Estimates of Rates of Biological Productivity at BATS: Is there convergence?

Rachel H. R. Stanley

Woods Hole Oceanographic Institution

Outline

1) Introduction to Bermuda Atlantic Time-series Site (BATS)

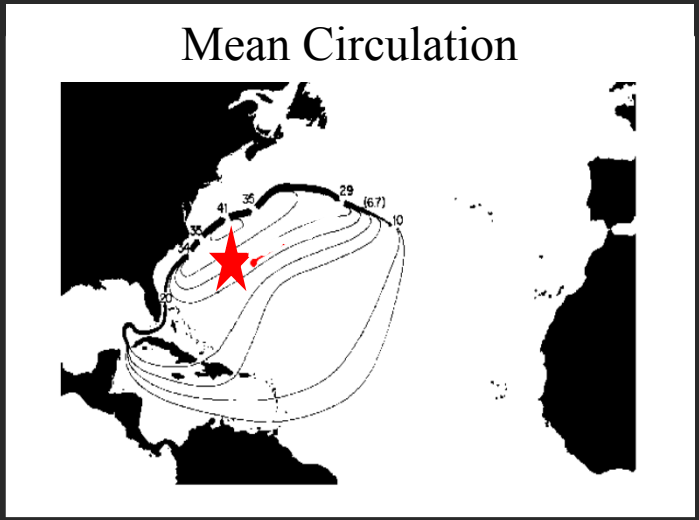
2) A Tour of Primary Production Rate Measurements

3) What could be cause for disagreement?

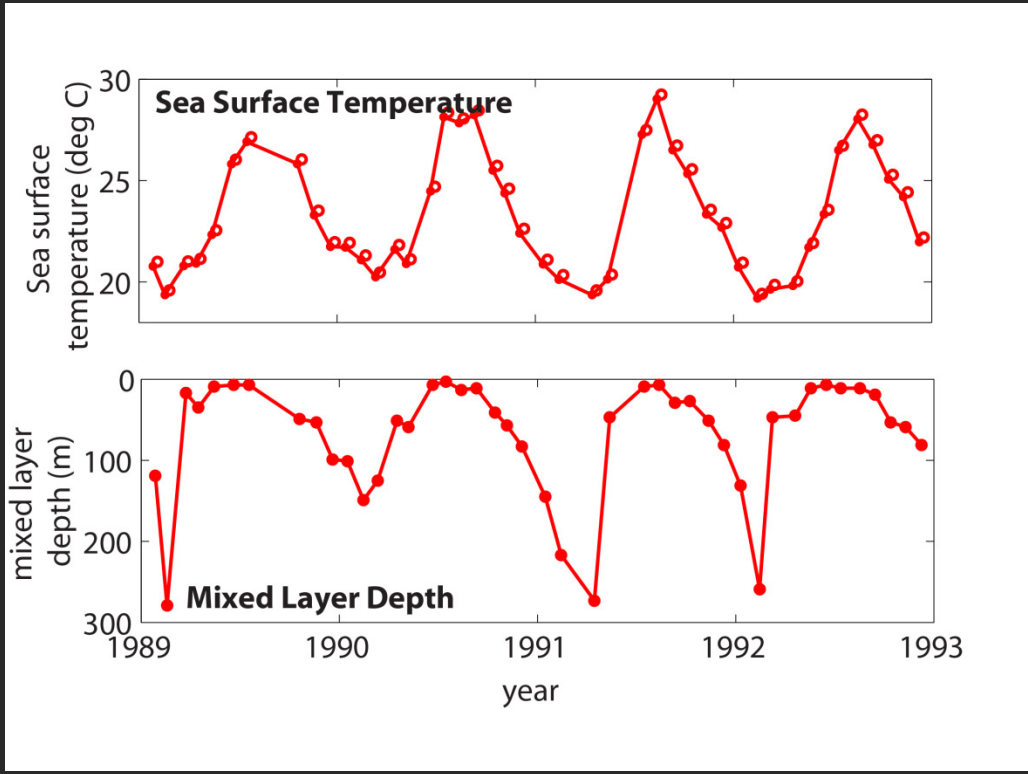
4) Research Highlight: Submesoscale Variability in Primary Production

Bermuda Atlantic Time-series Site

- BATS (red star) located in oligotrophic, subtropical North Atlantic
- Strong seasonal cycle, deep winter mixing

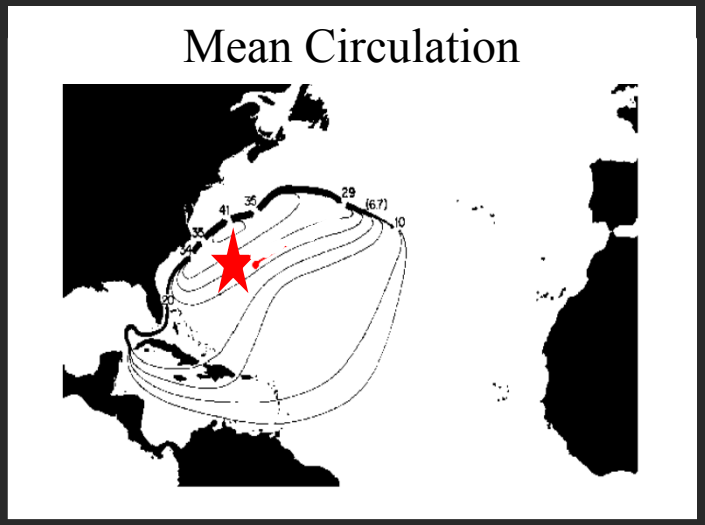


From Worthington, 1976

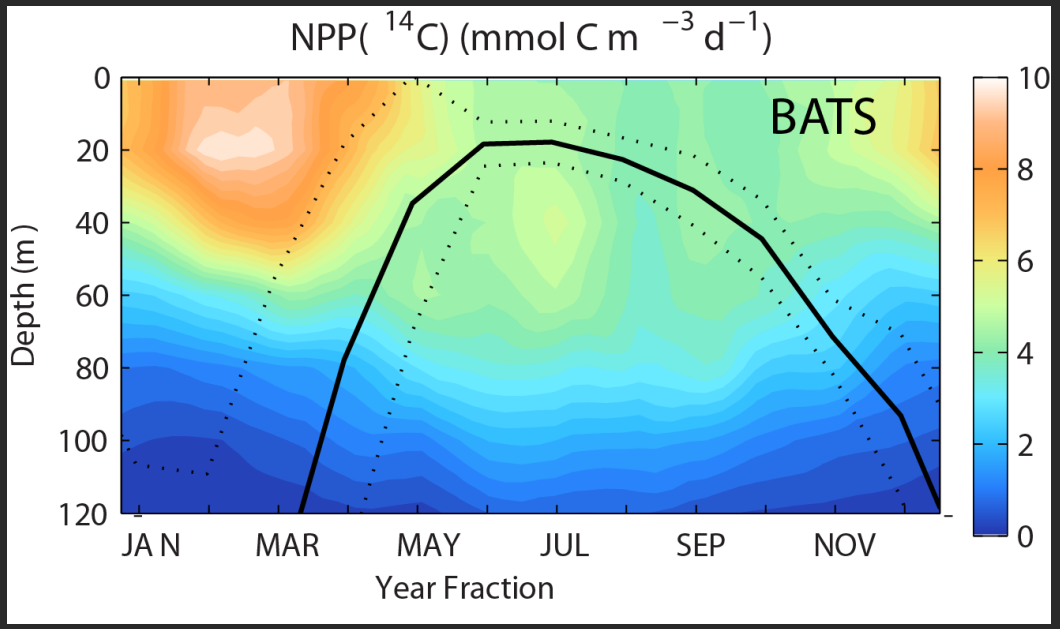


Bermuda Atlantic Time-series Site

- BATS (red star) located in oligotrophic, subtropical North Atlantic
- Strong seasonal cycle, deep winter mixing → seasonal cycle in primary productivity



From Worthington, 1976



From Nicholson et al., 2012

Vocabulary Primer

- Gross Primary Production (GPP): Total photosynthetic flux.
- Net Primary Production (NPP): Photosynthesis minus autotrophic respiration
- Net Community Production (NCP): Photosynthesis minus autotrophic and heterotrophic respiration
- New Production: Fueled by input of new nutrients into euphotic zone
- Export Production: Flux of organic matter that leaves euphotic zone

