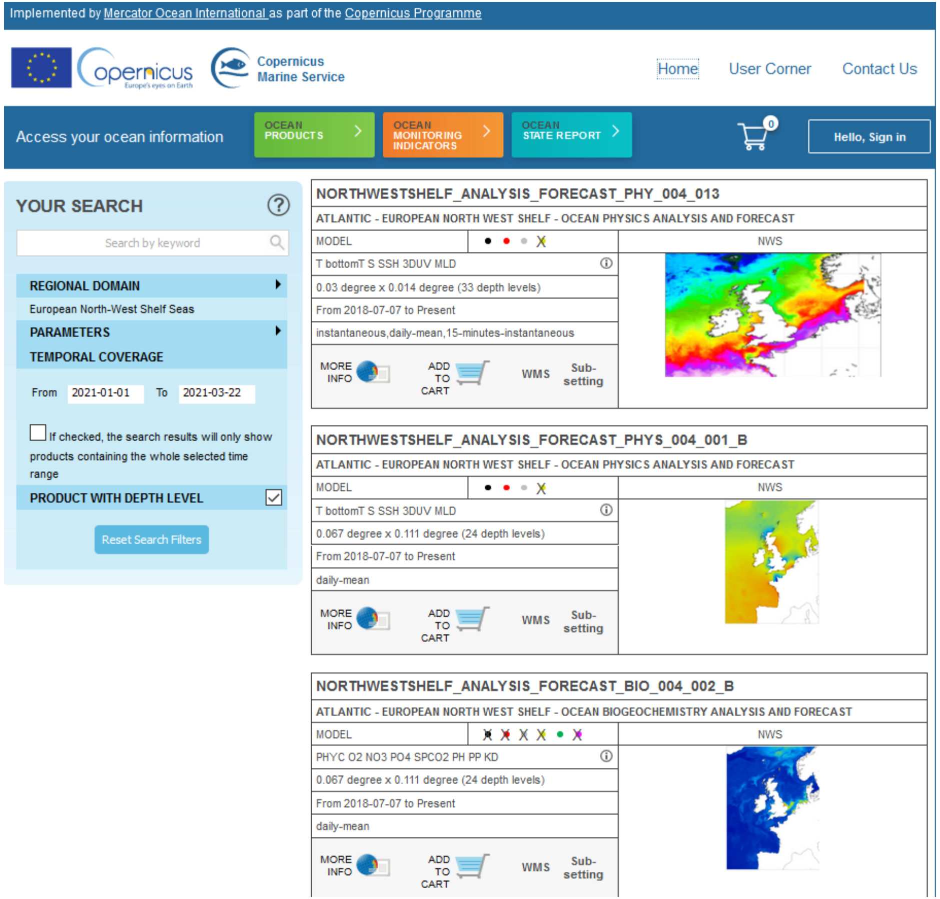
+

NEMOVAR
(3D-Var assimilation)



7km resolution

- Operational forecasts
  - Analysis and six-day forecast available from Copernicus Marine
  - 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/

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

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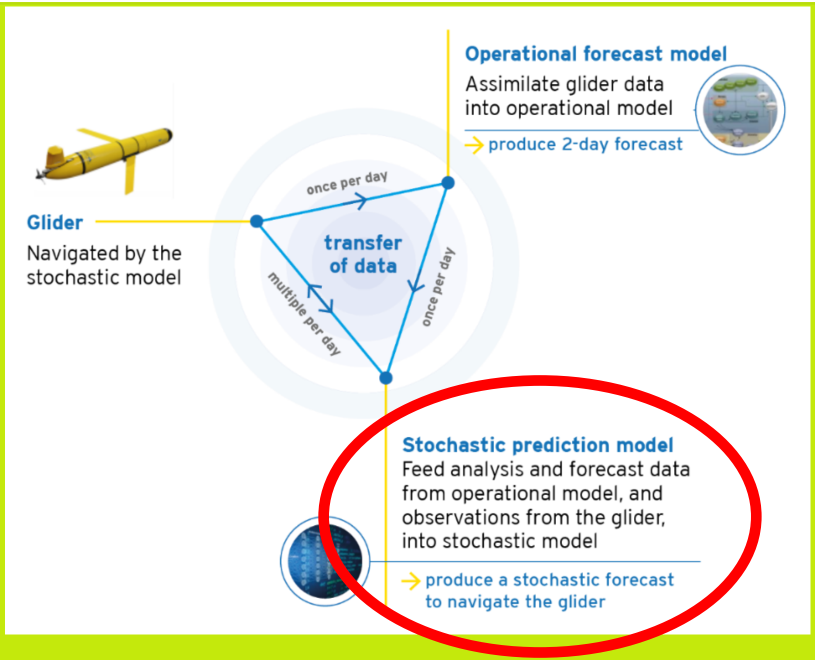
Stochastic model and path planning



