Investigating the active flux of carbon in the Southern Ocean: the contribution of a prominent euphausiid

PhD research

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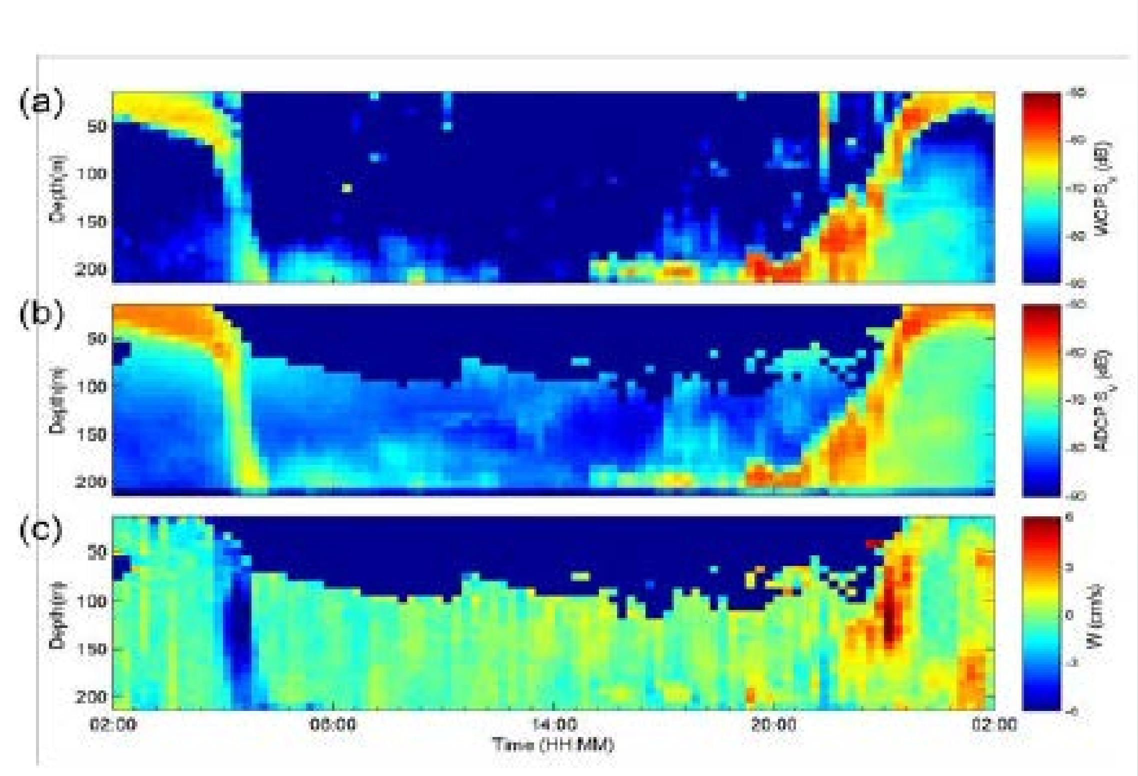
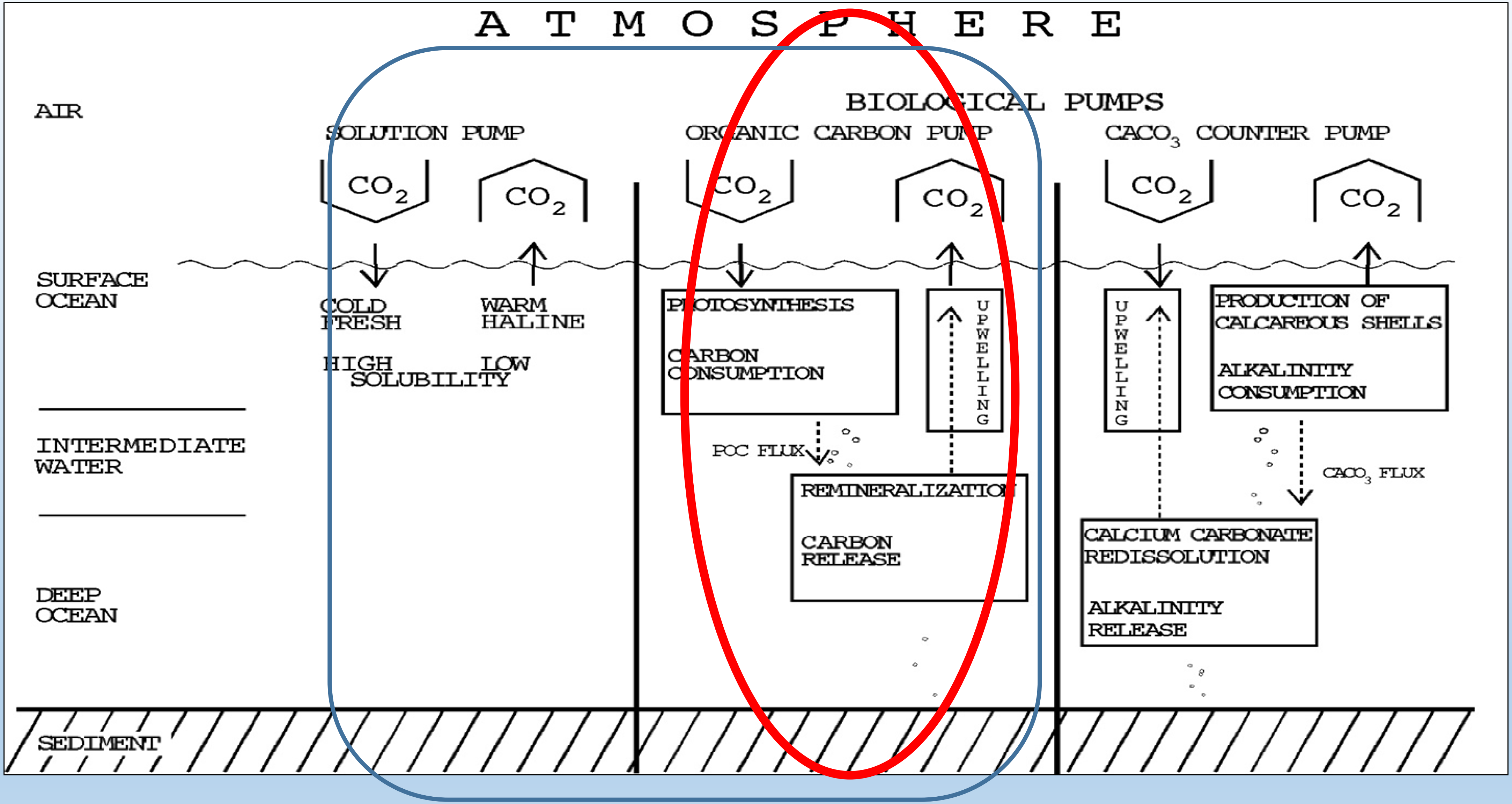
Diel Vertical Migration and active carbon flux

- Well-known and essential element of pelagic ecology
- May represent important macronutrient fluxes (C, N, P) across pycnocline
- Biggest migration on the planet in terms of biomass
- Complex: Synchronicity? Amplitudes? Seasonal/ ontogenetic superimpositions...



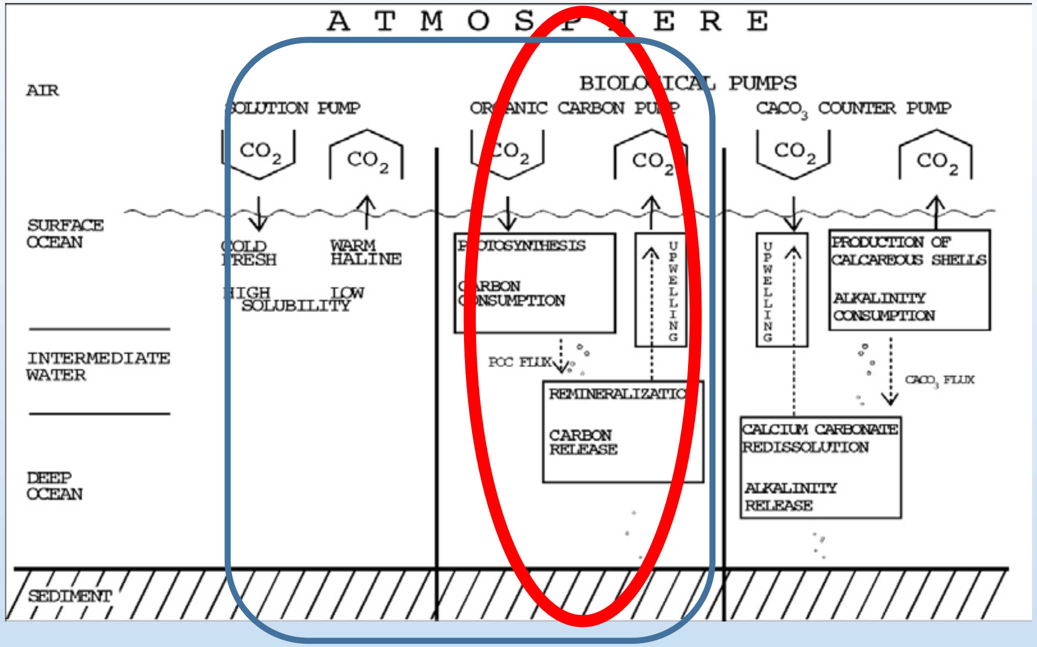
Diel cycle of volume backscattering strength (Sv) and vertical velocity (w) from a) water column profiler (WCP) and b-c) ADCP

Source: JR304 Cruise Report (2015)



Schematic of the three major ocean carbon pumps involving the regulation of atmospheric CO_2 changes by the ocean (taken from Heinze et al, 1991)

The mismatch…



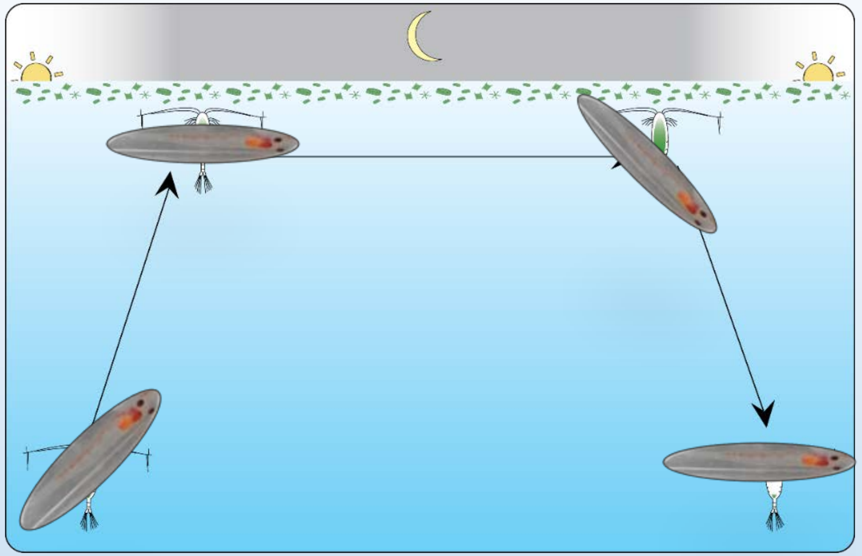
- Sources/ sinks unbalanced by up to two orders of magnitude (e.g. Giering et al, 2014)
- Sources of uncertainty?
  - Chl based production estimates
  - Sediment trap inaccuracies – only passive flux
  - Zooplankton-microbial synergies
  - DVM…
- Faecal pellets may contribute 25-65% more to POC flux, depending on gut passage time
- Respiratory flux also important: may be up to 20-70% of sinking POC flux

Why the Southern Ocean?