Over long temporal and spatial scales:

$$NCP = New = Export \ll NPP$$

Net Primary Production: ^{14}C Bottle Incubations

Technique:

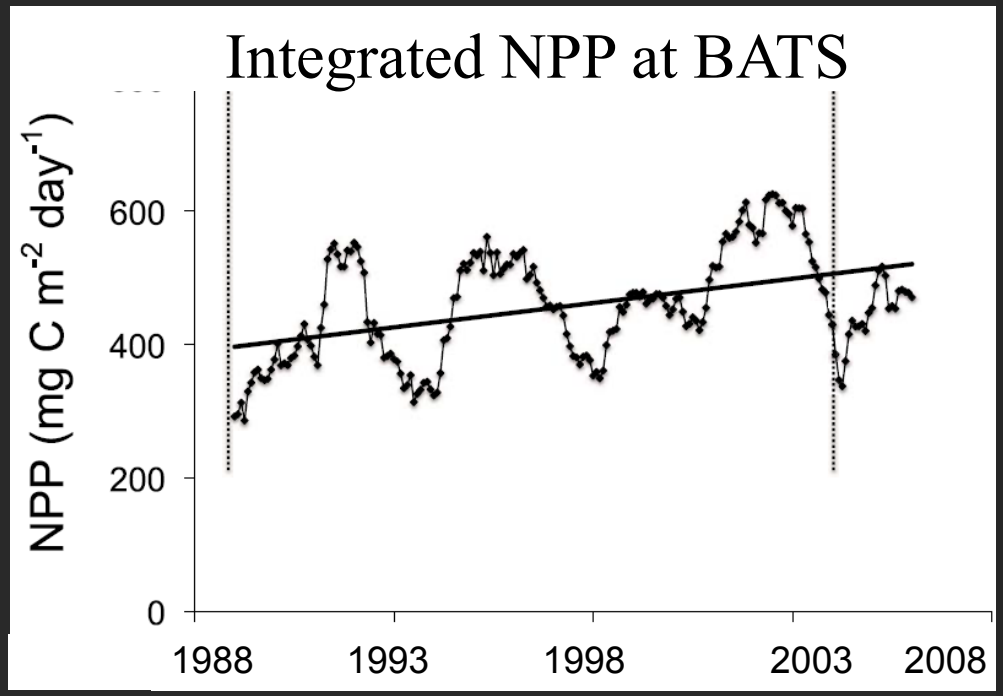
- ^{14}C bottle incubation from dawn to dusk and integrate to depth of euphotic zone

- Issues: bottle effects, rates between NPP and GPP, DOC

Results:

- Annual average
  = 14 mol C m^{-2} y^{-1}

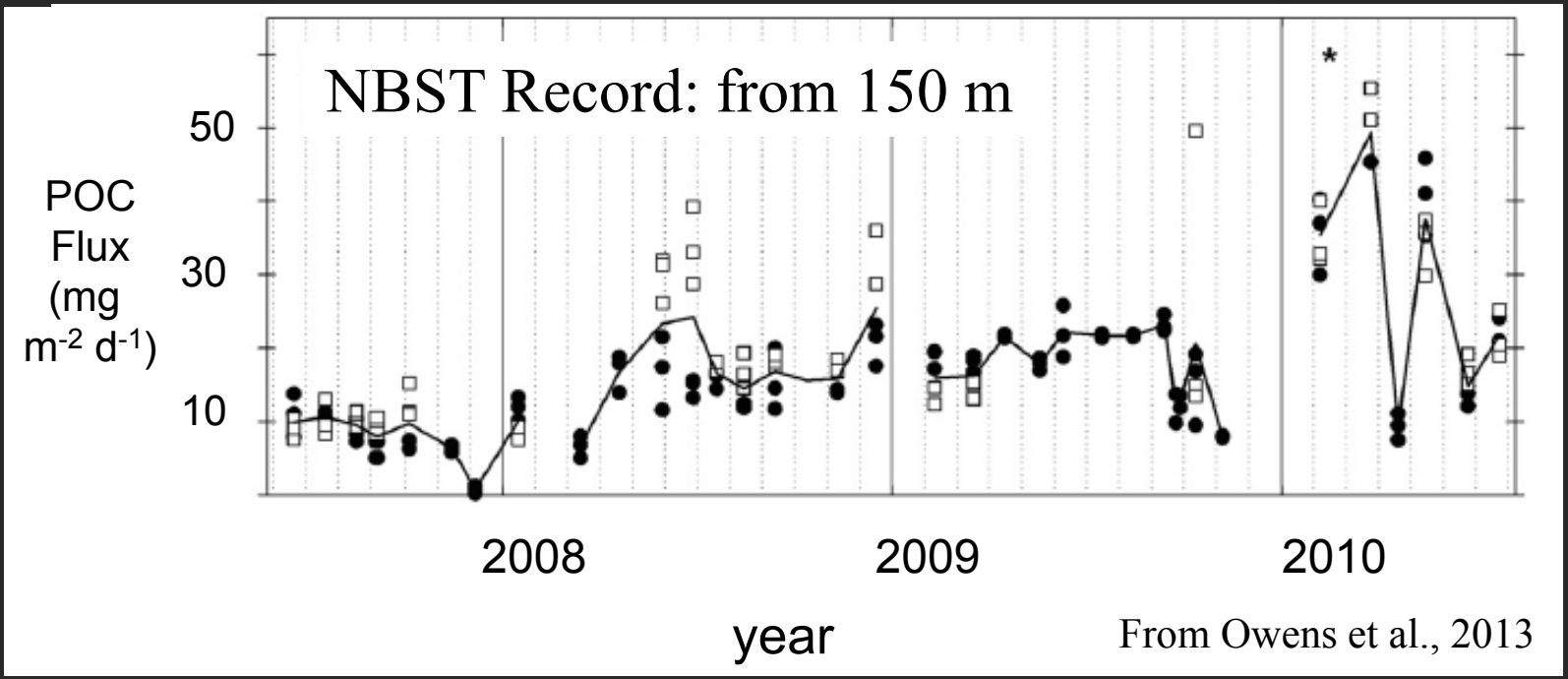
- NPP can be combined with estimates of export production to calculate an e-ratio



From Saba et al., 2010

Export Production: Sediment Traps

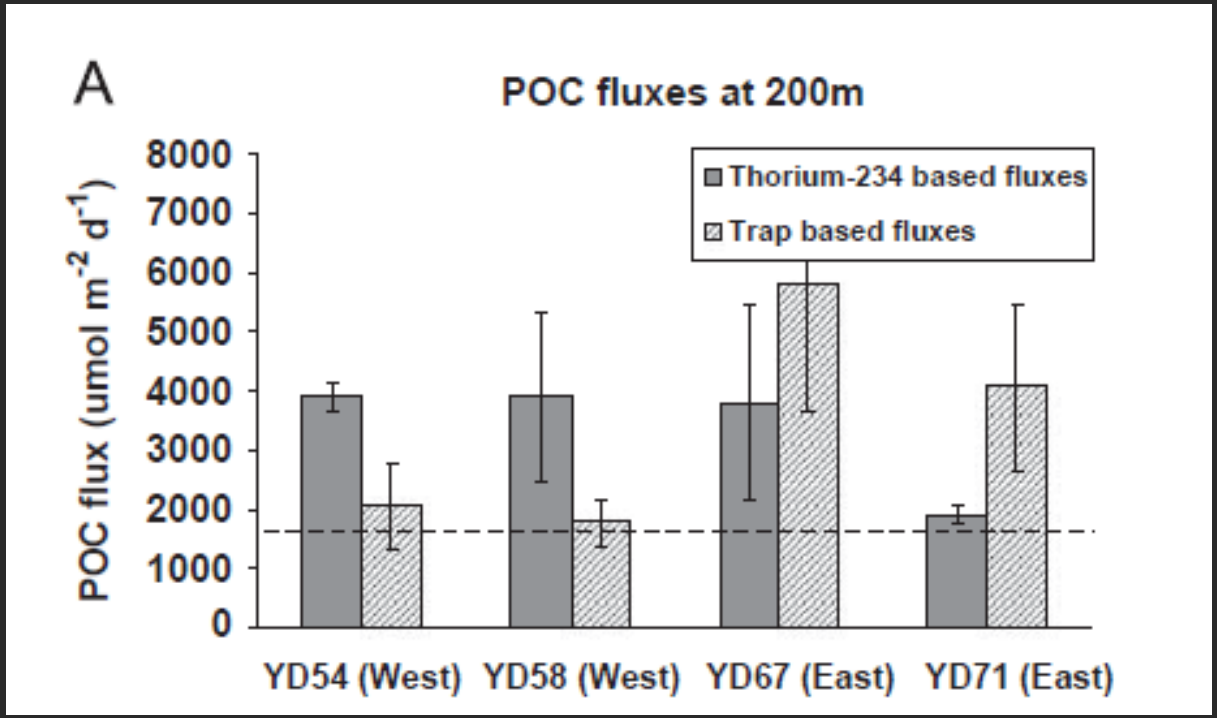
- Technique: similar to rain gauge, either tethered (PITs) or neutrally buoyant (NBST). Deployed at 150, 300 and 500 m.
- Issues: swimmers, no DOC or zooplankton migration, hydrodynamic biases
- NBSTs shown to collect slightly smaller fluxes than PITs (Owens et al 2013)
- POC flux at 150 m annual avg: 0.3 to 0.8 mol C m^{-2} y^{-1}



