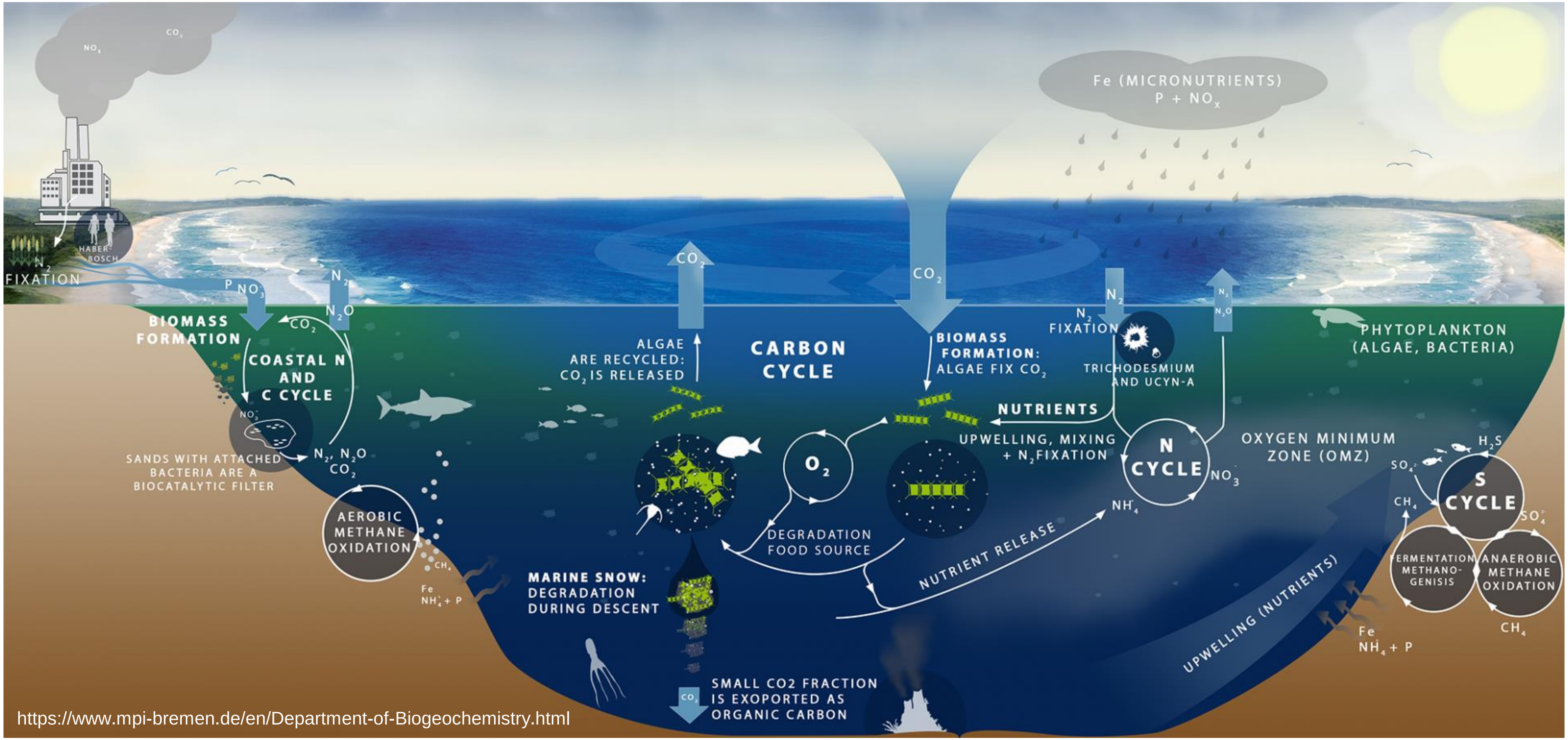
PARTICLE TRACKING FOR BIOGEOCHEMISTRY APPLICATIONS

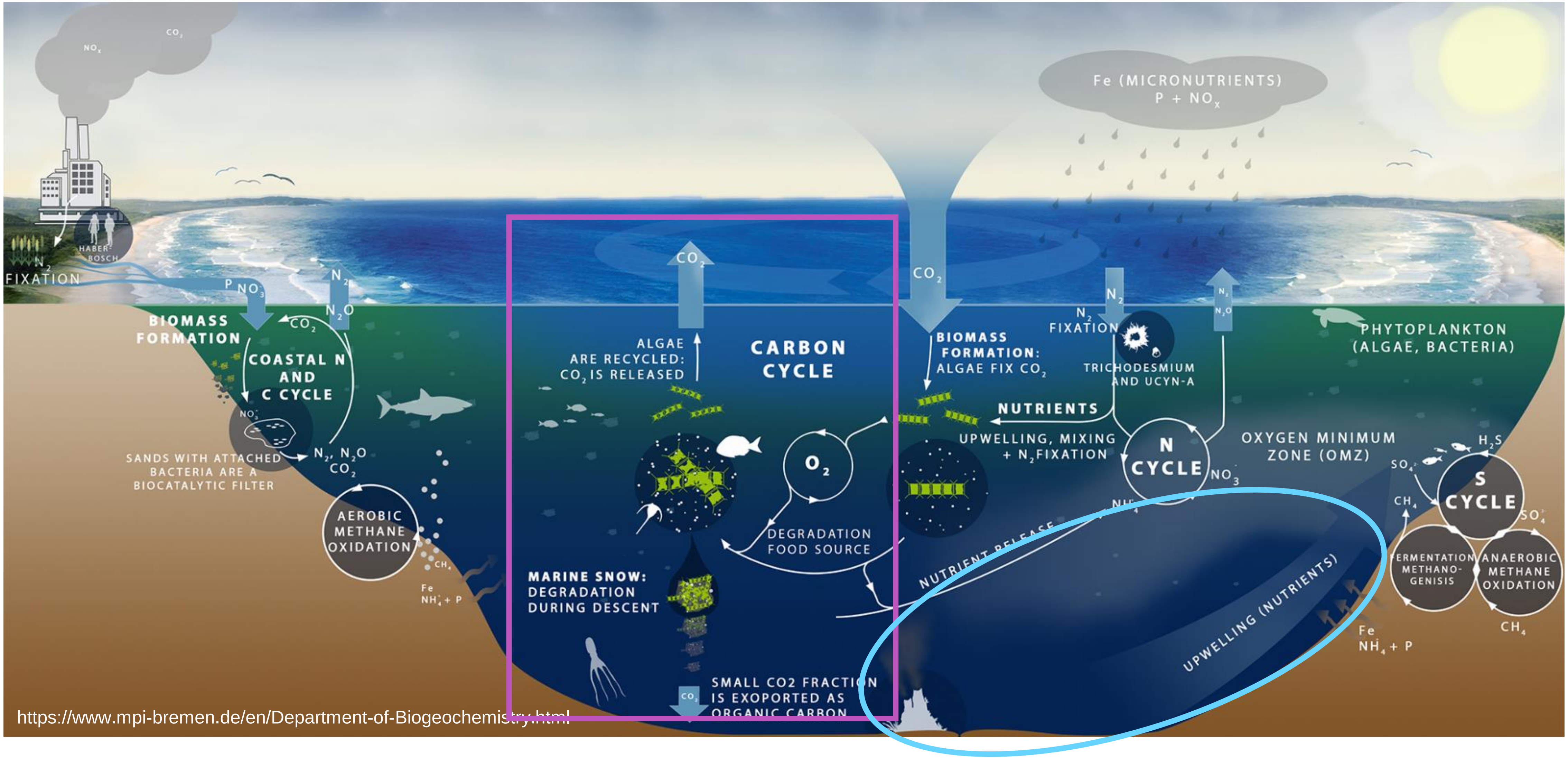
CHELSEY BAKER

MARINE BIOGEOCHEMISTRY



https://www.mpi-bremen.de/en/Department-of-Biogeochemistry.html

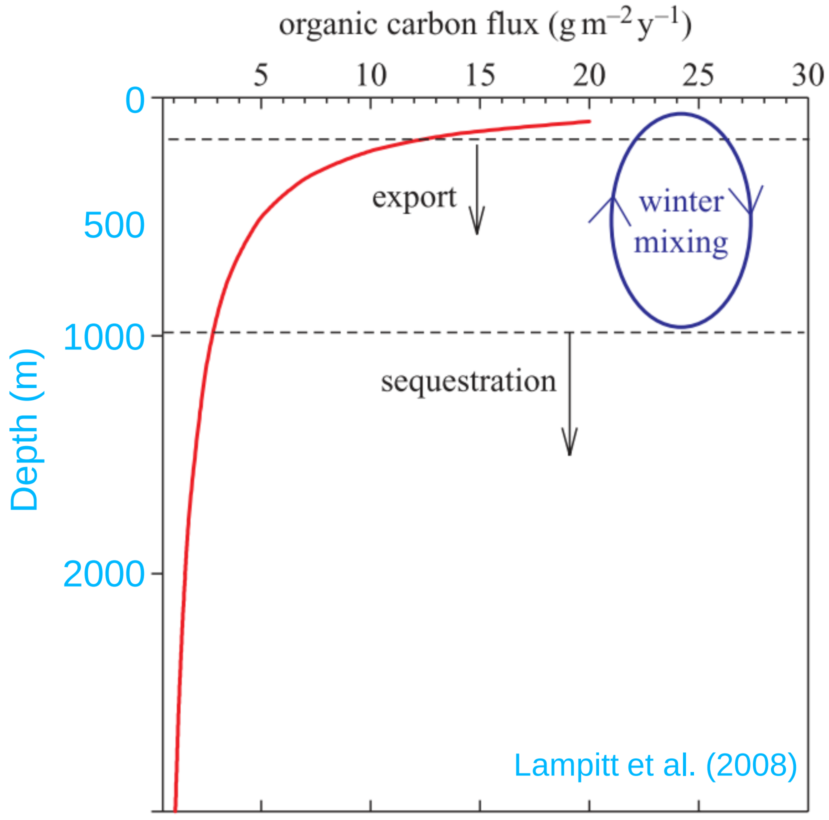
TWO EXAMPLES



https://www.mpi-bremen.de/en/Department-of-Biogeochemistry.html

EXAMPLE 1: LONG-TERM CARBON SEQUESTRATION

- Carbon sequestration usually defined as carbon below **<u>1000m</u>** that is stored for **<u>>100</u>** years *(IPCC, 2007; Lampitt et al. 2008)*
- Carbon that penetrates below the annual maximum mixed layer depth is thought to be sequestered on climate-relevant timescales *(Antia et al. 1999)*
- For simplicity, fixed-depth carbon sequestration horizons are often used to estimate the magnitude of long-term carbon sequestration
- Sequestration horizons of 500m, 1000m and 2000m and the depth of the permanent pycnocline have previously been used *(Guidi et al. 2015; Jin et al. 2020; Henson et al. 2012)*



LAGRANGIAN PARTICLE SIMULATIONS TO TRACK REMINERALIZED EXPORTED CARBON

National Oceanography Centre

Biological Carbon Pump Sequestration Efficiency in the North Atlantic: A Leaky or a Long-Term Sink?

Chelsey A. Baker[1], Adrian P. Martin[1], Andrew Yool[1], and Ekaterina Popova[1]

[1]National Oceanography Centre, Southampton, UK

- oceanparcels *(Delandmeter and Van Sebille, 2019; Lange and Van Sebille, 2017; https://oceanparcels.org/)*
- 1/4° degree horizontal resolution configuration of a coupled physics-biogeochemistry ocean model
  - ORCA025-N006; NEMO MEDUSA 1996-2015; 5 day means of velocity components *(Yool et al. 2013; Yool et al. 2015)*
- Virtual particles were released at 500m, 1000m and 2000m in the North Atlantic and tracked for 100 years
- Virtual particles track the physical flow of remineralized exported carbon (**not** tracking concentrations or particulates)
- Mixing and diffusive processes not accounted for

CLASS
CLIMATE LINKED ATLANTIC SECTOR SCIENCE

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Carbon that enters the mixed layer will come into contact with the atmosphere in <1 year.