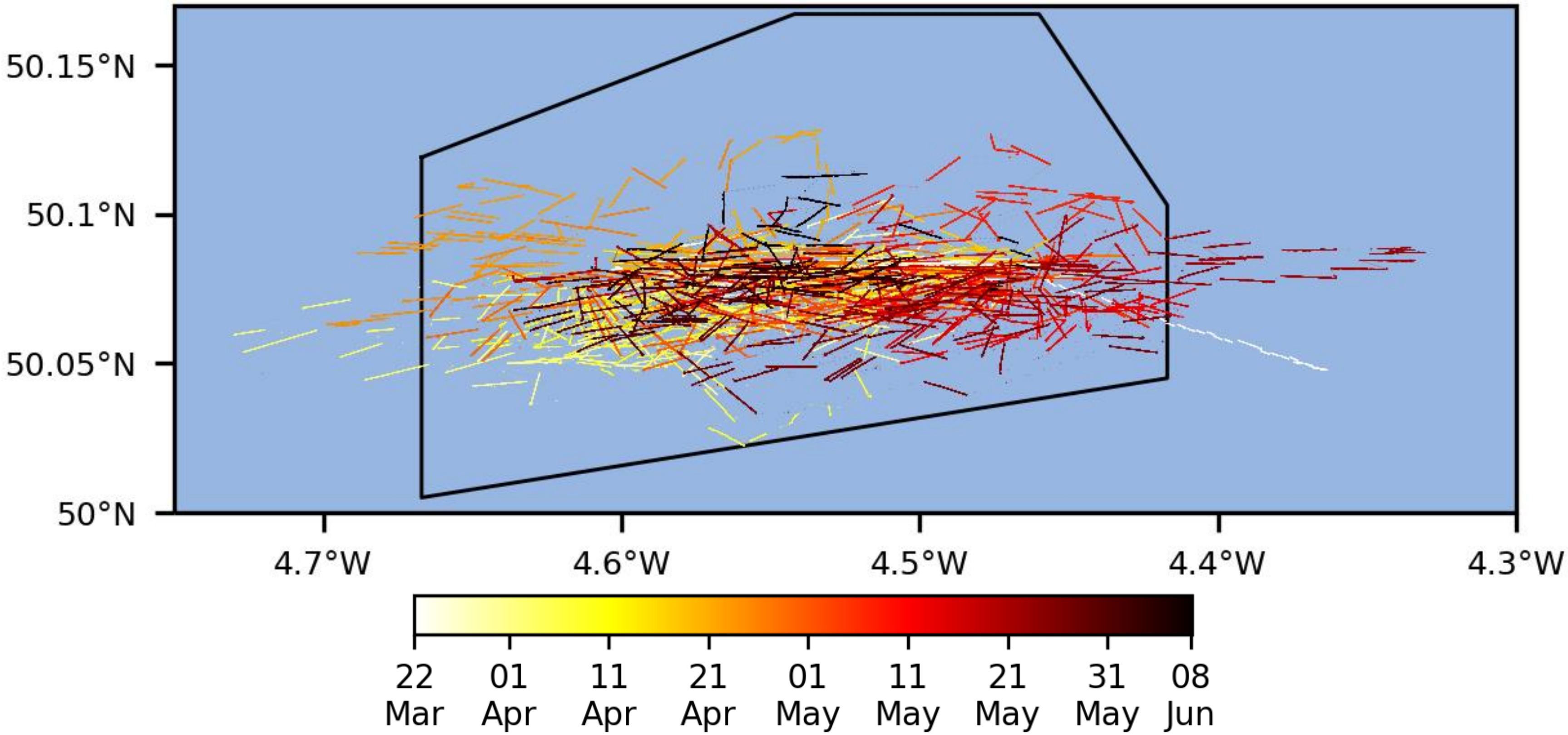
Stochastic prediction model

- 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