From Owens et al., 2013

Export Production: ^{234}Th

- Technique: water column disequilibrium between particle-reactive ^{234}Th ($t_{1/2}$=24 days) and conservative ^{238}U. Could use instead ^{210}Po.
- Issues: POC/^{234}Th ratio, doesn't include DOC or zooplankton migration
- Annual Average: ?????.

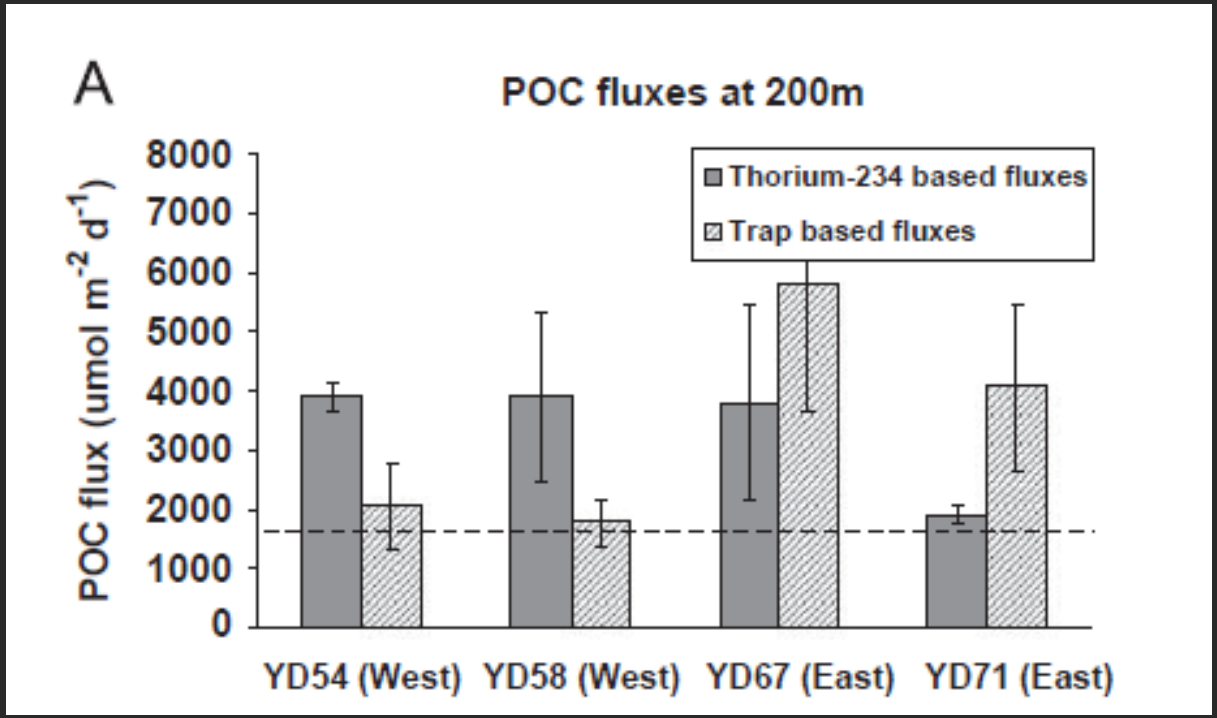


From Maiti et al 2009

Usually within a factor of 2 of sediment traps, sometimes greater and sometimes smaller

Export Production: ^{234}Th

- Technique: water column disequilibrium between particle-reactive ^{234}Th ($t_{1/2}$=24 days) and conservative ^{238}U. Could use instead ^{210}Po.
- Issues: POC/^{234}Th ratio, doesn't include DOC or zooplankton migration
- Annual Average: 0.3 to 0.8 mol C m^{-2} y^{-1}

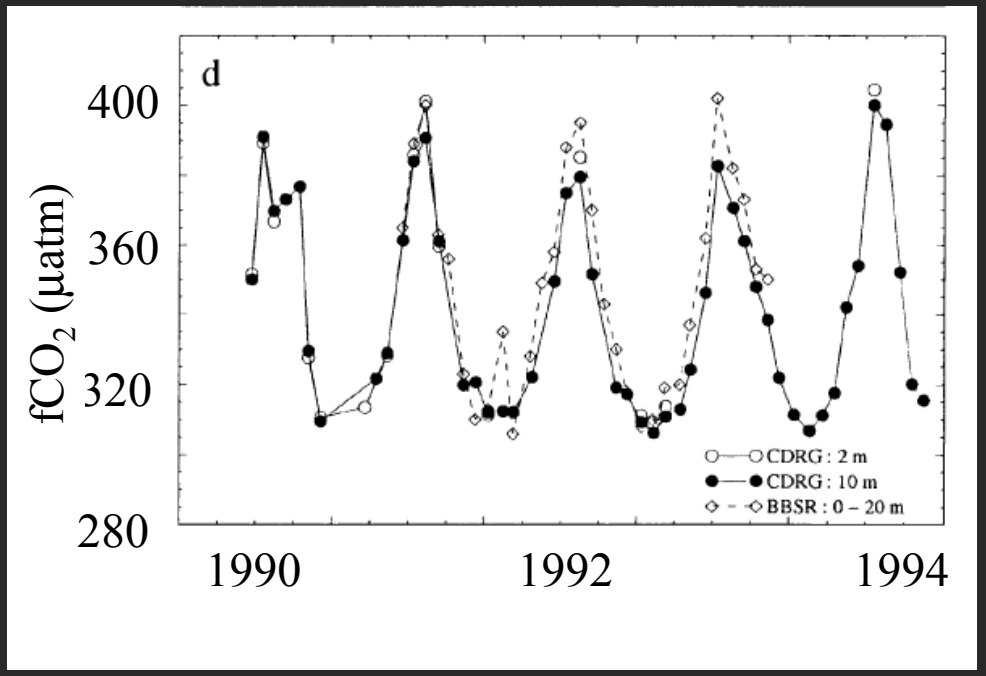


Usually within a factor of 2 of sediment traps, sometimes greater and sometimes smaller

From Maiti et al 2009

Net Community Production: DIC

- Technique: seasonal pattern in $\delta^{13}C$ or DIC – photosynthesis draws down pCO_2 and increases $\delta^{13}C$ of DIC
- Issues: physical transport, assumptions about winter
- Annual Average: 2.3 to 4.9 mol C m^{-2} y^{-1}
  Gruber et al, 1998, Brix et al., 2006, Fernandez-Castro et al, 2012