- One of the biggest ocean carbon sinks
- Hotspots of productivity e.g. ice edge, Polar Front, South Georgia/Scotia arc
- Deep water formation linked to THC and carbon drawdown
- Not quantified for SO but zooplankton faecal pellets important in export and attenuation of SO flux
- What about respiratory carbon..?

Theories of DVM

- Falls into 3 categories:
  i. Nocturnal: shallowest depth reached between sunset and sunrise
  ii. Twilight: ascent to surface at dusk; descent to depth at dawn
  iii. Reverse: shallowest depth reached during the day
- Exhibited by many abundant SO zooplankters
- Feeding-satiation hypothesis?



Source: http://www.planktoneer.com/forays.html

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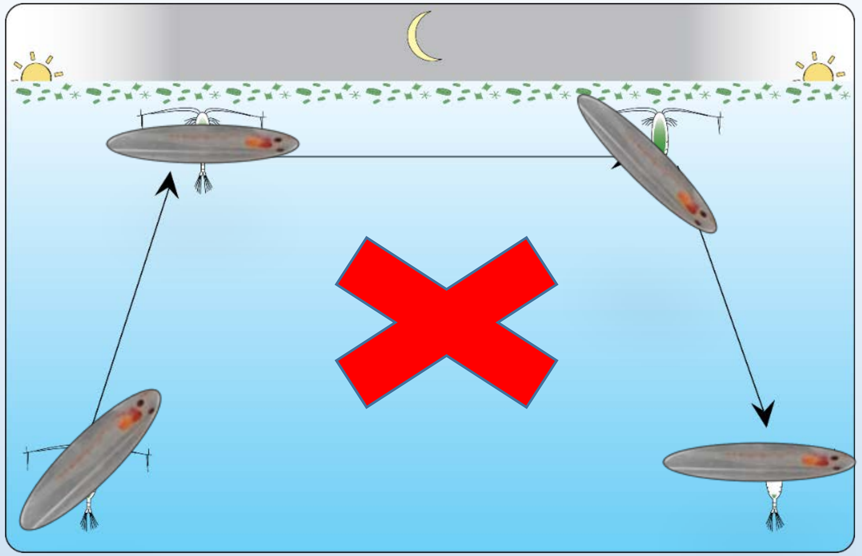

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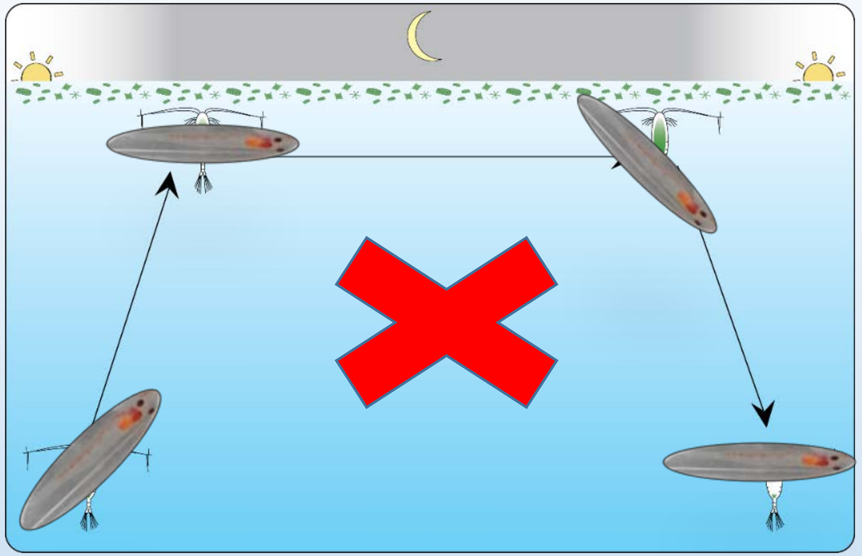
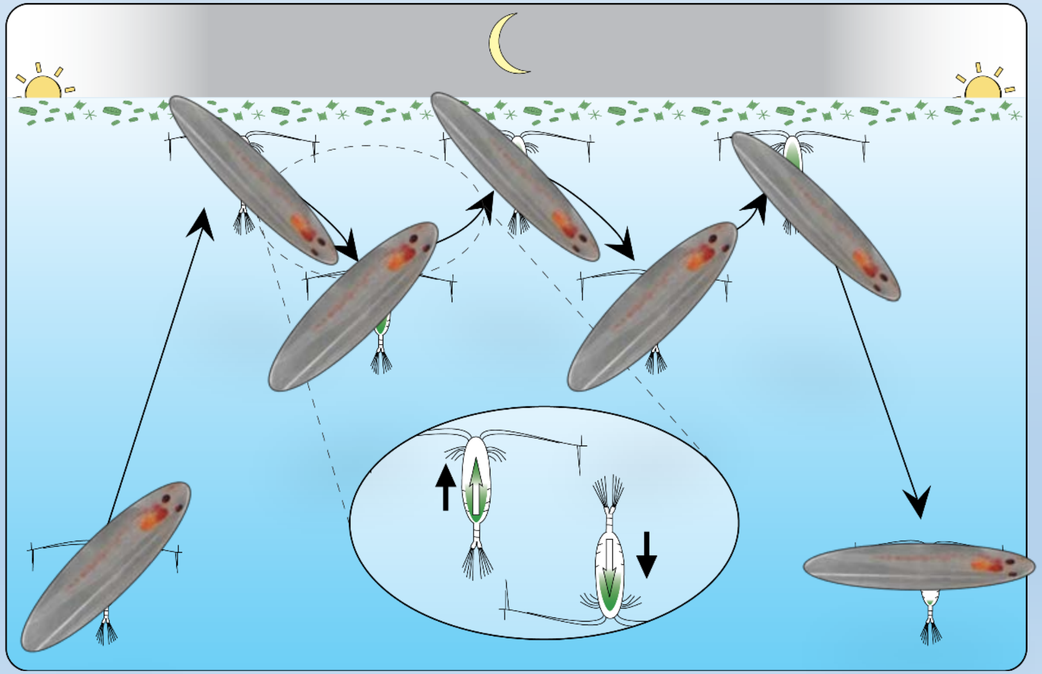




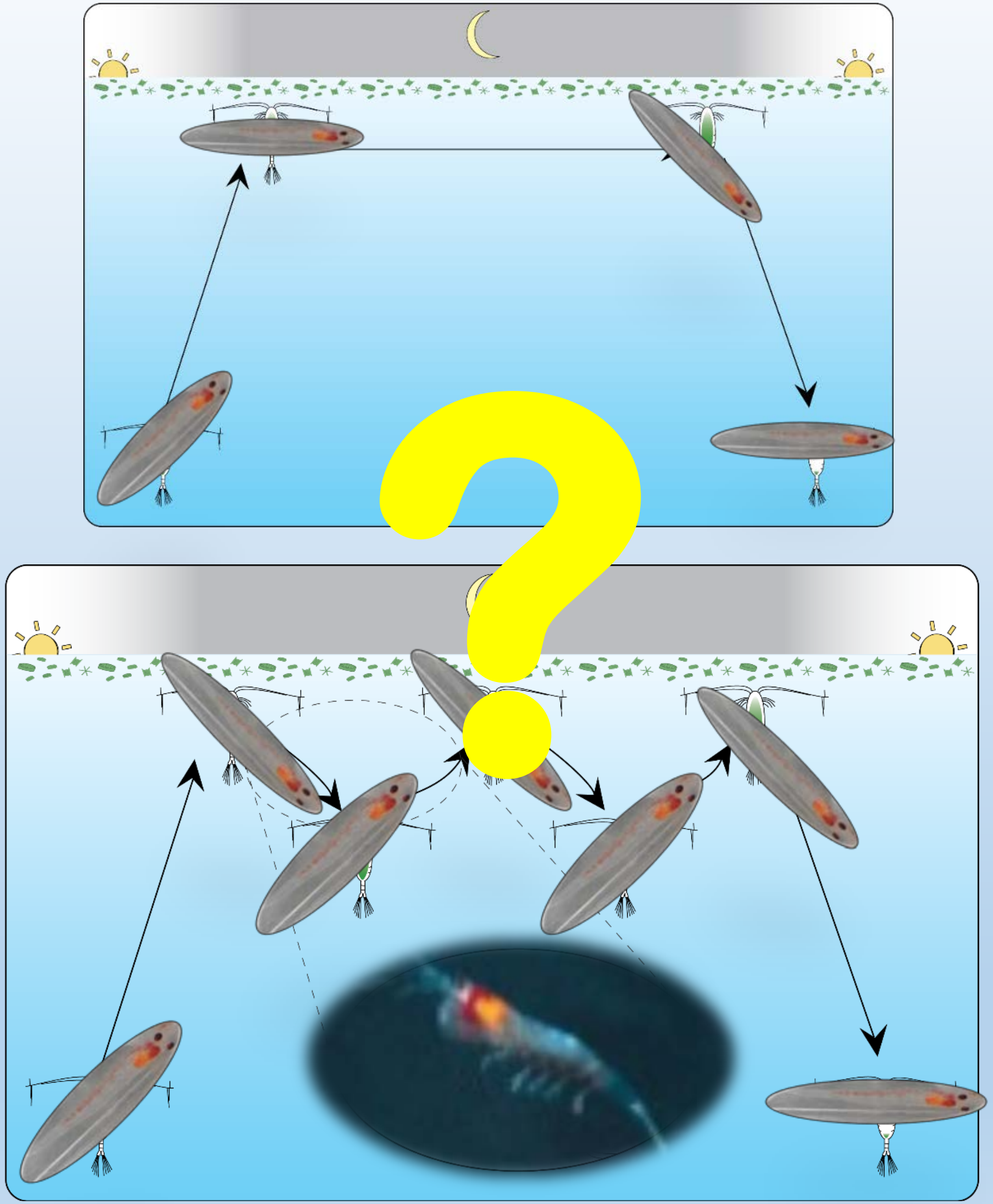
Source: http://www.planktoneer.com/forays.html

Objectives:

Investigate importance of prominent SO euphausiid for C export:

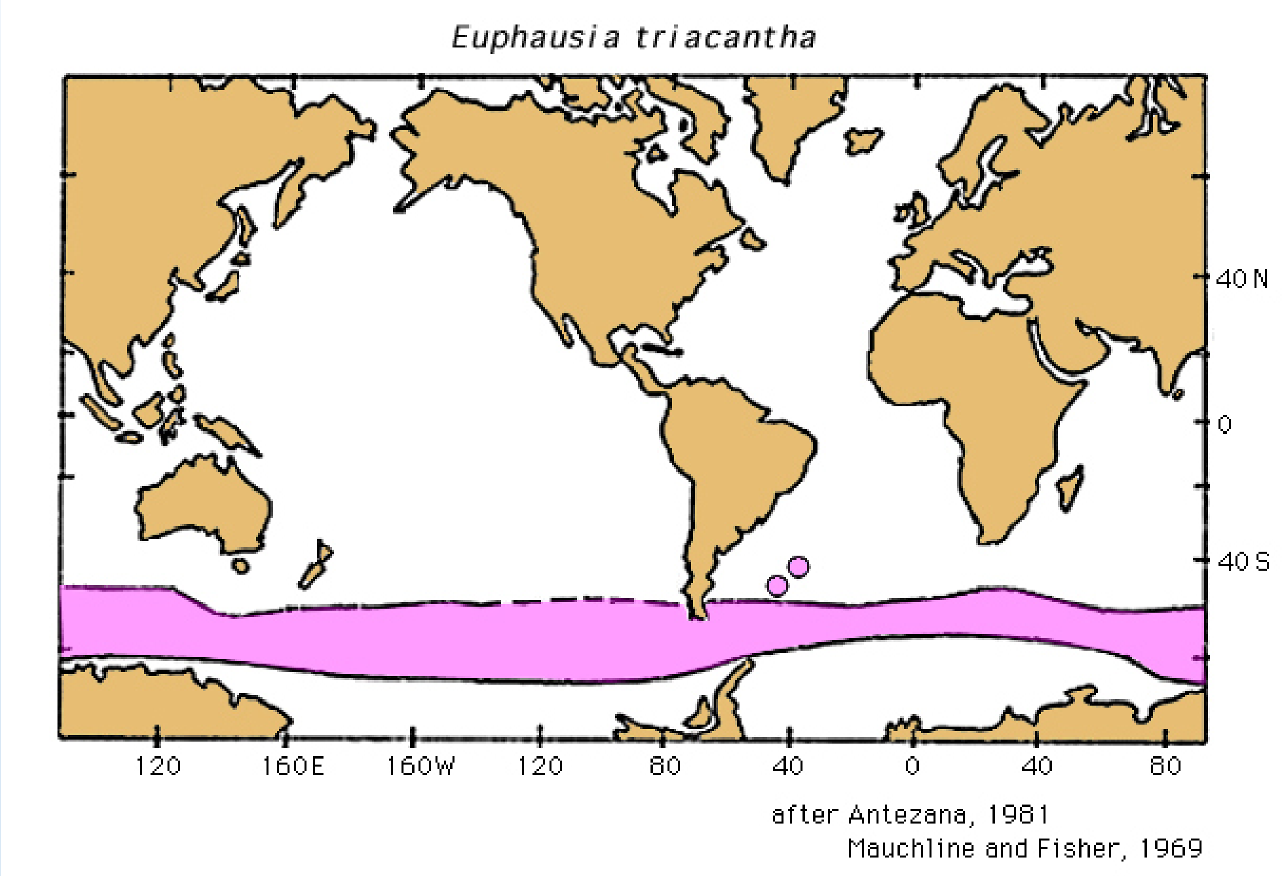
i. Establish vertical distribution over diel cycle
ii. Measure metabolic rate over migratory temperature range
iii. Model carbon export potential - respiration and egestion

Focus on *<u>Euphausia triacantha</u>*



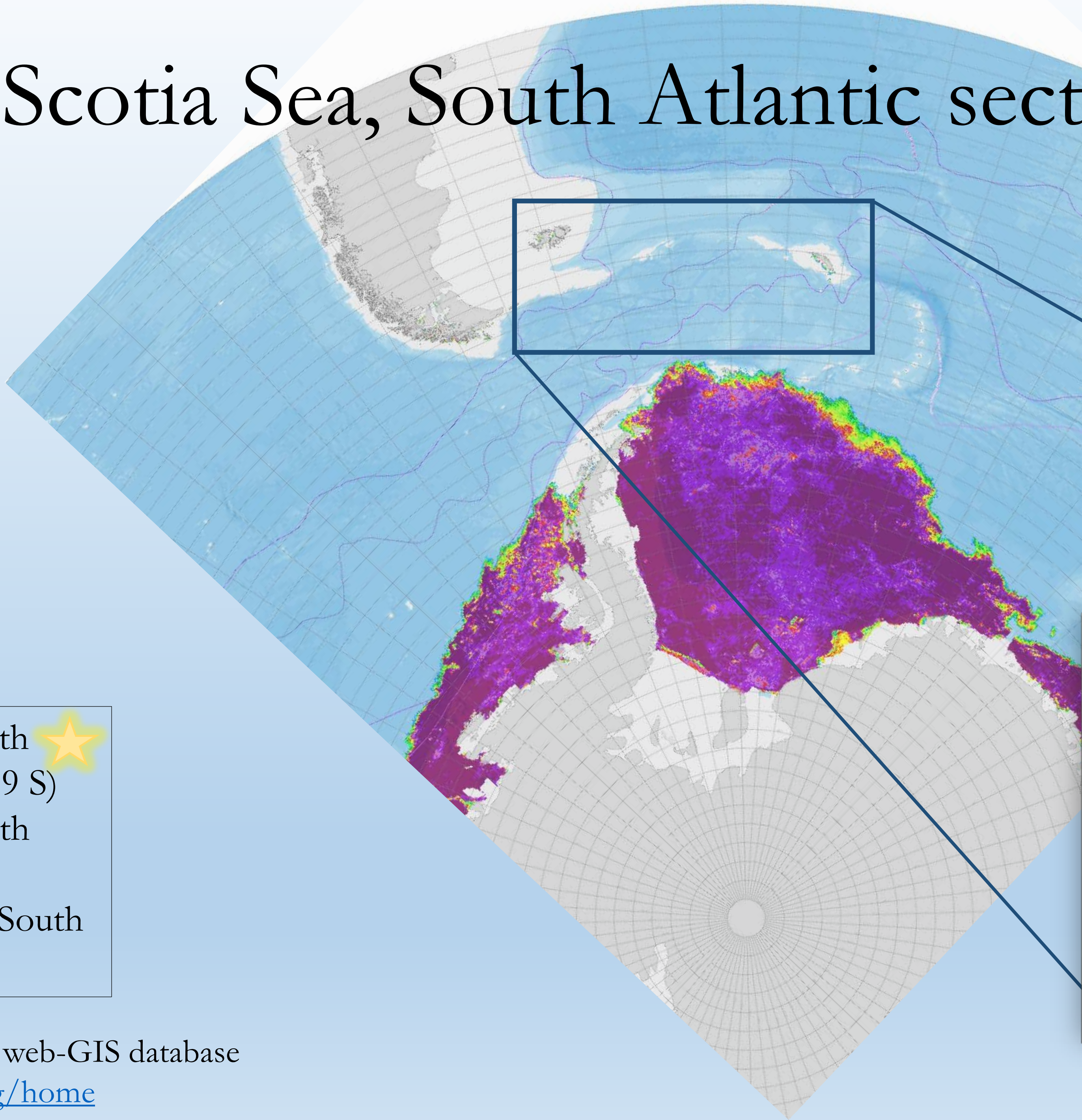
Source: http://www.planktoneer.com/forays.html

Euphausia triacantha, Holt & Tattersall 1906



- Performs DVM
- Wide vertical spread: up to 1,000 m
- Occurs between 50 S - 65 S
- Distributed over >24,300,000 km^2
- Limited by northern limit of Weddell and East Wind drifts
- Adults 24 – 41 mm
- Omnivorous feeder

Where: Scotia Sea, South Atlantic sector



Stations marked with ⭐
- C3: open water (59 S)
- P2: upstream South Georgia (55 S)
- P3 : downstream South Georgia (52 S)

Map from CCAMLR web-GIS database
https://gis.ccamlr.org/home

DISCOVERY 2010 Summer Cruise Track, Scotia Sea

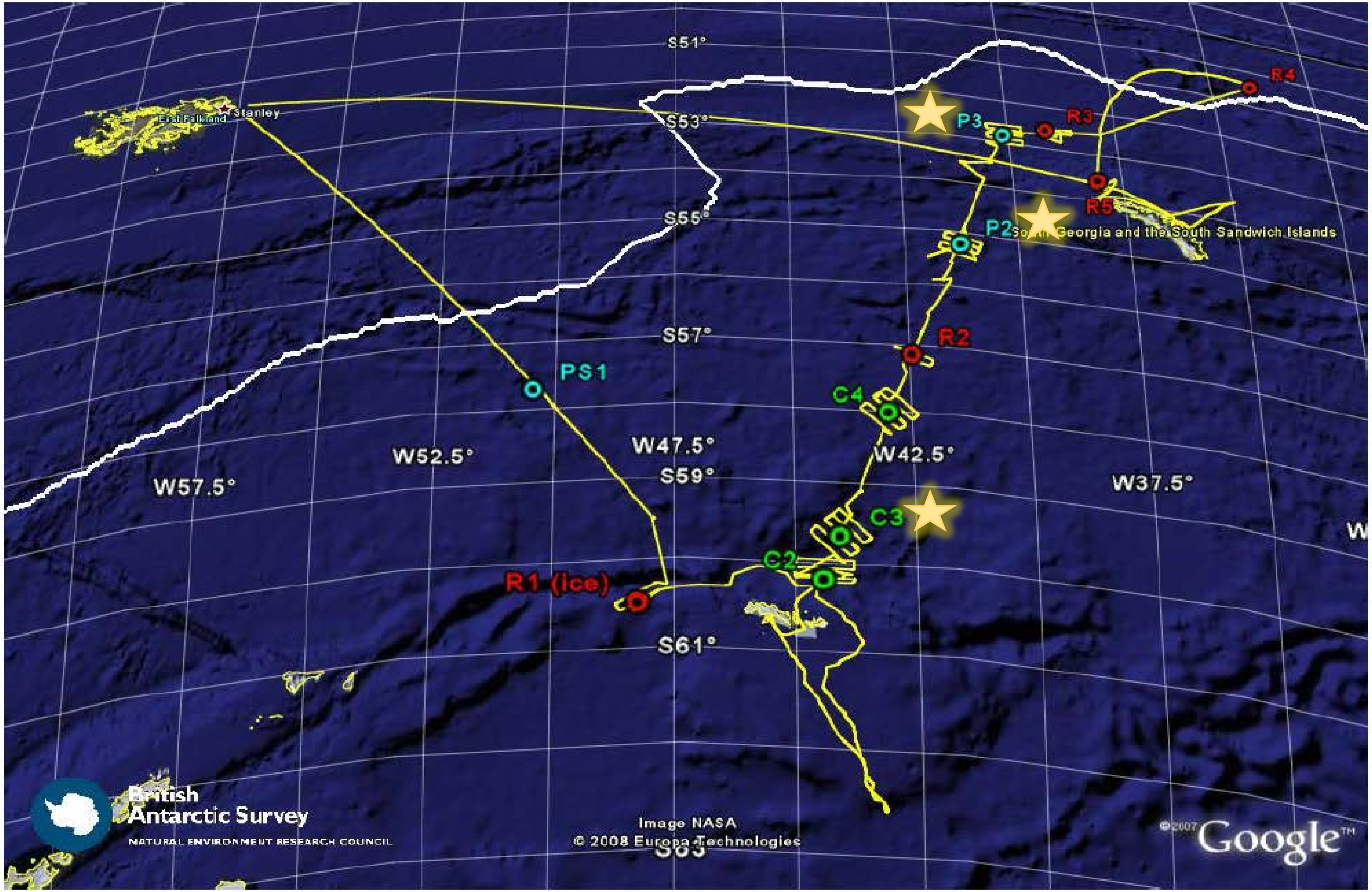
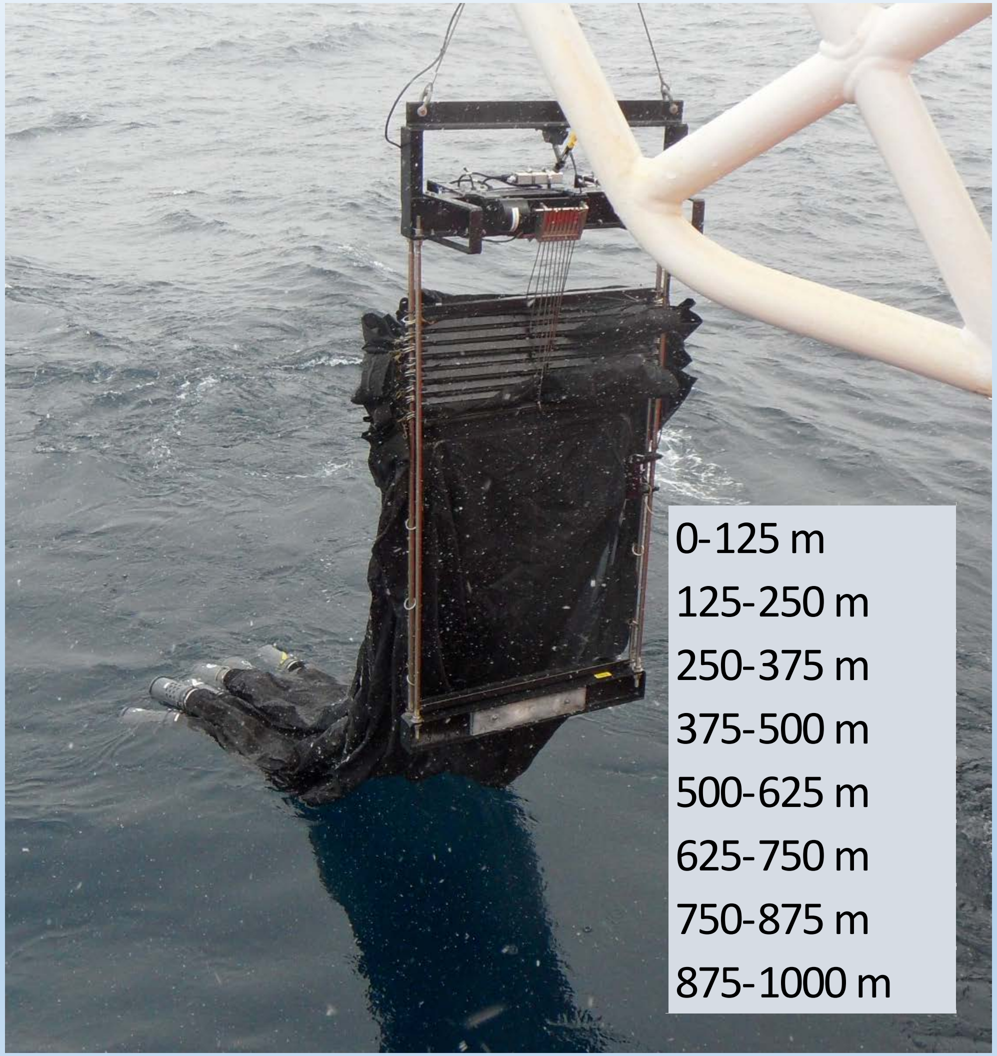