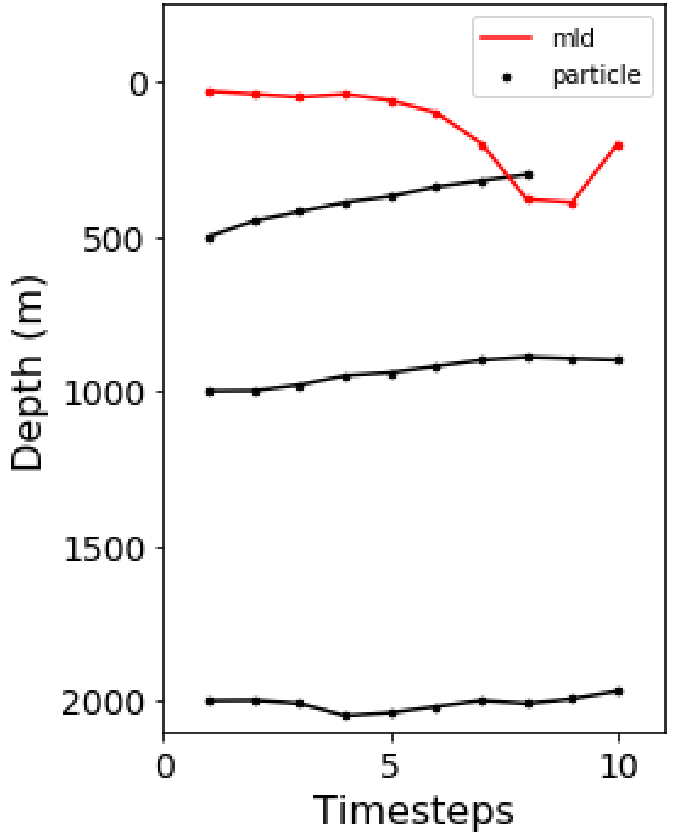
At every timestep along the trajectory the particle depth and mixed layer depth (MLD) are evaluated:

If

particle depth < MLD

then the particle has been **re-entrained into the mixed layer** and has **not remained sequestered** during the experiment.

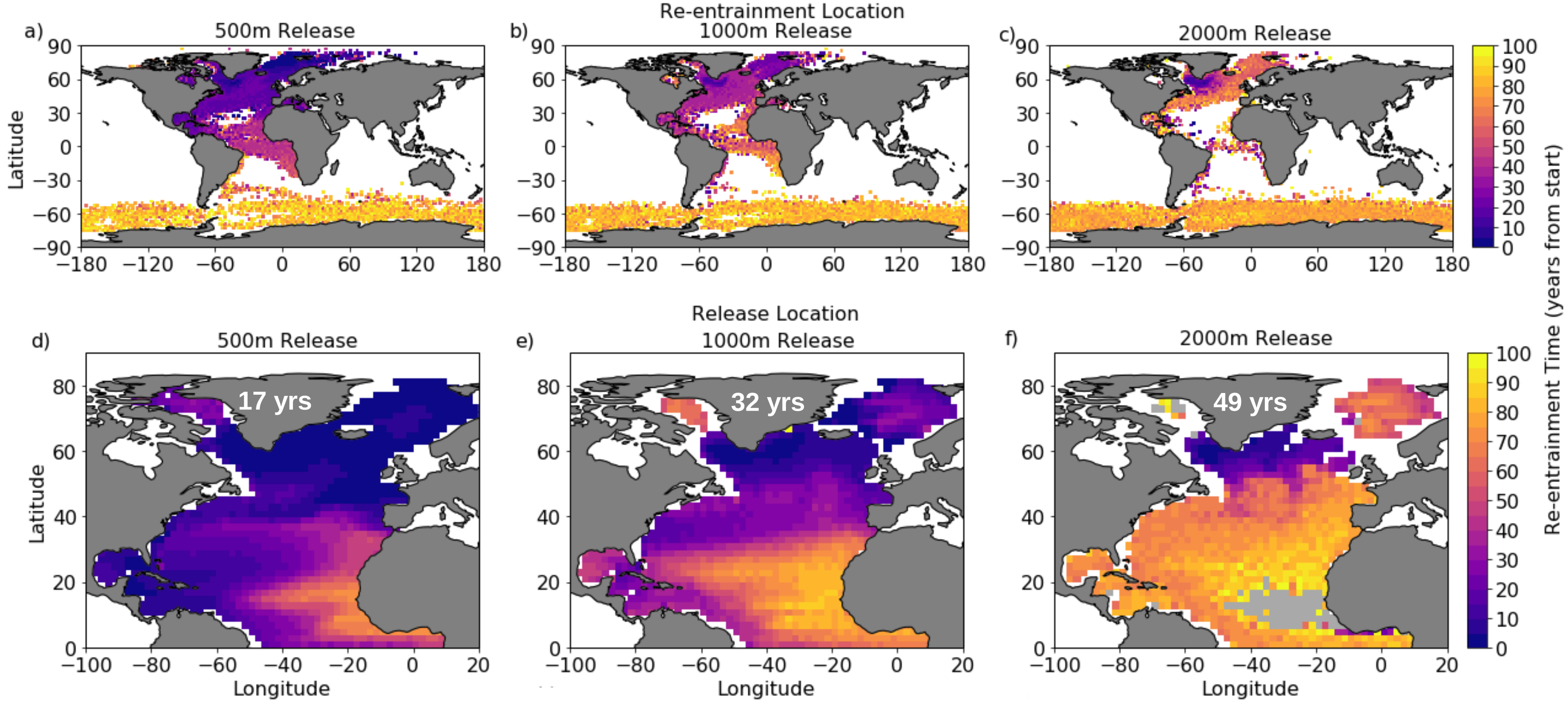
Particles that remain below the ML for the 100 year experiment are sequestered.



MLD = mixed layer depth

Baker et al. (2022)