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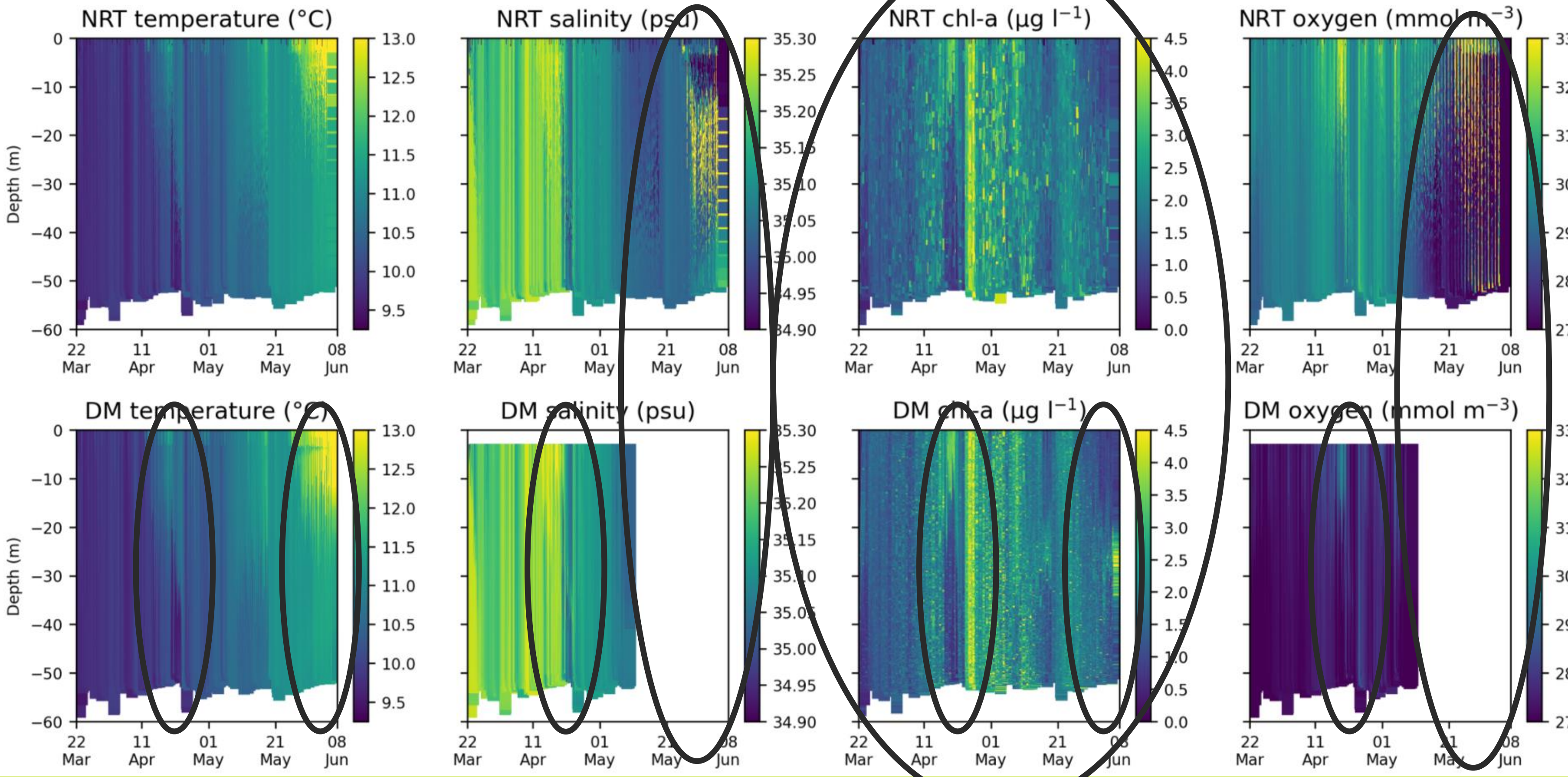