FIGURE 1.3 ACTUAL CRUISE TRACK

Stations marked with ★
- C3: open water (59 S)
- P2: upstream South Georgia (55 S)
- P3 : downstream South Georgia (52 S)

From JR177 Cruise Report

How: (i) Mocness net sample analysis

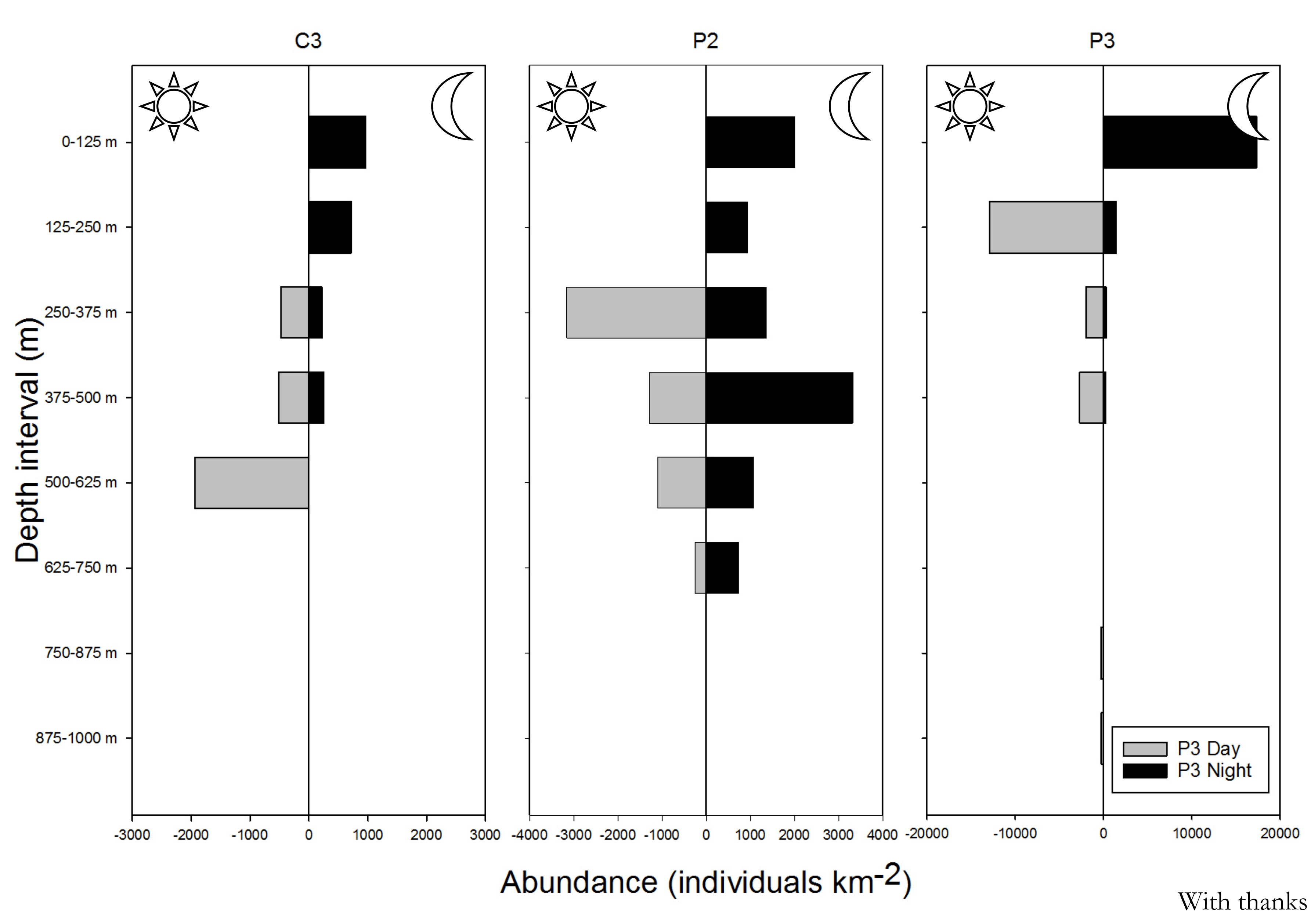


- 330 um mesh size
- Depth-discrete samples over 1,000 m
- 125 m depth intervals
- Temporal and spatial resolution
- From JR177 (austral summer 2008)

How: (ii) Respiration experiments

- On-board JR304 (austral spring 2014)
- Using fibre-optic, non-invasive oxygen optode
- Different temperatures

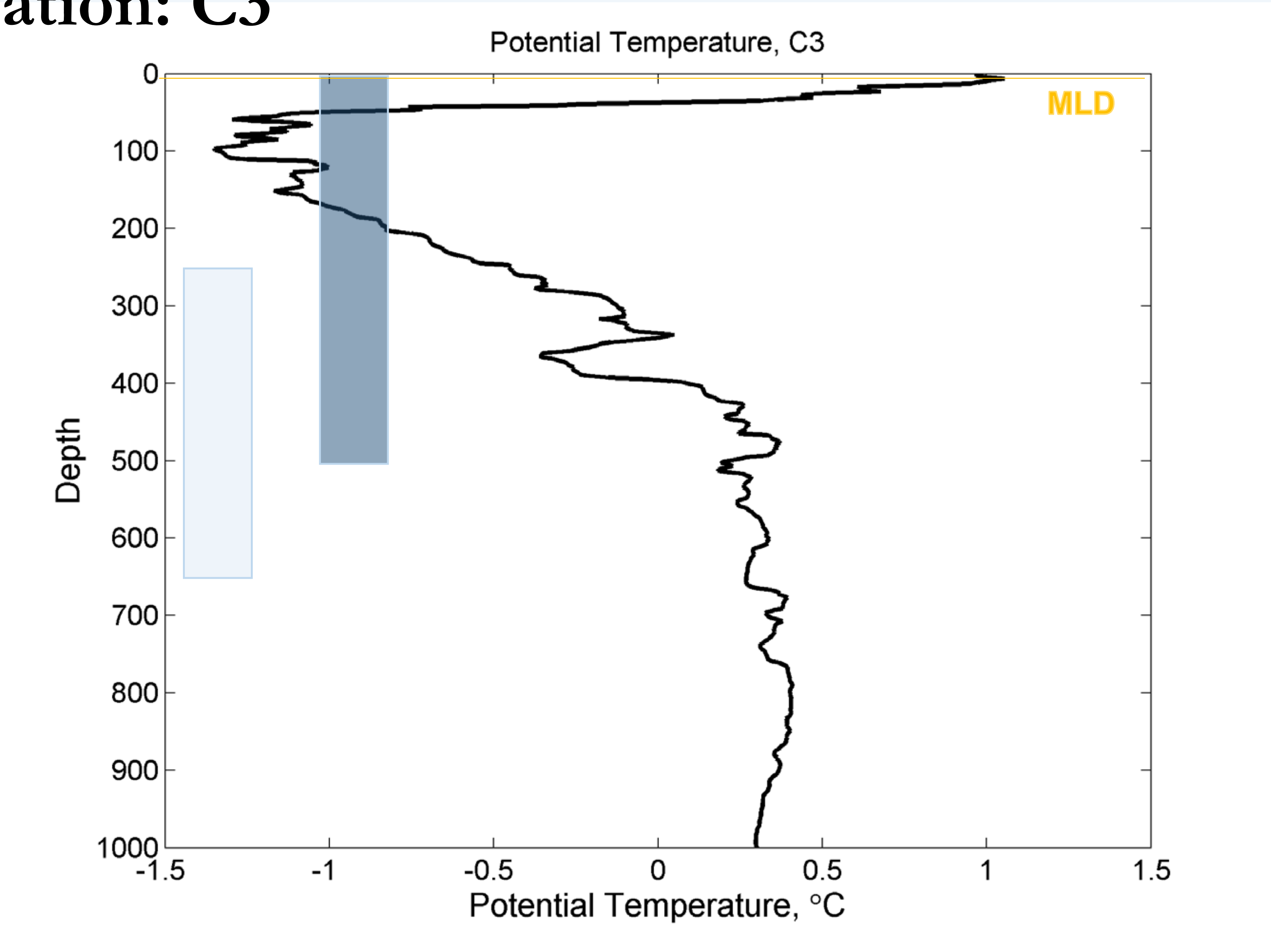
Results: (i) *E. triacantha* day vs night