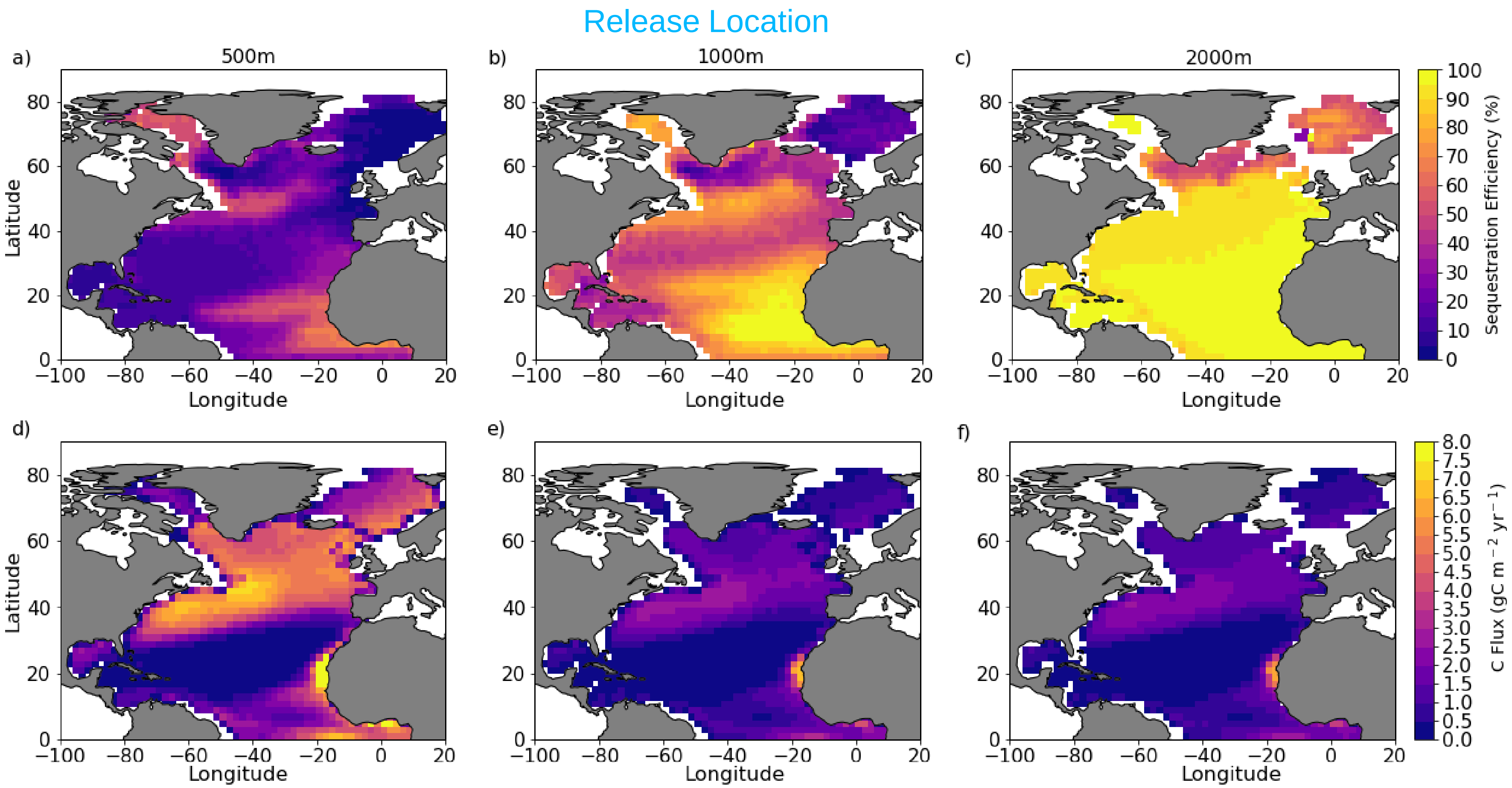
TIMESCALES OF PARTICLE RE-ENTRAINMENT INTO THE MIXED LAYER



Baker et al. (2022)

- Particles are re-entrained into the mixed layer on shorter timescales in the Subpolar North Atlantic
- The timescales of re-entrainment increase the away from the Subpolar North Atlantic and with deeper release depths
- Regions with deep mixed layers are key locations for re-entrainment

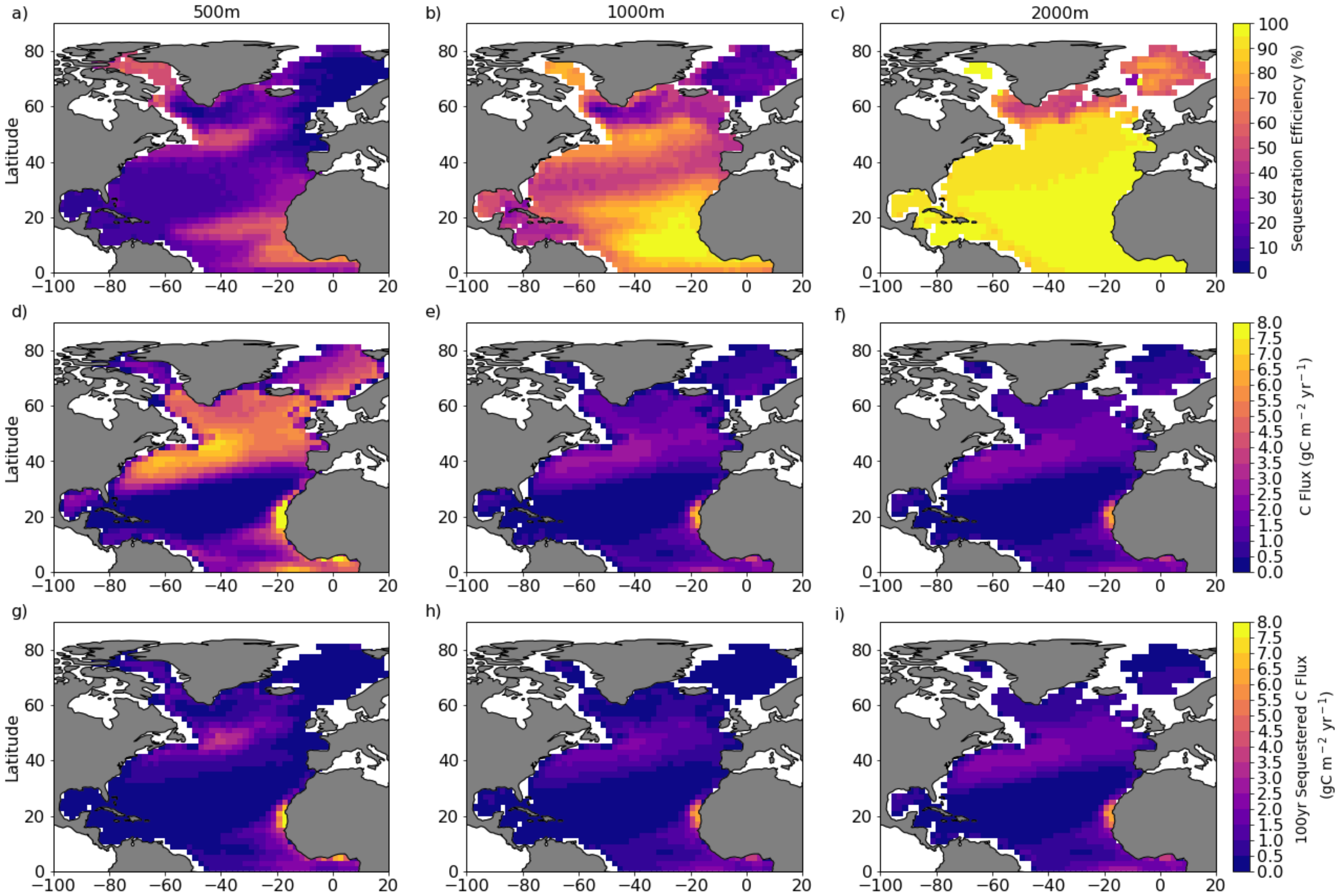
100 YEAR SEQUESTRATION EFFICIENCY



Baker et al. (2022)

- Sequestration efficiency varies regionally
- 28% sequestered at 500m, 66% sequestered at 1000m, 94% sequestered at 2000m
- Balance between magnitude of carbon and sequestration efficiency

CARBON FLUX SEQUESTERED FOR 100 YEARS



Baker et al. (2022)

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PARTICLE TRACKING FOR BIOGEOCHEMISTRY APPLICATIONS

- Particle-tracking simulations can used to track dissolved constituents in the ocean
- A useful tool to assess the influence of current pathways on biogeochemistry
- Fun to apply to different problems ☺
- Any questions?