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Results

Impact of glider assimilation on forecasts

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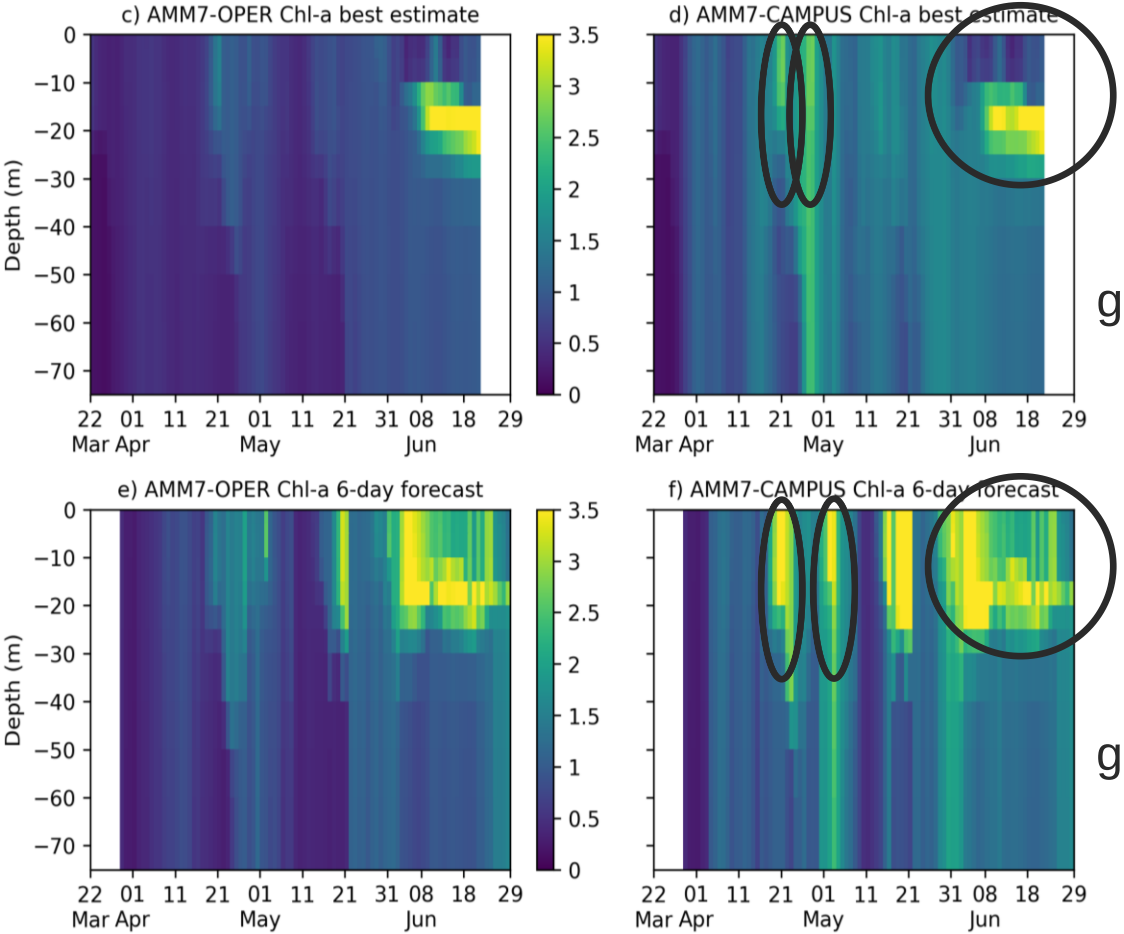
Chl-a analysis
without
glider assimilation

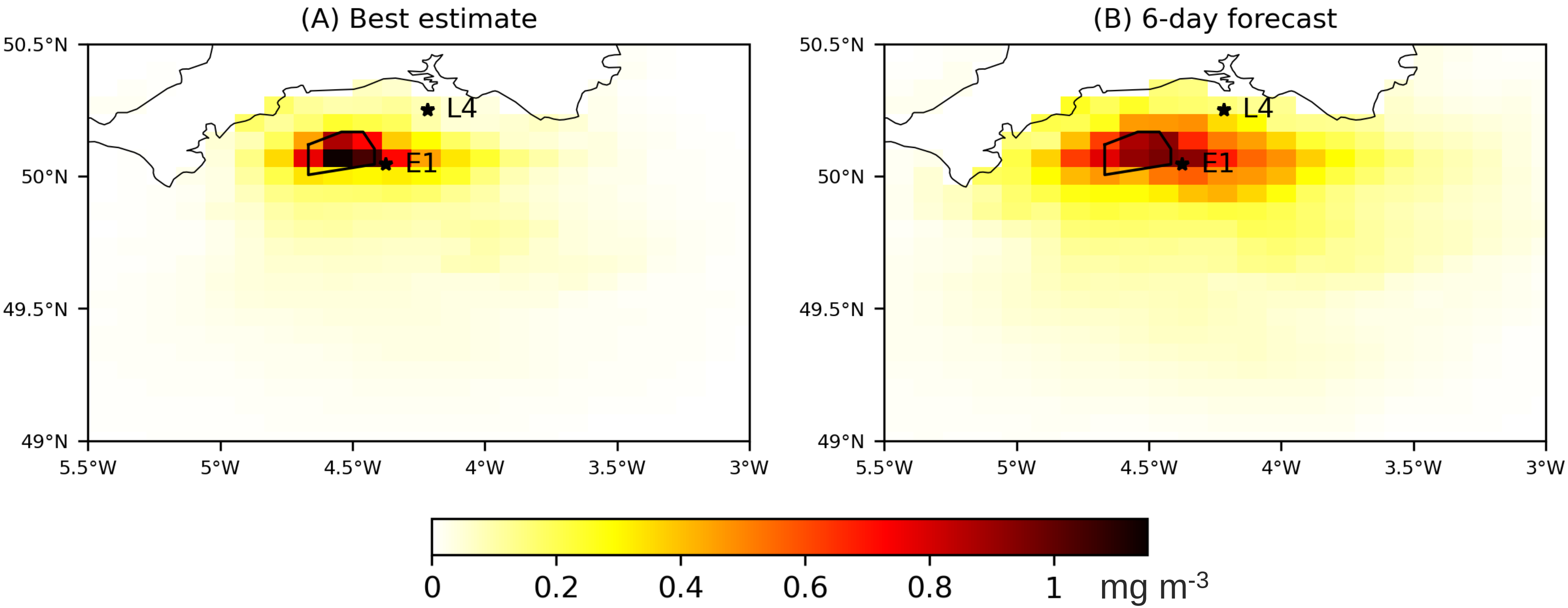
6-day forecast
without
glider assimilation