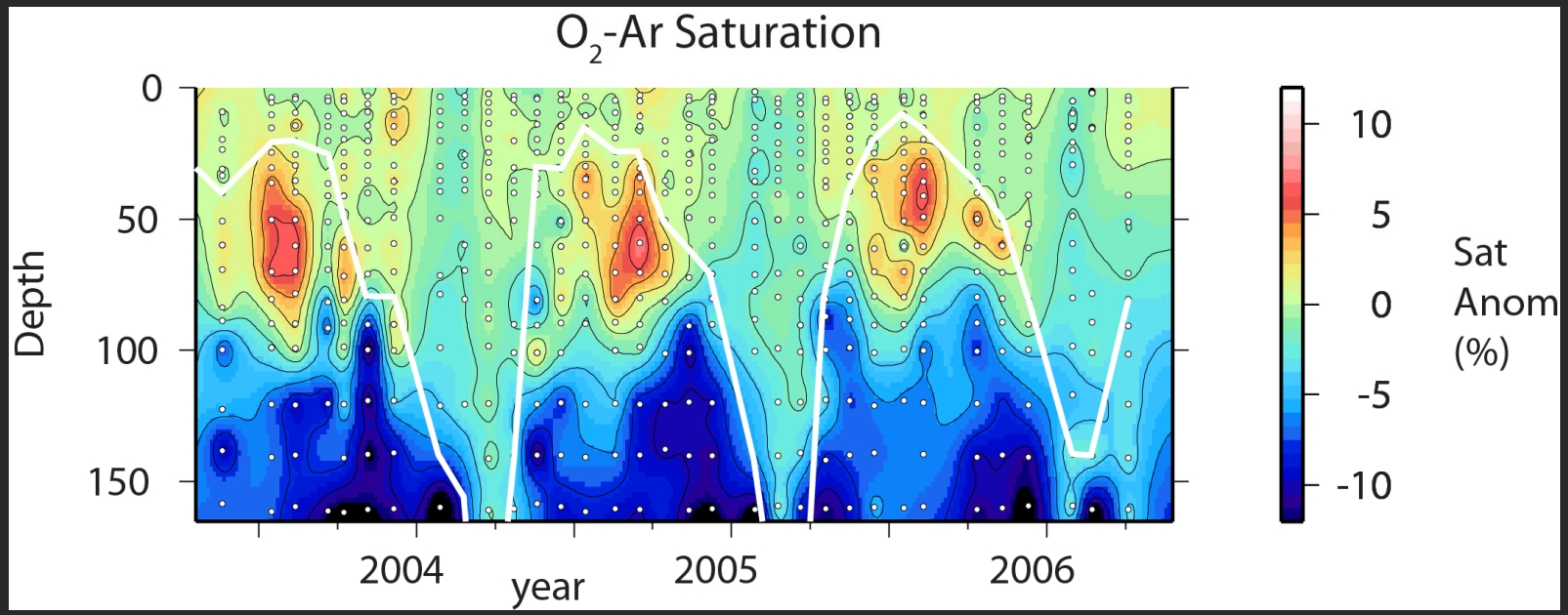


From Gruber et al., 1998

Net Community Production: O_2/Ar

- Technique: O_2 produced by photosynthesis and consumed by respiration, Ar is abiotic and used to correct for physics. Measure over seasonal cycle in mixed layer or below.
- Issues: physical transport, air-sea gas exchange, assumptions about winter
- Annual Average: 1.2 to 2.4 mol C m^{-2} y^{-1} from this data;
  2.2 to 3 mol C m^{-2} y^{-1} from other studies

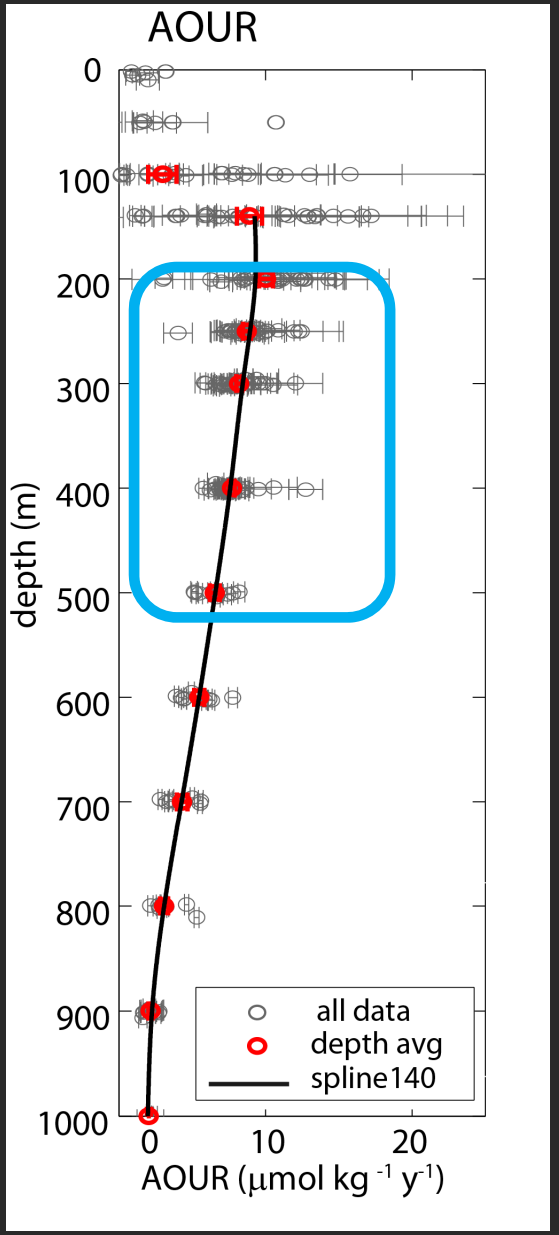
Luz et al 2009
Spitzer and Jenkins 1988



Updated from Stanley et al, 2007

Export Production: AOUR

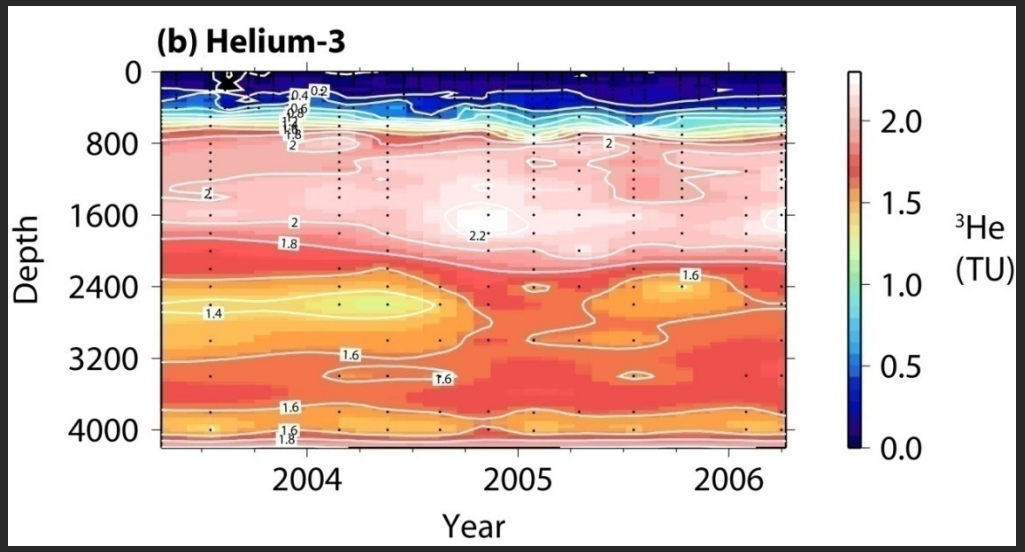
- Technique:
  - Respiration consumes O_2.
  - AOU = $[O2]_{sat} - [O2]_{meas}$ = measure of how much O_2 is consumed
  - Use T/^{3}He as clock to determine age of water
  - → Apparent Oxygen Utilization Rate
- Issues: Large spatial scale, When was the O_2 used? Below 500 m questions on Tritium source function.
- Annual export between 200 and 500 m = 2.1 ± 0.5 mol C m^{-2} y^{-1}



From Stanley et al., 2012

New Production: ^{3}He Flux Gauge

- Technique:
  - Upwelled water brings ^{3}He into mixed layer
  - Calculate ^{3}He flux.
  - Relate to NO_3 flux by correlation of ^{3}He and nitrate.