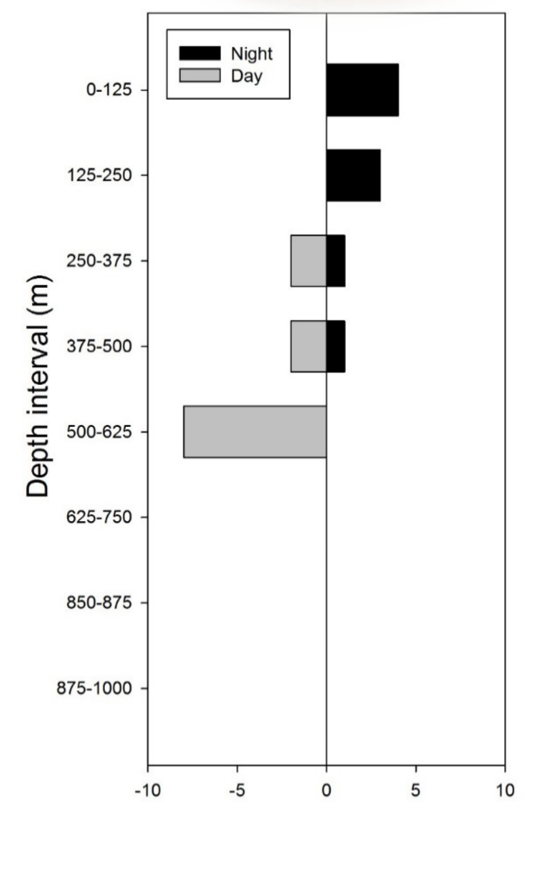
- Evidence of DVM
- Differentiated depths of peak abundance
- Wide (1,000 m) distribution
- Evidence of asynchronous/ foray behaviour?

With thanks to Peter Ward for help with taxonomic analysis

Station: C3

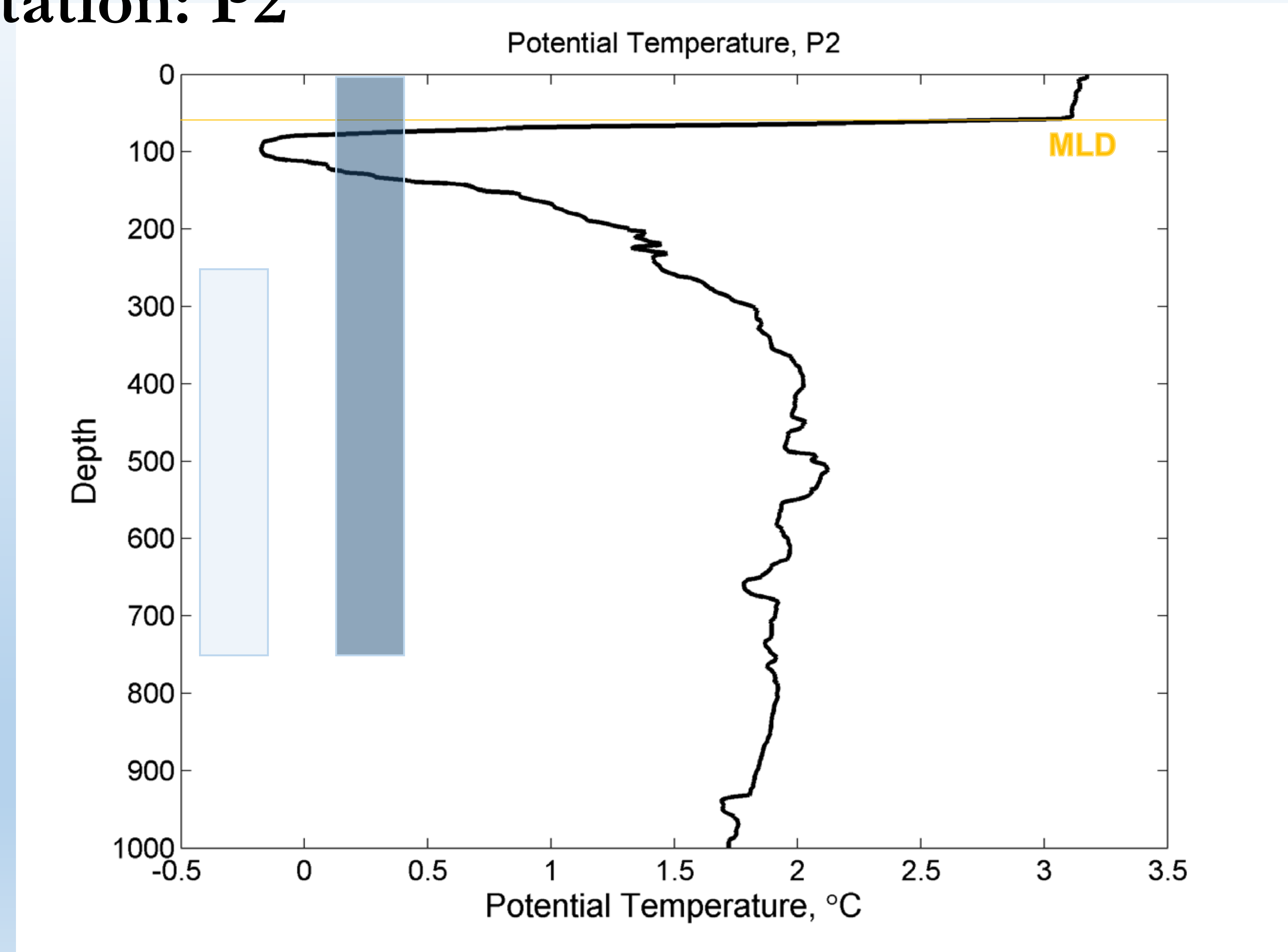


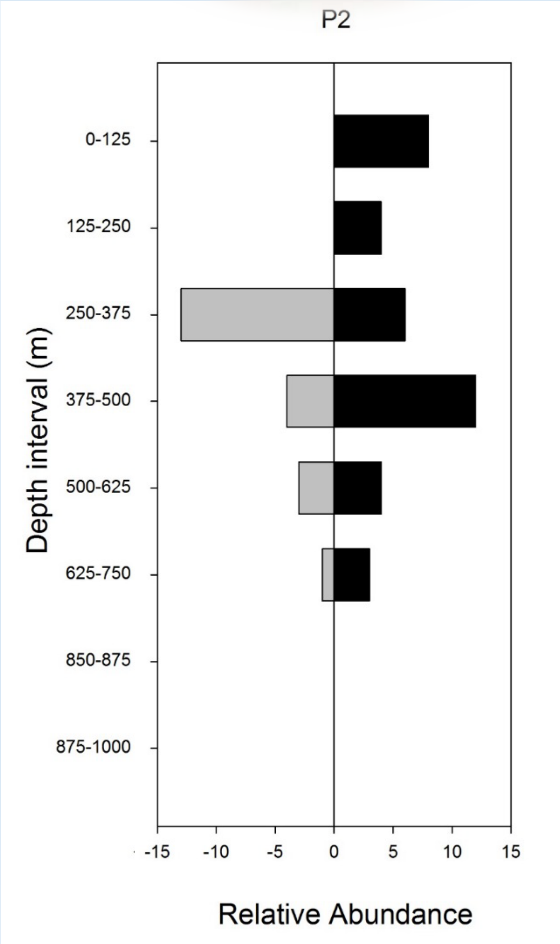
Potential Temperature, C3
MLD
Depth
Potential Temperature, °C
0
100
200
300
400
500
600
700
800
900
1000
-1.5
-1
-0.5
0
0.5
1
1.5



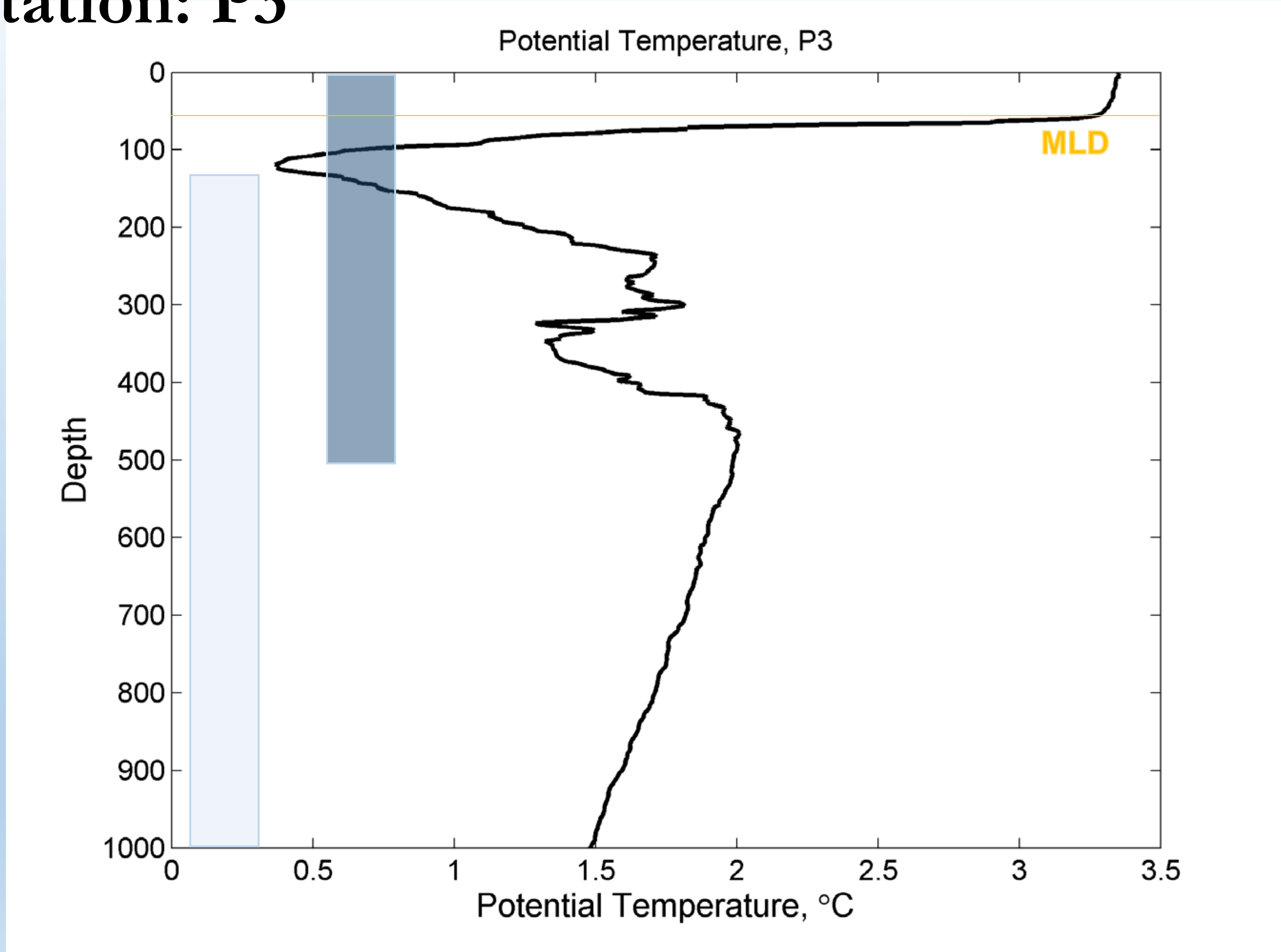
Night
Day
Depth interval (m)
0-125
125-250
250-375
375-500
500-625
625-750
850-875
875-1000
-10
-5
0
5
10