FINDING OUT WHO YOU ARE…

- Raise you hand if…
  1. You are currently using modelling in your research
  2. Your research focuses on
     a) Ocean physics
     b) Ocean biogeochemistry
     c) Marine biology
     d) Something else
  3. Have used particle-tracking software before
  4. Have used oceanparcels before
  5. Are hoping to do some particle-tracking in the future

THE BASICS OF LAGRANGIAN PARTICLE-TRACKING

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OceanParcels

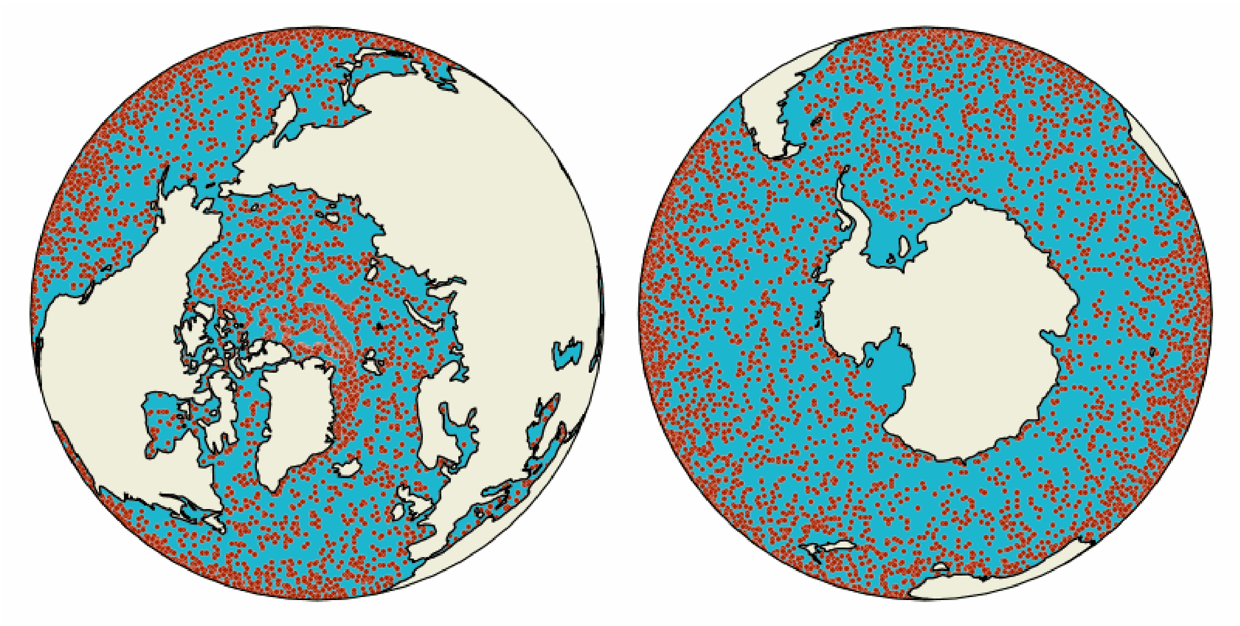
TRACMASS

Ariane

- Uses the model velocity components to move virtual particles around the ocean – it predicts where the future position of each virtual particle will be based on the velocity fields
- No mixing or diffusion represented
- Chaotic – need high numbers of particles and numerous releases to extract robust statistics
- Usually some type of compromise to make simulations feasible (run time, output storage, analysis)
- Need a clear research question and an idea of what metrics you want out of the simulations
  - This will guide experimental design and choice of model

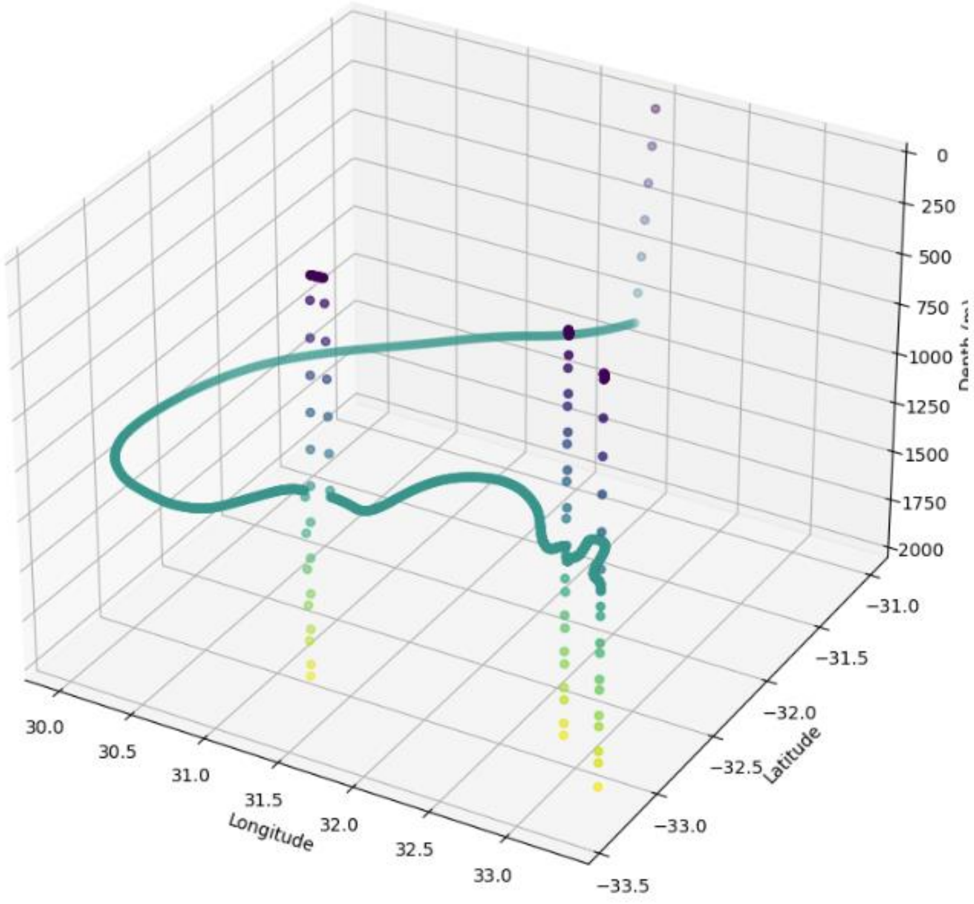
Disclaimer: other particle-tracking simulators are available…

WHAT IS OCEANPARCELS?