Chl-a analysis
with
glider assimilation

6-day forecast
with
glider assimilation

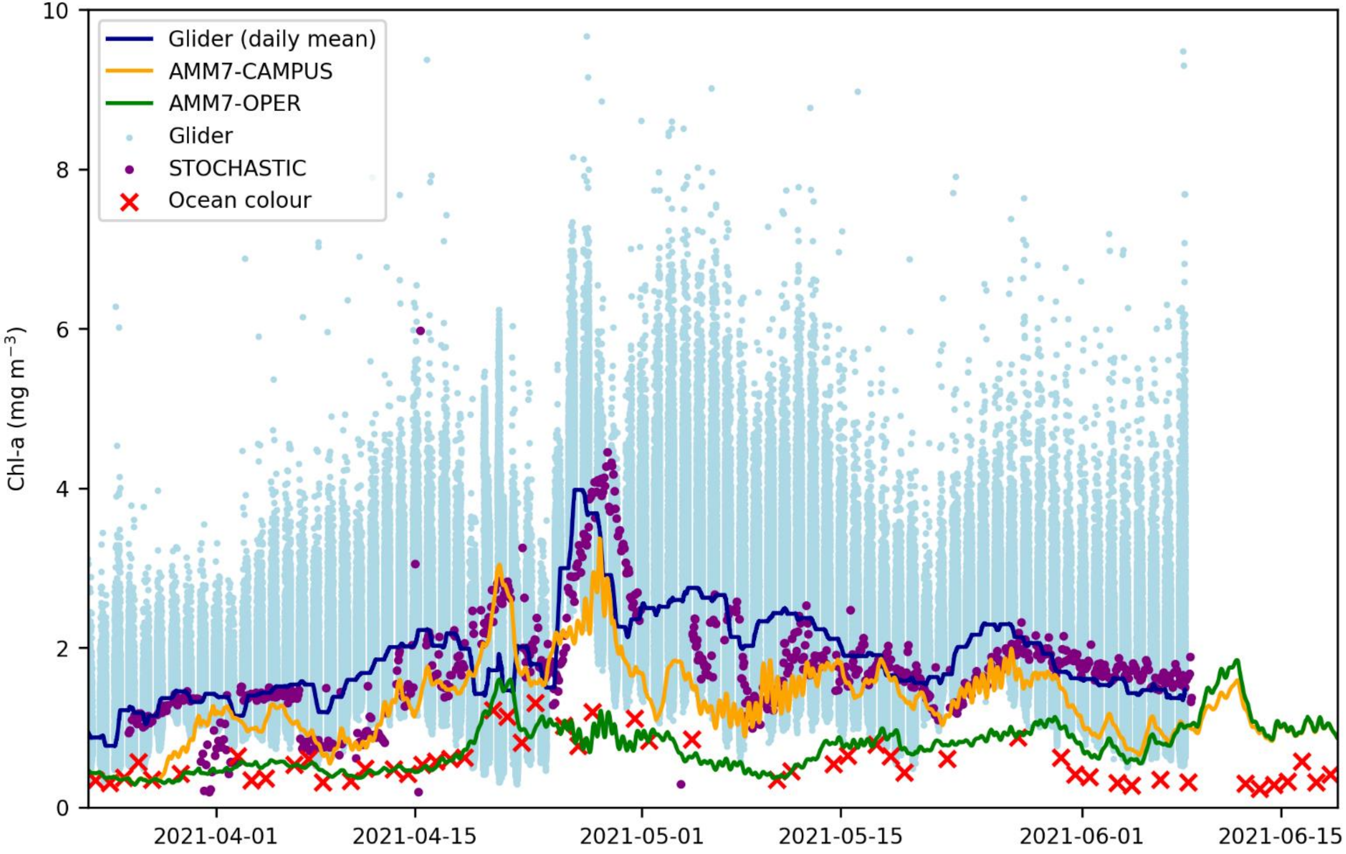
Mean absolute difference in surface chlorophyll with and without glider assimilation