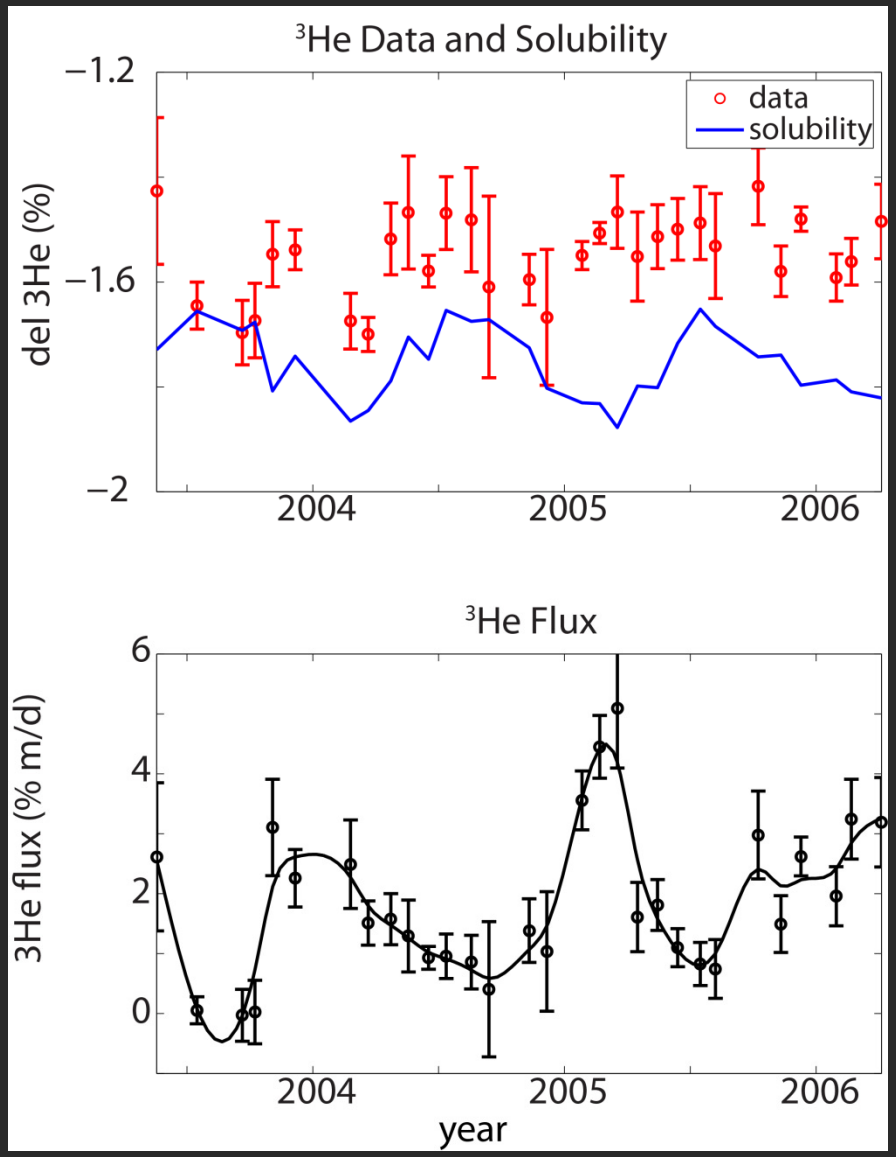


- Issues: Air-sea gas exchange including bubbles, correlation with nitrate, C:N ratios, region estimate represents

- Annual average = 8.7 ± 0.3 mol C m^{-2} y^{-1}

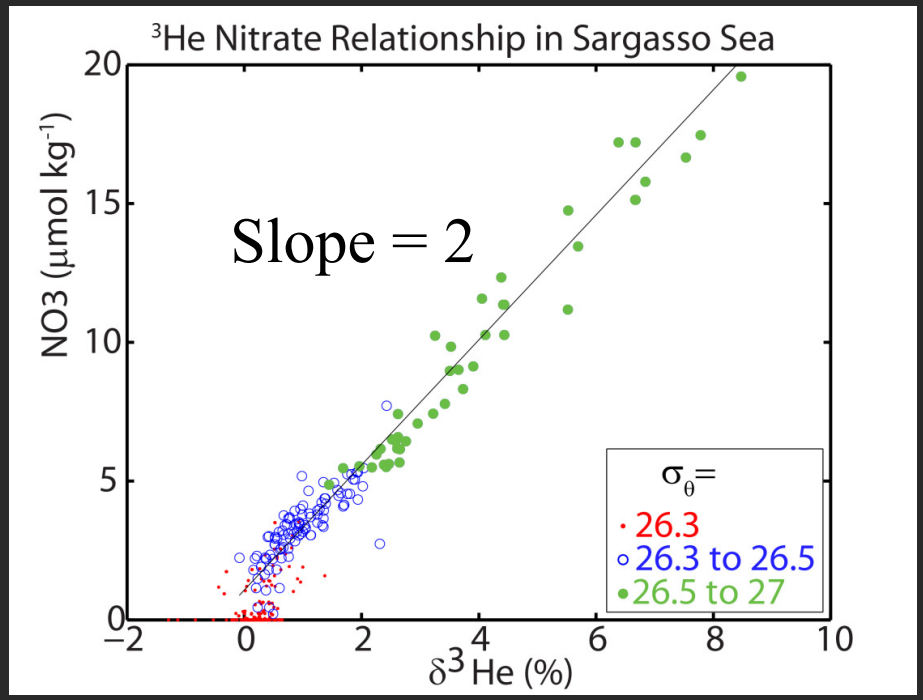
New Production: ^{3}He Flux Gauge

- Technique:
  - Upwelled water brings ^{3}He into mixed layer
  - Calculate ^{3}He flux.
  - Relate to NO_3 flux by correlation of ^{3}He and nitrate.
- Issues: Air-sea gas exchange including bubbles, correlation with nitrate, C:N ratios, region estimate represents
- Annual average = 8.7 ± 0.3 mol C m^{-2} y^{-1}



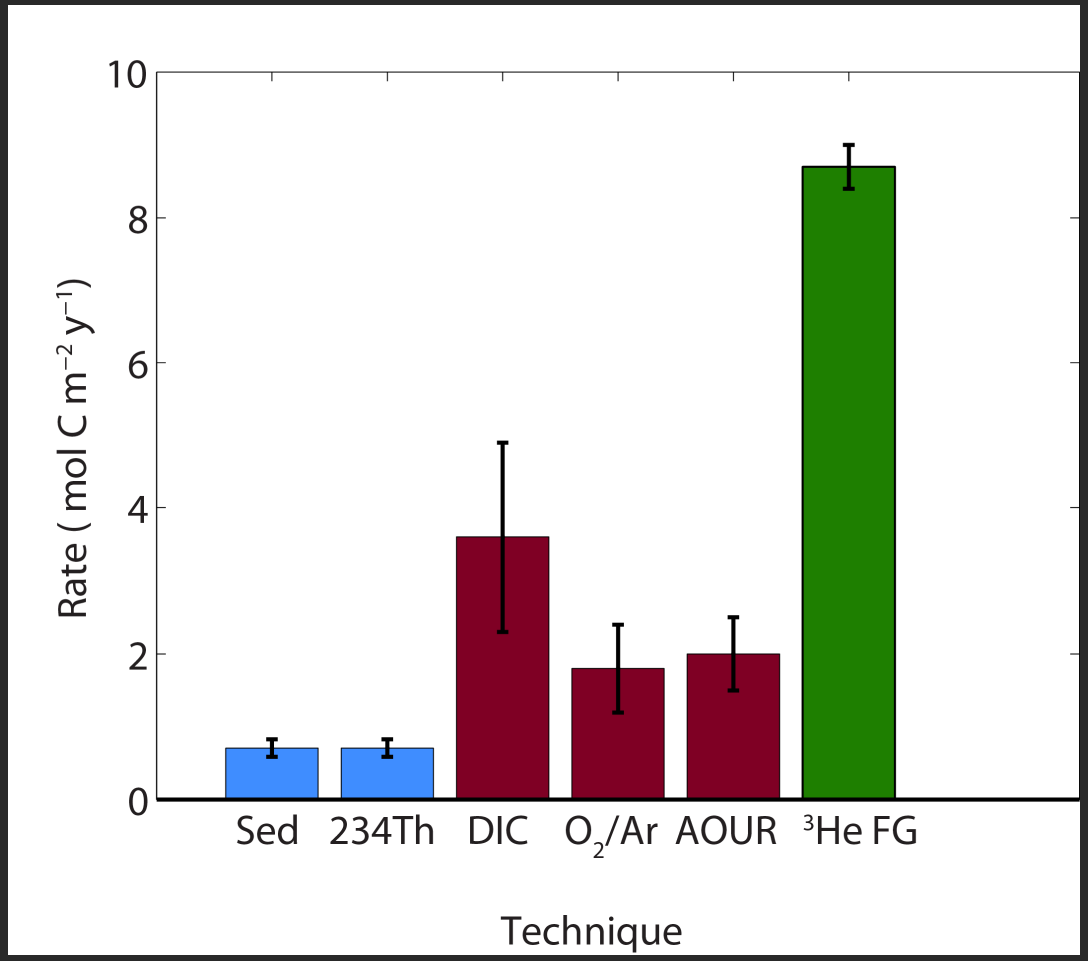
New Production: ^{3}He Flux Gauge

- Technique:
  - Upwelled water brings ^{3}He into mixed layer
  - Calculate ^{3}He flux.
  - Relate to NO_3 flux by correlation of ^{3}He and nitrate.
- Issues: Air-sea gas exchange including bubbles, correlation with nitrate, C:N ratios, region estimate represents
- Annual average = 8.7 ± 0.3 mol C m^{-2} y^{-1}



Represents N half of subtropical gyre. Decoupling of ^{3}He and NO_3 during obduction.