- The Ocean**Parcels** project develops **Parcels** (**P**robably **A** **R**eally **C**omputationally **E**fficient **L**agrangian **S**imulator), a set of Python classes and methods to create customisable particle tracking simulations using output from Ocean Circulation models. Parcels can be used to track passive and active particulates such as water, plankton, plastic and fish.
- https://oceanparcels.org/

WHAT IS OCEANPARCELS?



Advantages

- Easy to setup and use
- Lots of tutorials and documentation available
- Efficient
- Can extract model variables along trajectories
- Can include custom behaviour to particles such as:
  - Plastic characteristics (i.e. buoyancy, biofouling; Lobelle et al. 2021)
  - Argo float profiles
  - Sinking rates

TODAYS TASK

Aims:

- Understand and get a flavour for particle-tracking and its potential uses
- Get familiar with running simulations using parcels
- Plot up and analyse the simulations
- Learn the pitfalls and caveats of running and extracting *useful* information from Lagrangian simulations

Task:

- **Ready, set, go!**
  - 11:00-12:30: get setup and get a 5 year simulation running
- **Lunch**
- **Tour of NOC** – 13:30-14:45
- **Where did they go?**
  - 14:45-16:00 & 16:30-17:30: analysing the simulation results and attempting the challenges

MODEL OUTPUT WE WILL BE USING

- NEMO-MEDUSA ORCA025
  - ¼ degree horizontal resolution
  - 75 vertical levels
  - Monthly output
- Using the velocity components to 'drive' the particle-tracking simulations
  - U - zonal velocity
  - V - meridional velocity
  - W - vertical velocity
- Extracting local mixed layer depth along the trajectory
  - mldr10_1 - as defined using a standard NEMO diagnostic of a 0.01 kg m^{-3} change in density with respect to that at 10 m
- In the group workspace you only have model output for U, V, W and T files (no biogeochemistry)

READY, SET, GO!

- Running the parcels simulation
- Follow worksheet instructions – any problems, just ask!
- Log in to sci3 server – it has more memory for the simulations
- **Please make sure you are not in the group workspace when editing the scripts!**

Top tips

1. If you aren't sure of the latitude, longitude or water depth of the region you would like to release particles in use Google Earth
2. Don't skip the parcels_test.py steps… you want to check everything is working properly before a 5 year simulation (including the lat, lon and depth)
3. Ask questions! Want to understand something in more detail? Are your trajectories doing something weird? Is your outfile empty? We can (probably) help!

- Talk through of the script

```
(base) [train011@sci1 lagran]$ ls
2005  2008  2011  2014    parcelsenv.yml      parcels_test.py
2006  2009  2012  2015    parcels_plot.ipynb  trajectory_metrics.py
2007  2010  2013  domain  parcels_run.py
(base) [train011@sci1 lagran]$
```

WHERE DID THEY GO?

- Reading in the trajectories, plotting them up and analysing the simulations
- Run through the worksheet instructions and follow the notebook and run trajectory_metrics script.py
- Plots in the notebook are global… change the x and y limits to zoom in to your region of interest
- Near the end it includes some calculations and plots similar to the long-term carbon sequestration study I presented earlier
  - Will only be interesting for particles released deeper than the summer MLD and shallower than 1000m
- Notebook plots to get you started… feel free to create your own plots
- Scripts not infallible… any problems just ask.
- Show notebook…

WHERE DID THEY COME FROM, WHERE DID THEY GO?

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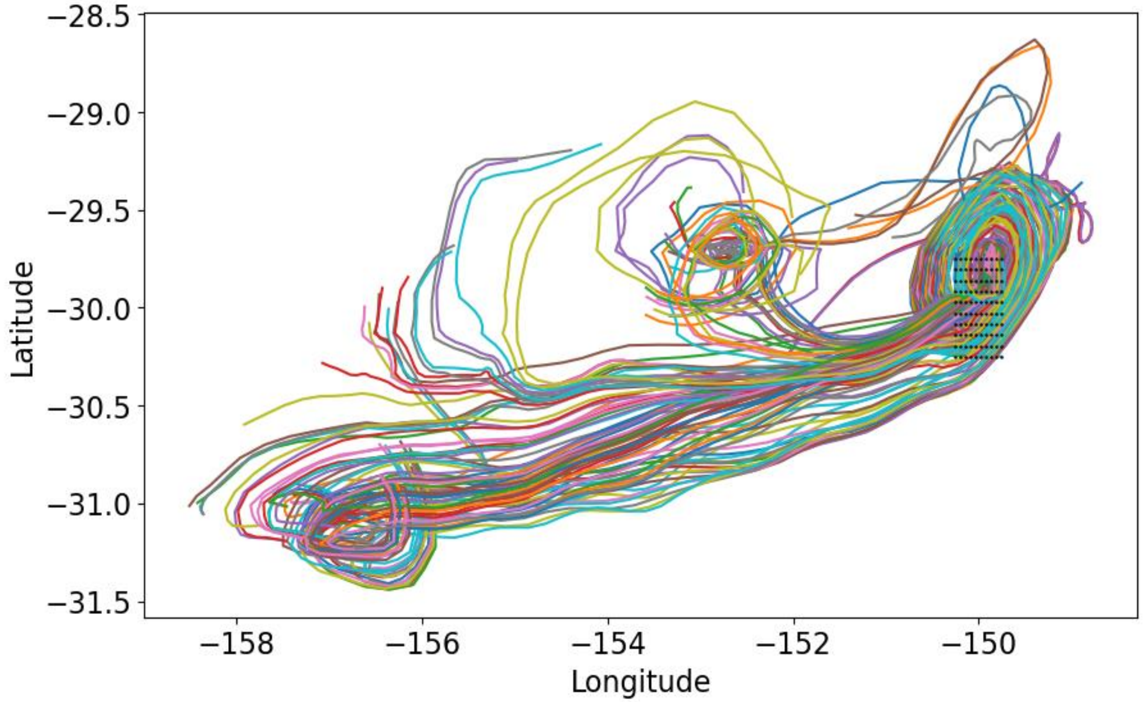
Challenges