Station: P2

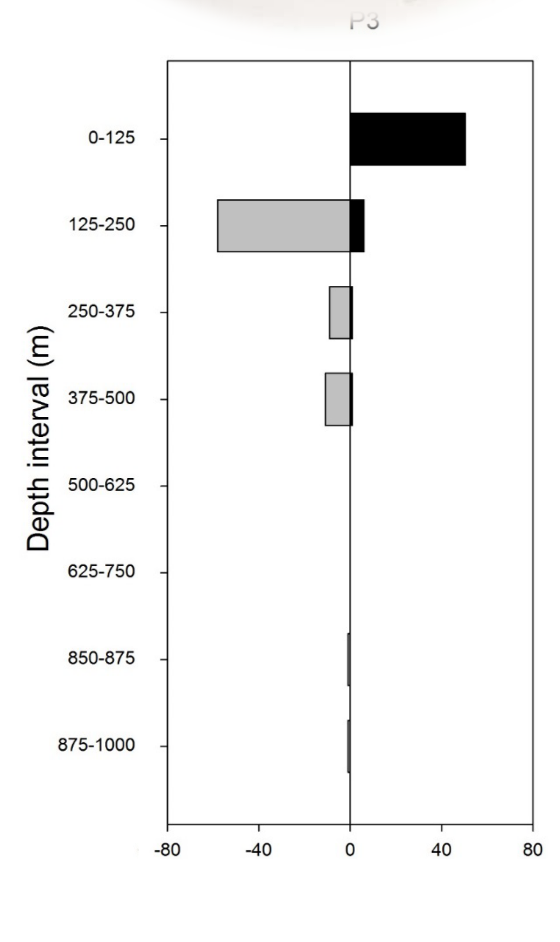

Potential Temperature, P2
0
100
200
300
400
500
600
700
800
900
1000
Depth
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
Potential Temperature, °C
MLD


P2
0-125
125-250
250-375
375-500
500-625
625-750
850-875
875-1000
Depth interval (m)
-15
-10
-5
0
5
10
15
Relative Abundance

Station: P3

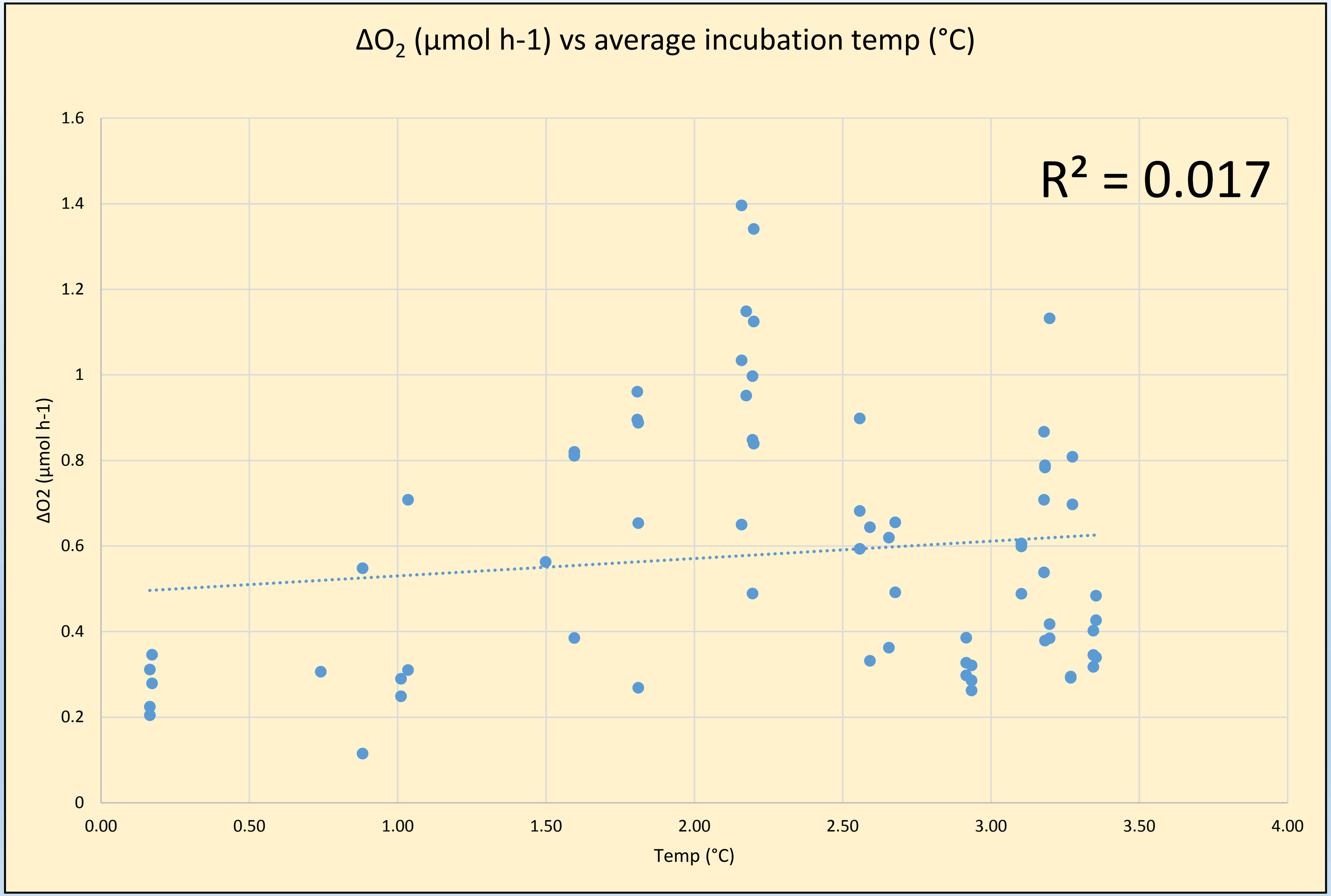


Potential Temperature, P3
Depth
0
100
200
300
400
500
600
700
800
900
1000
0
0.5
1
1.5
2
2.5
3
3.5
Potential Temperature, °C
MLD

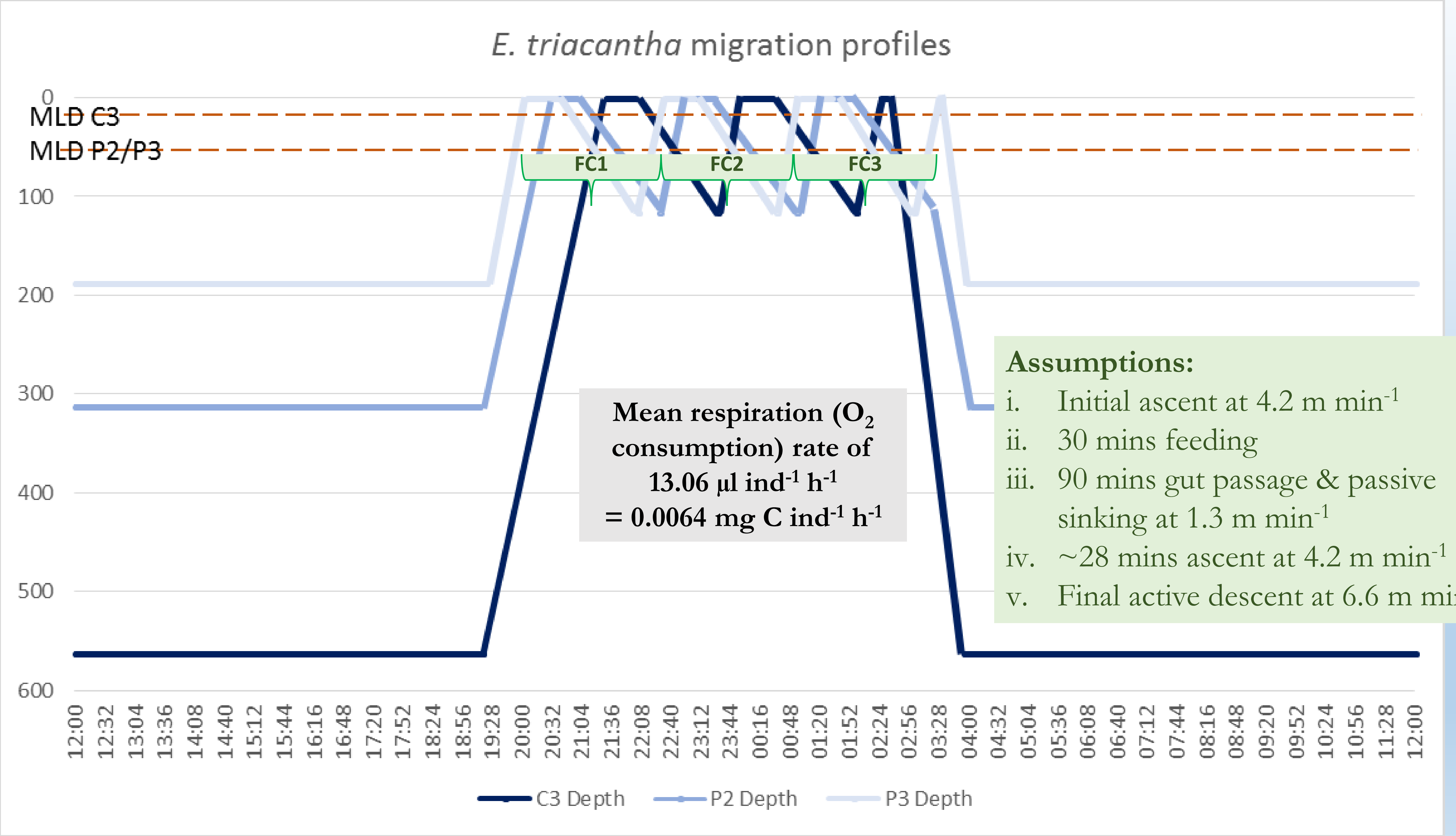


P3
Depth interval (m)
0-125
125-250
250-375
375-500
500-625
625-750
850-875
875-1000
-80
-40
0
40
80

Results: (ii) *E. triacantha* incubations: effect of temperature?