How do they stock up?



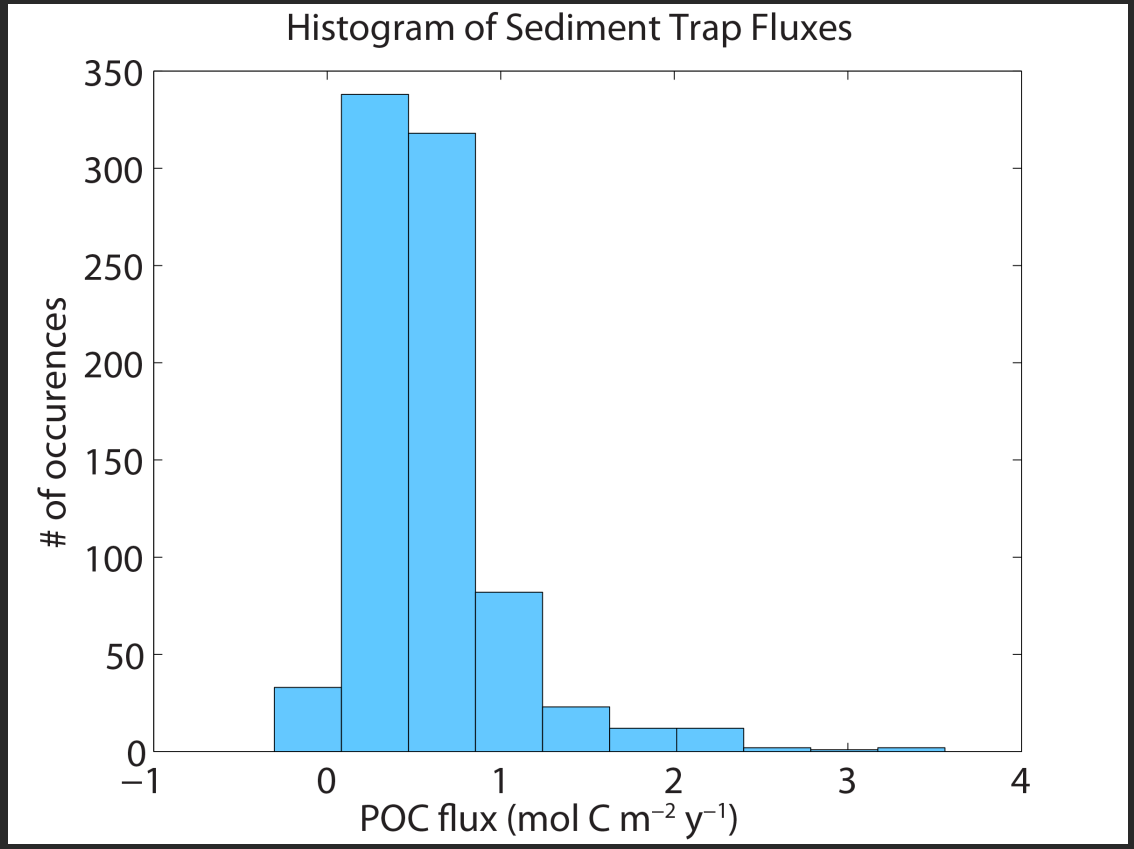
- If sediment/^{234}Th is right, then
  e-ratio = 2 to 5%
- If DIC, O_2/Ar, and AOUR right, then e-ratio = 12 to 25%
- Which is it?

1) O_2/Ar and triple oxygen isotopes → e-ratio = 25% (Luz and Barkan 2009)
2) Laws et al. 2011 → e-ratio=11 to 23%

Why the discrepancies?

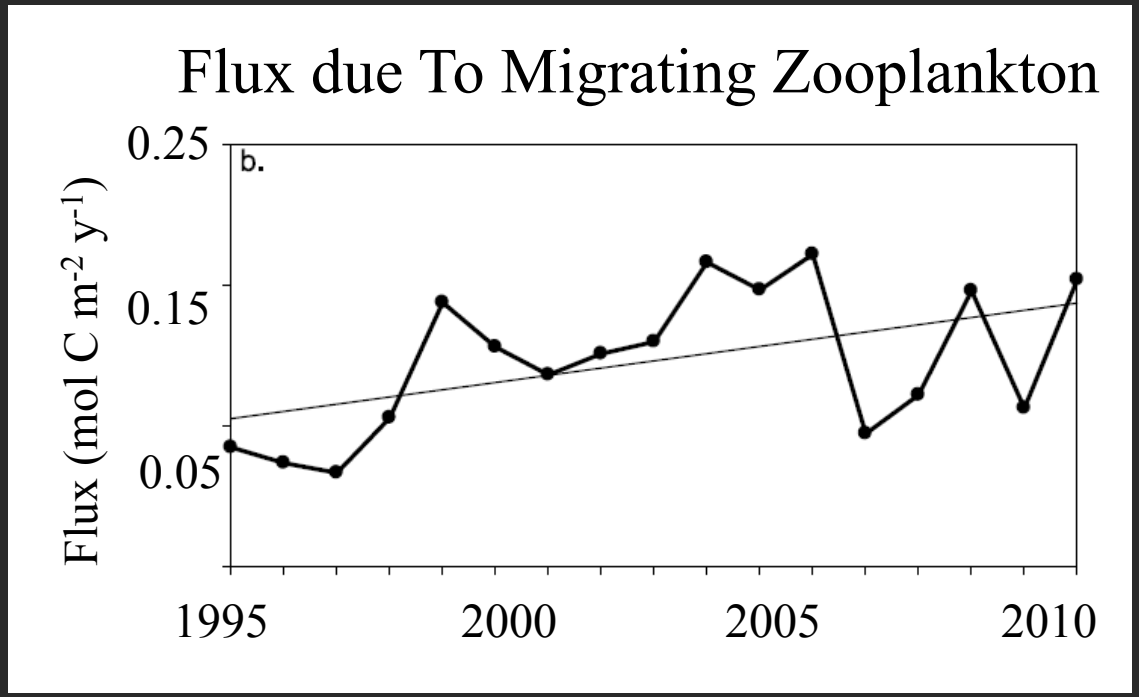
- Timescales of Measurement
  - Sediment Traps = several days
  - ^{234}Th = approx 1 month
  - Other tracers are seasonal or greater
  - Are traps and ^{234}Th missing high flux events?

But no sign of really high flux events in 25 year long record at BATS



Why the discrepancies?

- Zooplankton Migration
  - Not included in sediment traps and ^{234}Th
  - Estimate of export due to direct zooplankton migration is 0.05 to 0.15 mol C m^{-2} y^{-1} (Steinberg et al., 2012)



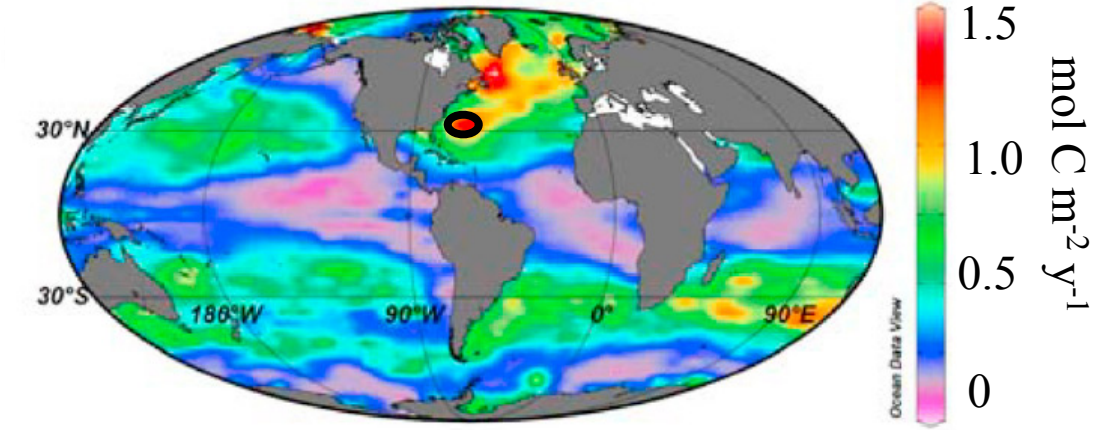
From Steinberg et al., 2012

Too Small To Explain Discrepency

Why the discrepancies?