1. Simulate a trajectory that travels the furthest in 5 years
2. Simulate a trajectory that travels the fastest over 5 years
3. Simulate a trajectory that has the largest depth change in 5 years
4. Find a depth and location which has a sequestration efficiency of 50% outside of the North Atlantic (closest to 50% wins)
5. Plot the most charismatic trajectory pathways (this is not scientific and extremely subjective – Andrew and Chelsey will judge!) e.g.



```
P[0](lon=-38.020924, lat=17.296710, depth=92.420368, mld=53.410271, bathy=5451.978027, time=157680000.000000)
P[1](lon=-48.877161, lat=25.431133, depth=59.834480, mld=84.000618, bathy=4580.828125, time=157680000.000000)
P[2](lon=-55.855935, lat=14.262532, depth=96.255517, mld=52.264122, bathy=5234.144043, time=157680000.000000)
P[3](lon=-58.127680, lat=15.026195, depth=112.633368, mld=48.960861, bathy=4101.065430, time=157680000.000000)
P[4](lon=-58.750872, lat=26.553507, depth=69.380417, mld=84.963470, bathy=6039.192383, time=157680000.000000)
P[5](lon=-46.907931, lat=20.703408, depth=122.823304, mld=56.005436, bathy=3818.444336, time=157680000.000000)
P[6](lon=-72.173300, lat=18.267071, depth=23.971403, mld=67.679741, bathy=1629.825928, time=157680000.000000)
P[7](lon=-49.419677, lat=16.231893, depth=115.143532, mld=56.203564, bathy=4012.525146, time=157680000.000000)
P[8](lon=-55.902734, lat=17.369625, depth=119.103253, mld=51.670013, bathy=5409.121094, time=157680000.000000)
P[9](lon=-43.737067, lat=24.722153, depth=37.480211, mld=88.079224, bathy=3780.759277, time=157680000.000000)
P[10](lon=-58.859009, lat=26.834942, depth=44.301398, mld=82.065674, bathy=6002.248047, time=157680000.000000)
P[11](lon=-44.400415, lat=16.392827, depth=100.605685, mld=14.541555, bathy=4084.747559, time=157680000.000000)
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P[13](lon=-50.138624, lat=14.142309, depth=137.310019, mld=33.950420, bathy=4812.377930, time=157680000.000000)
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P[15](lon=-37.015588, lat=17.379506, depth=98.733481, mld=53.460121, bathy=5511.700195, time=157680000.000000)
P[16](lon=-39.372205, lat=17.020822, depth=87.671214, mld=48.358845, bathy=5322.715332, time=157680000.000000)
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P[20](lon=-44.951697, lat=19.165682, depth=84.752940, mld=54.205578, bathy=3491.342529, time=157680000.000000)
```
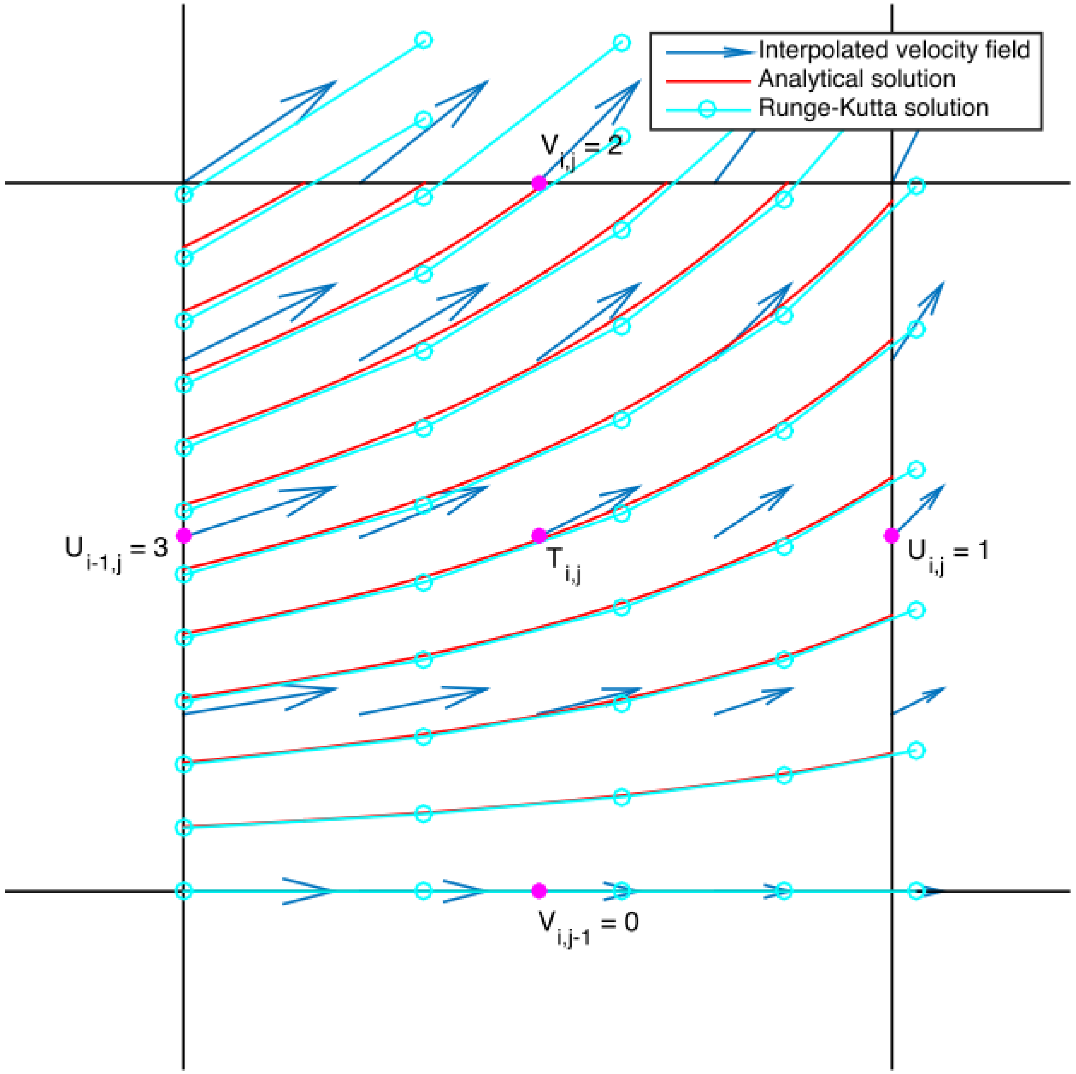