O_2 consumption = 0.6 µmol ind^{-1} h^{-1} = 13.06 µl ind^{-1} h^{-1}

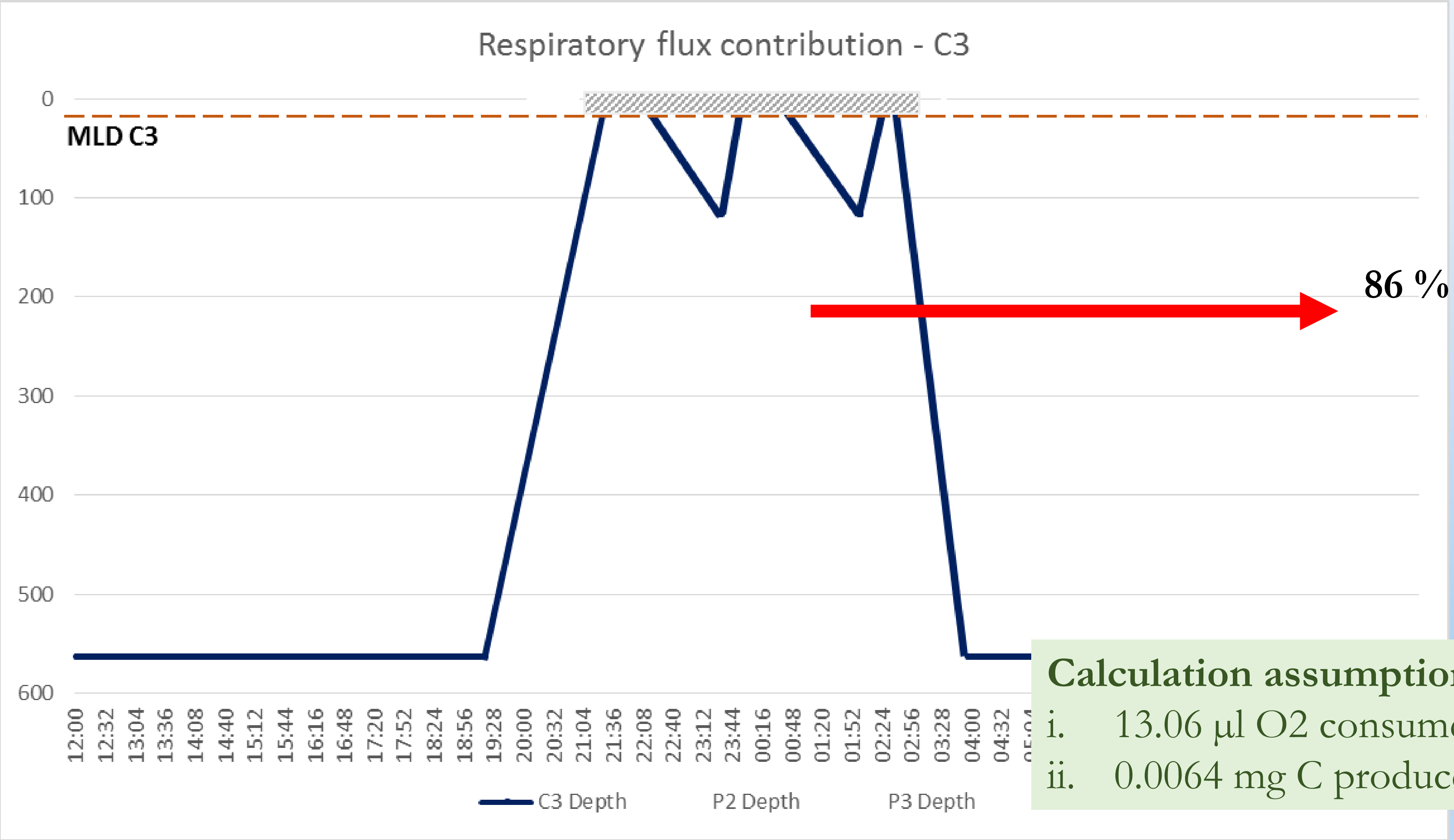


Mean respiration (O_2 consumption) rate of 13.06 µl ind^{-1} h^{-1} = 0.0064 mg C ind^{-1} h^{-1}

Assumptions:

i. Initial ascent at 4.2 m min^{-1}
ii. 30 mins feeding
iii. 90 mins gut passage & passive sinking at 1.3 m min^{-1}
iv. ~28 mins ascent at 4.2 m min^{-1}
v. Final active descent at 6.6 m min^{-1}

Calculating respired carbon flux



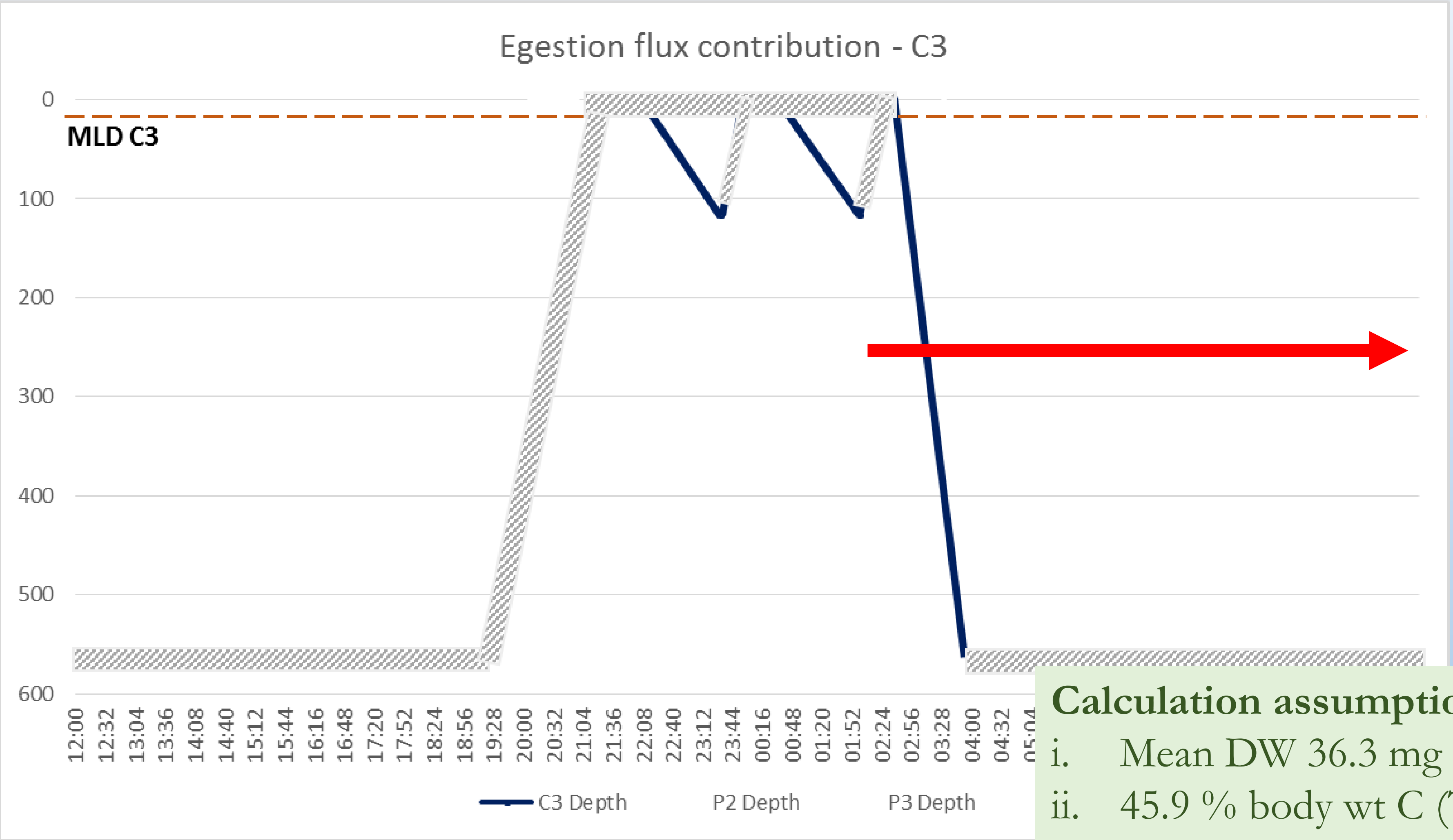
86 % time (20.6 hrs) respiring is below the MLD
= DOC flux

Calculation assumptions:

i. 13.06 µl O2 consumed ind^{-1} h^{-1}

ii. 0.0064 mg C produced ind^{-1} h^{-1}

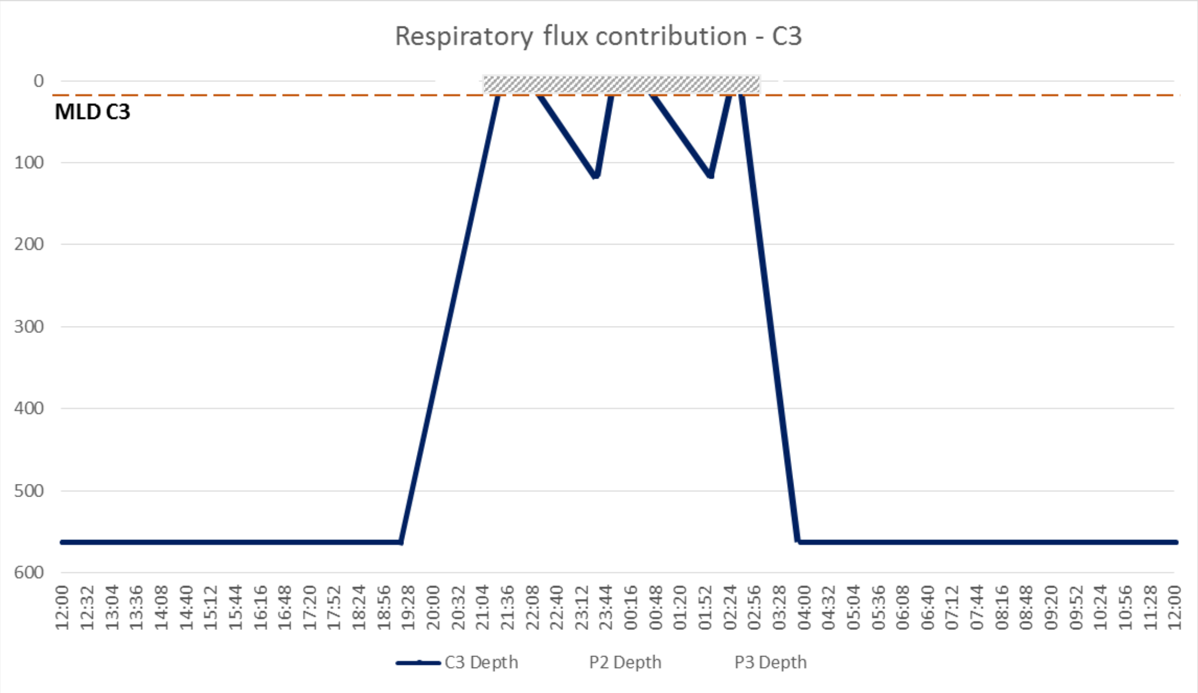
Calculating egested carbon flux

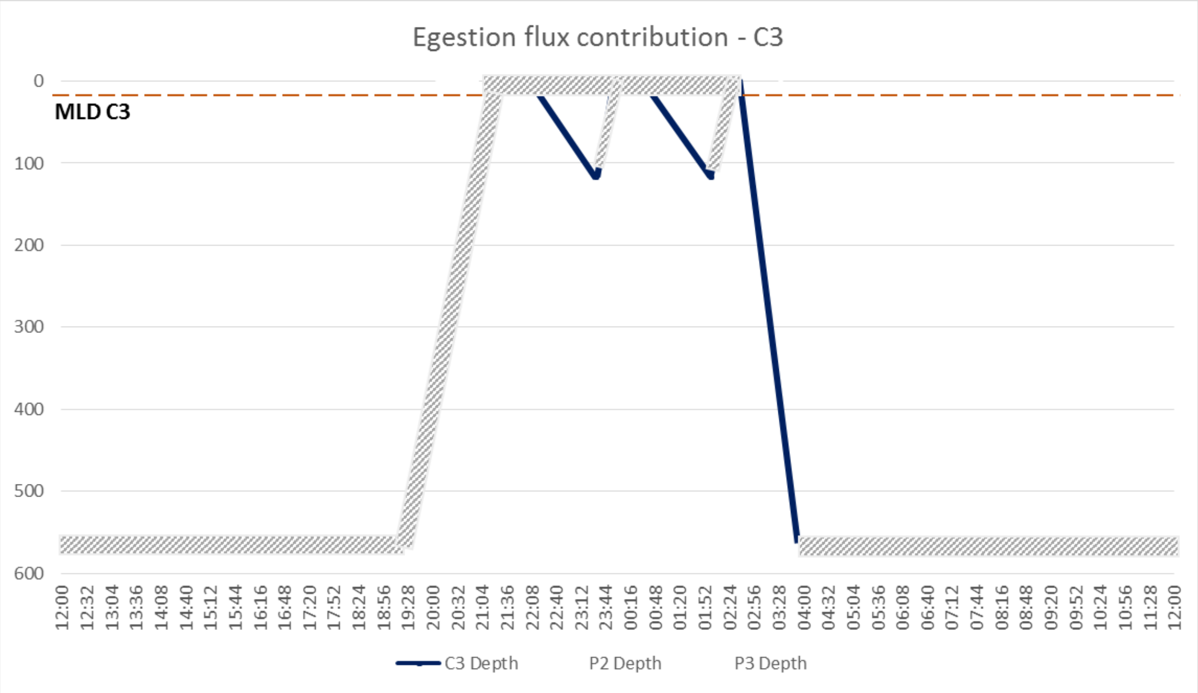


64 % time spent egesting is spent below the MLD = POC flux

Calculation assumptions:

i. Mean DW 36.3 mg
ii. 45.9 % body wt C (Torres et al, 1994)
iii. 15 % body C wt ingested (Pakhomov, 2002)
iv. 60-80 % assimilated; 40-20 % egested

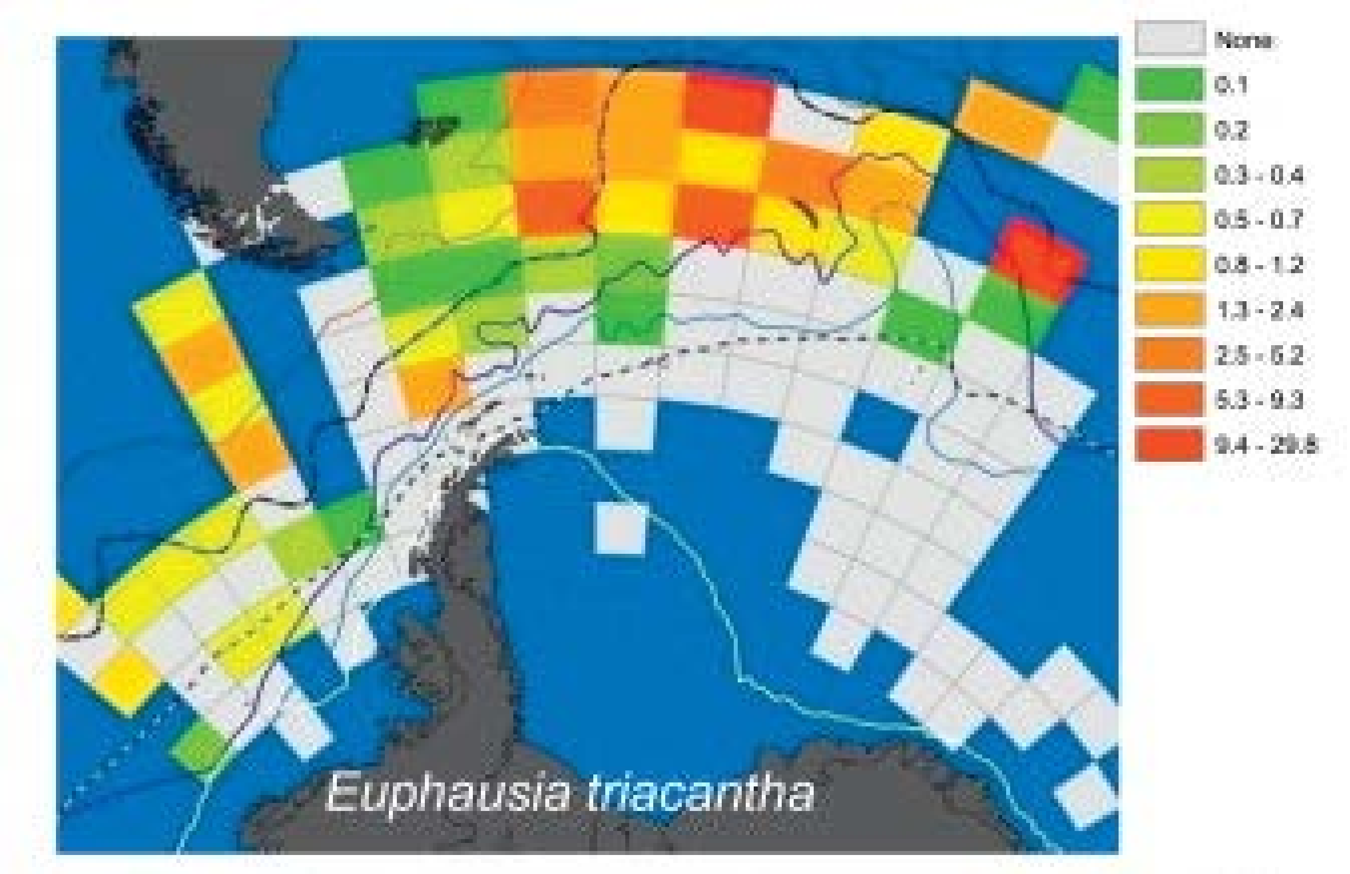




Respiratory flux		
C ind^{-1} d^{-1}	0.132	mg

Egestion flux		
C ind^{-1} d^{-1}	0.318 - 0.636	mg

Scaling to abundance and distribution in Scotia Sea



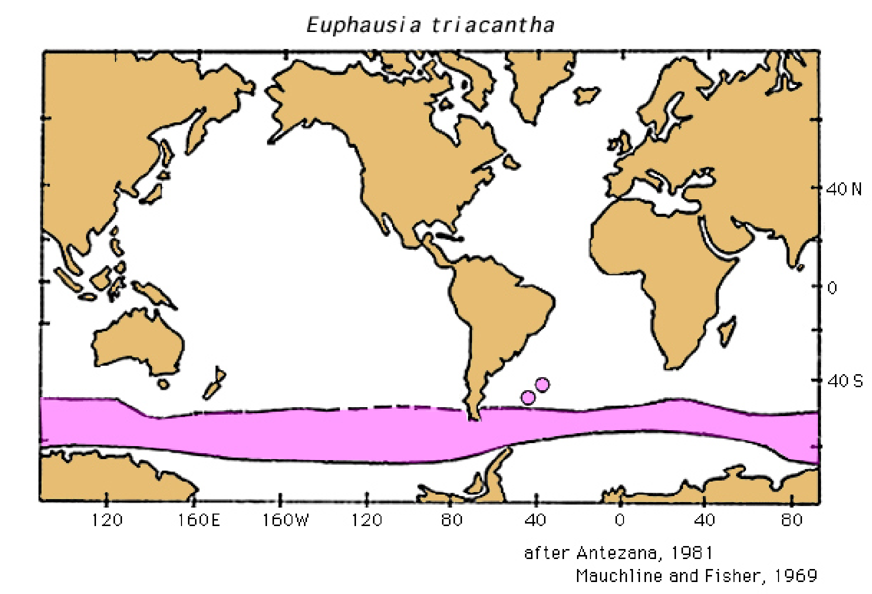
Distribution of *E. triacantha* in Scotia Sea. Data are means of all stations lying within each 2° by 5° grid cell. Blue cells contain no data.
Source: http://dx.doi.org/10.1016/j.dsr2.2011.08.011

- > 8.5 billion individuals
- Mean abundance 1 ± 4 m^{-2}
- Range: 0 – 30 inds m^{-2}
- Total area: 7,125,727 km^{-2}

What does this mean for total active flux?

Respiratory flux		
C ind^{-1} d^{-1}	0.132	mg
C m^{-2} y^{-1}	56.14	mg
Total flux for SS	400.1	tonnes y^{-1}
Total flux for SO	0.0014	Gt y^{-1}

Egestion flux		
C ind^{-1} d^{-1}	0.318 - 0.636	mg
C m^{-2} y^{-1}	136.1 - 272.2	mg
Total flux for SS	970 - 1,939	tonnes y^{-1}
Total flux for SO	0.0033 - 0.0066	Gt y^{-1}



SO distribution area: ≈24,335,757 km^{-2}

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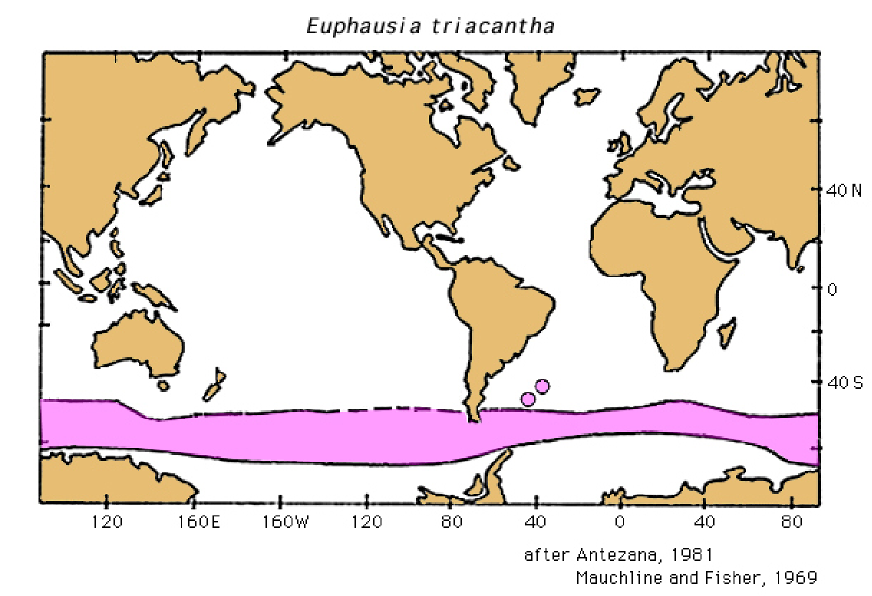

SO distribution area: ≈24,335,757 km^{-2}

192.2 – 328.3 mg C m^{-2} y^{-1} in Scotia Sea

Greater than for all seasonal migrants in North Atlantic:

274.5 mg C m^{-2} y^{-1} (Longhurst & Williams, 1992)

In conclusion

- *E. triacantha* are a significant component of migratory biomass in Scotia Sea
- Migratory amplitude is wide with evidence of foray behaviour below MLD
- Total active C flux from respiration and egestion over *E. triacantha* SO distribution could be as much as 0.008 Gt C y^{-1}, more than 4 times the flux from seasonal migrants in the North Atlantic

Active flux from migrating zooplankton can be a significant contributor to total C flux in open ocean regions

Thank you!

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