- DOC
  - Not included in sediment traps and ^{234}Th
  - Estimate of fraction responsible for export in N Atl = 10 to 20% (Carlson et al. 2010)
  - DOC export in subtropical gyres, estimated at 1.0 to 1.2 mol C m^{-2} y^{-1} (Hansell et al. 2012)

Export of DOC



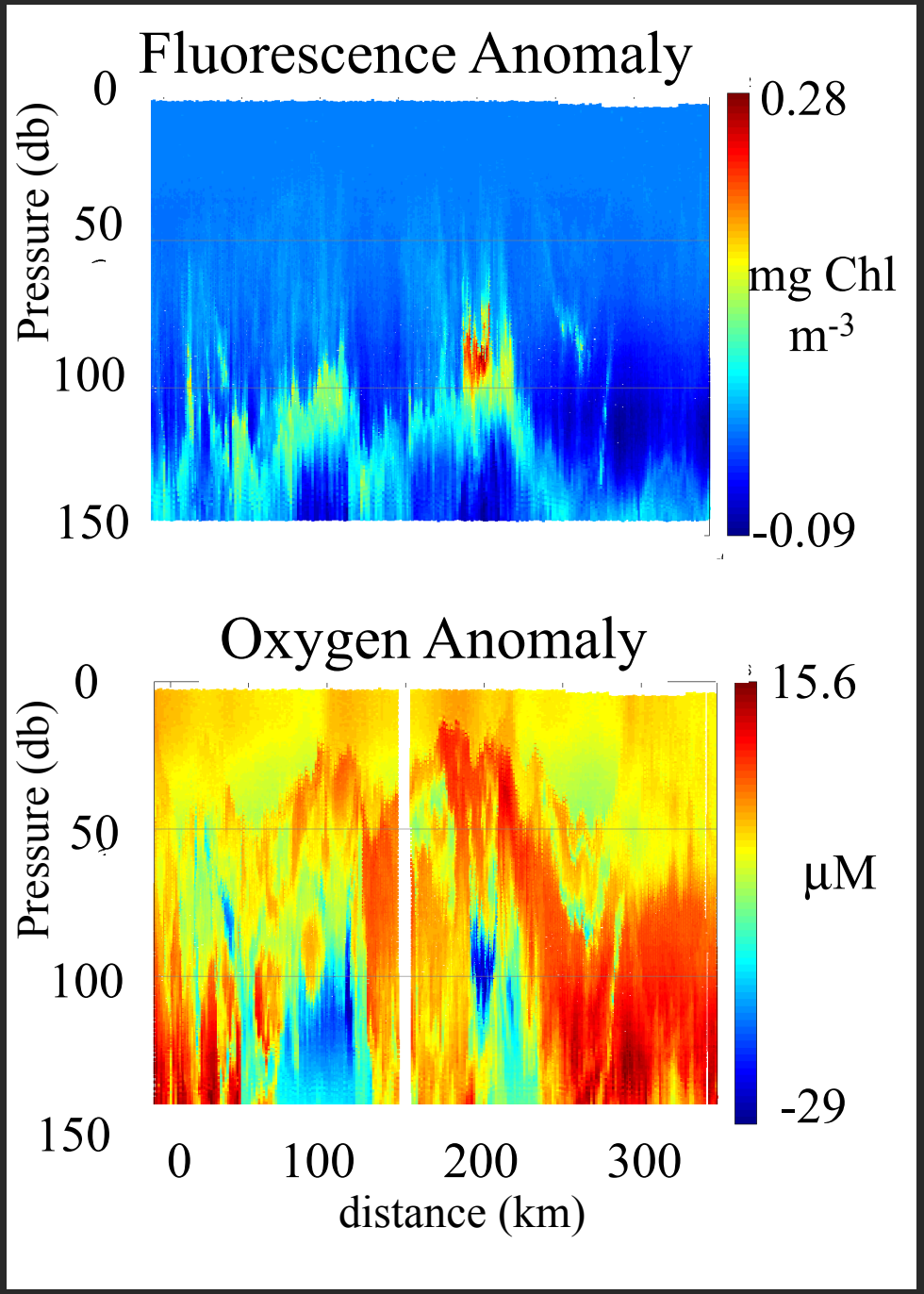
from Hansell et al. 2012

Most Promising Explanation So Far

Submesoscale Productivity

- Submesoscale "Hotspots" in production are ubiquitous, as observed by 2 km resolution, 140 m vertical profiles of fluorescence and O_2 from towed Video Plankton Recorder II
- Deep hotspots often represented as peaks in surface O_2/Ar record

This work was done by R. Stanley, D. McGillicuddy, and L. Anderson

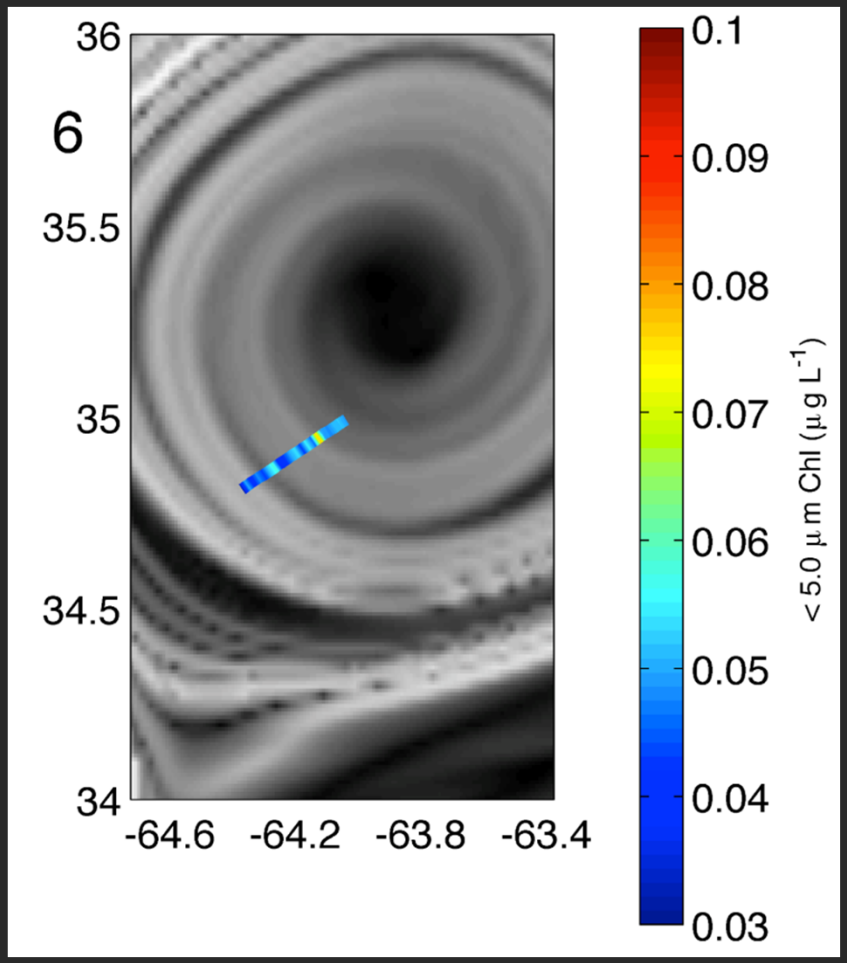


Submesoscale Productivity

- On two BATS validation cruises, we* measured NCP and export on several transects purposefully crossing submesoscale features

(we* = Buesseler, Siegel, Lomas, Nelson, Estapa, and Stanley)