VAN SEBILLE ET AL. 2018: LAGRANGIAN FUNDAMENTALS



DELANDMETER ET AL. 2019: PARCELS V2.0 - GRIDS

National Oceanography Centre

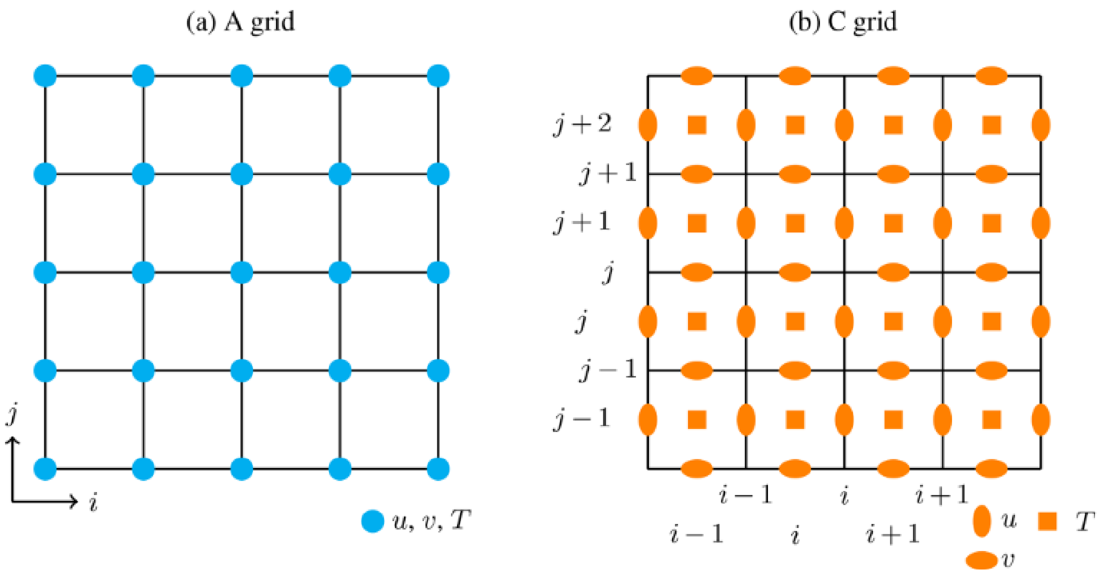


Figure 2. Arakawa's staggered grids (Arakawa and Lamb, 1977): **(a)** A grid and **(b)** C grid. In the C grid, i and j represent the variable column and row indexing in arrays where the variables are stored. The indexing of the C grid follows the NEMO notations (Madec and the NEMO team, 2016).

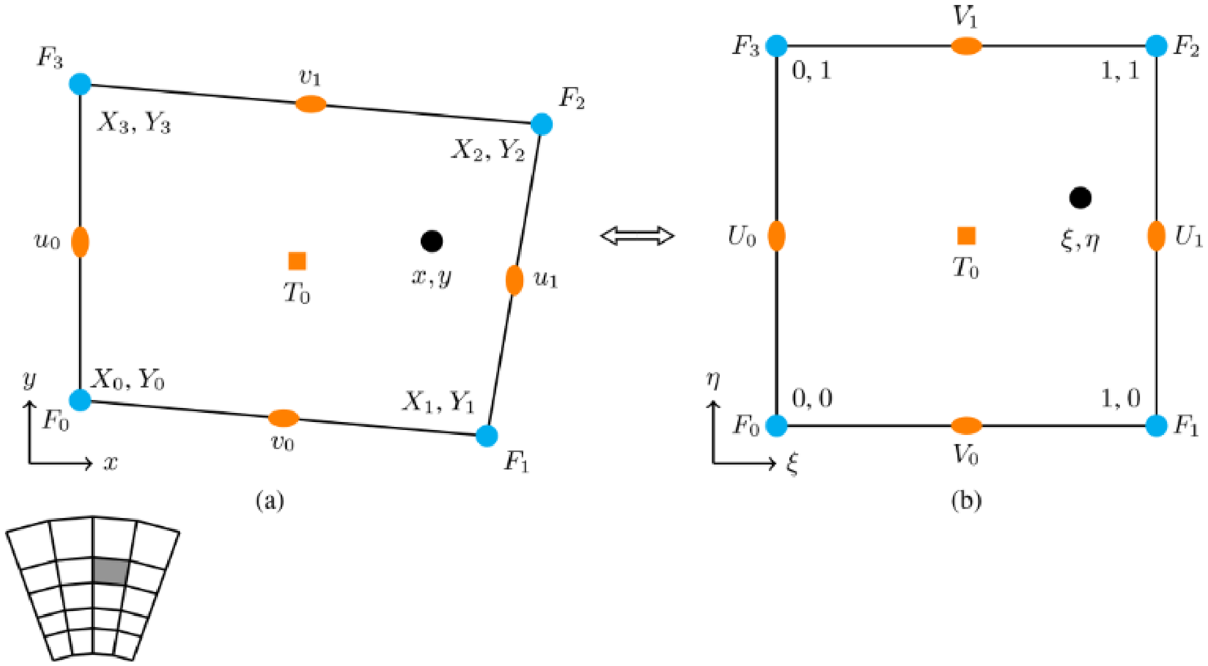


Figure 3. Positioning of the variables for an A grid (blue nodes) and C grid (orange nodes) cell with **(a)** physical coordinates in the mesh cell and **(b)** relative coordinates in the unit cell.

LAGRANGIAN PARTICLE SIMULATIONS TO TRACK REMINERALIZED EXPORTED CARBON

earch Letters

How deep is deep enough? Ocean iron fertilization and carbon sequestration in the Southern Ocean

J. Robinson[1,2], E. E. Popova[2], A. Yool[2], M. Srokosz[2], R. S. Lampitt[2], and J. R. Blundell[1]

[1]Ocean and Earth Science, University of Southampton, Southampton, UK, [2]National Oceanography Centre, Southampton, UK