Results

Intercomparison of observations and models

(Near-)surface chlorophyll

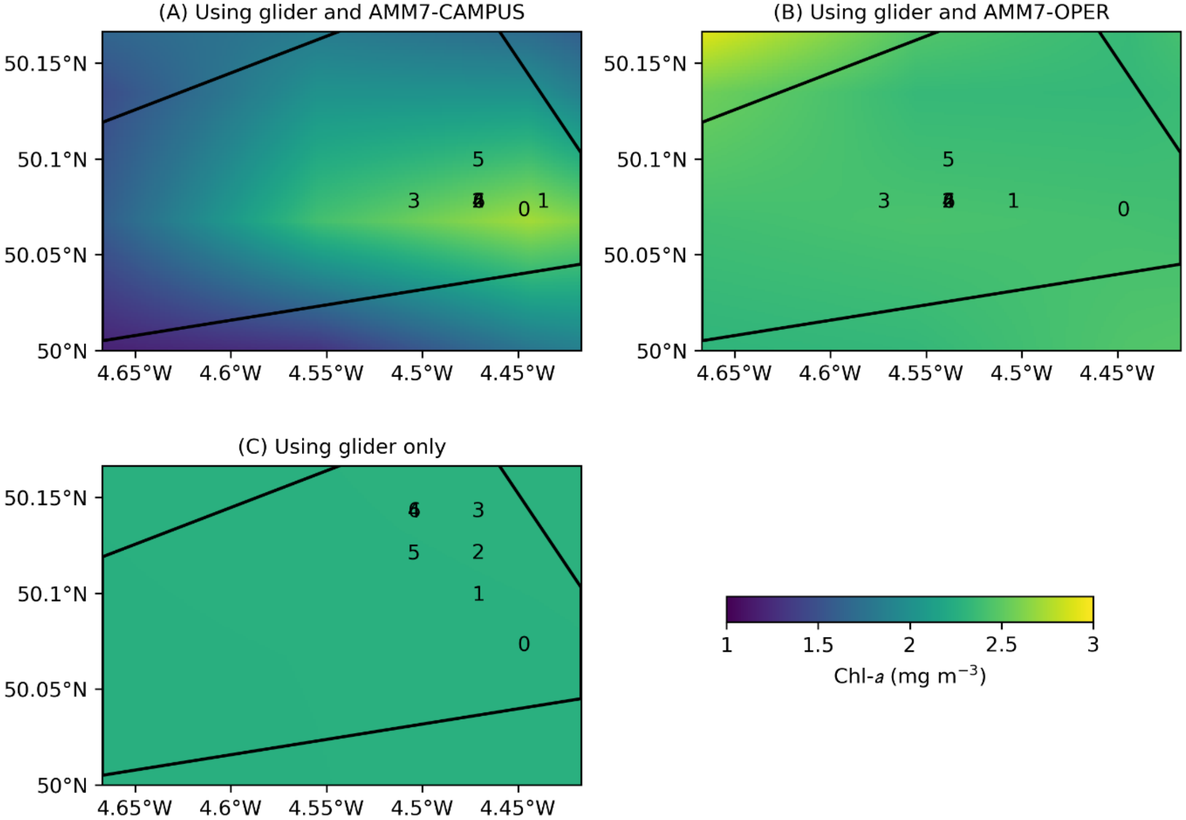


Results

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?

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ORIGINAL RESEARCH article

Front. Mar. Sci., 19 December 2022

Sec. Ocean Observation

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

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Questions?