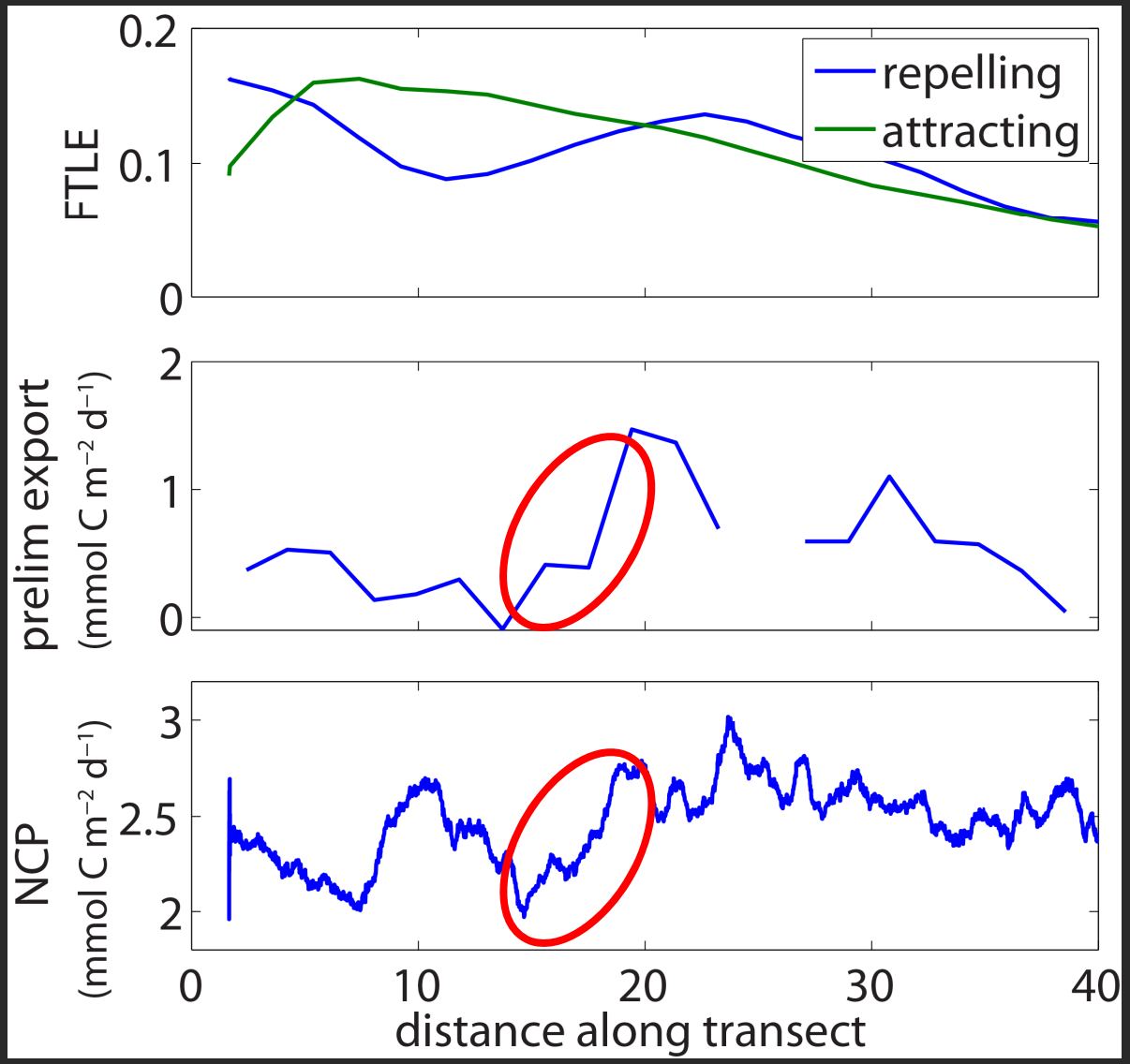
Grayscale: FFTLE ("repelling") surfaces (white = high)
Color: < 5.0 um Chlorophyll concentration



Submesoscale Productivity

- On two BATS validation cruises, we* measured NCP and export on several transects purposefully crossing submesoscale features

(we* = Buesseler, Siegel, Lomas, Nelson, Estapa, and Stanley)



Conclusions

- "Best Guess" of Export Flux at BATS = 2 to 4 mol C m^{-2} y^{-1}
  - Sediment traps and ^{234}Th too low because missing DOC
  - ^{3}He Flux Gauge → Can supply necessary nutrients. High because different region and decoupling of ^{3}He and NO_3
- e-ratio = 10 to 25%
- Fluxes are changing
  - Submesoscale variations can be large
  - Changing with time (Saba et al., 2010, Lomas et al. 2010)

Acknowledgements

- BATS Scientists and Technicians (past and present) have enabled this work to happen!

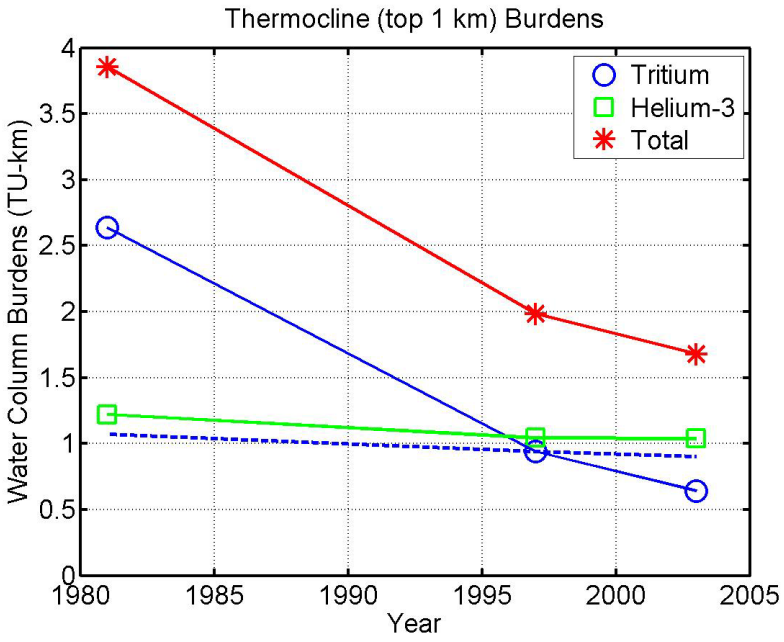
- Captain and crew of the *R/V Weatherbird II* and *R/V Atlantic Explorer*

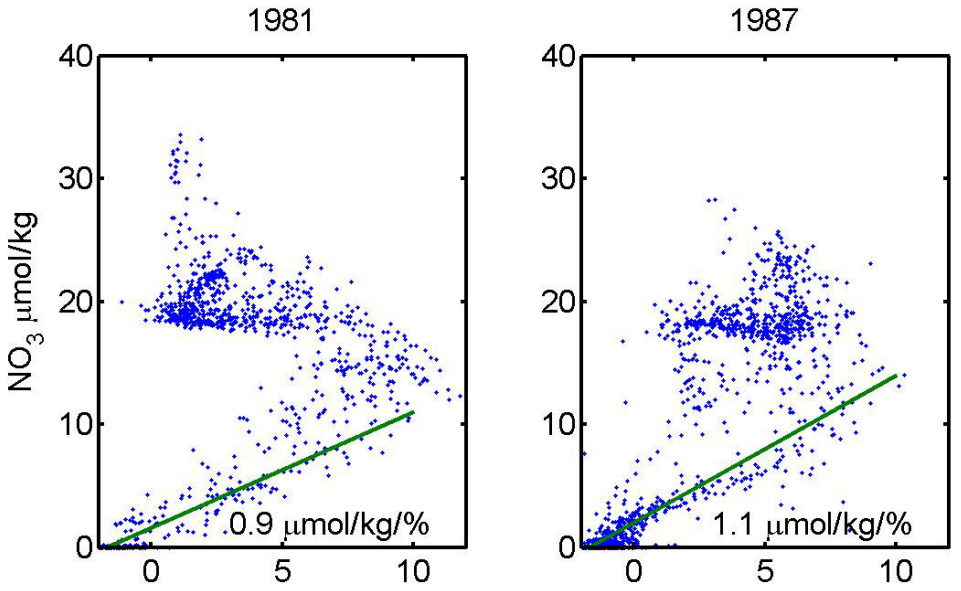
- National Science Foundation

Extra Slides

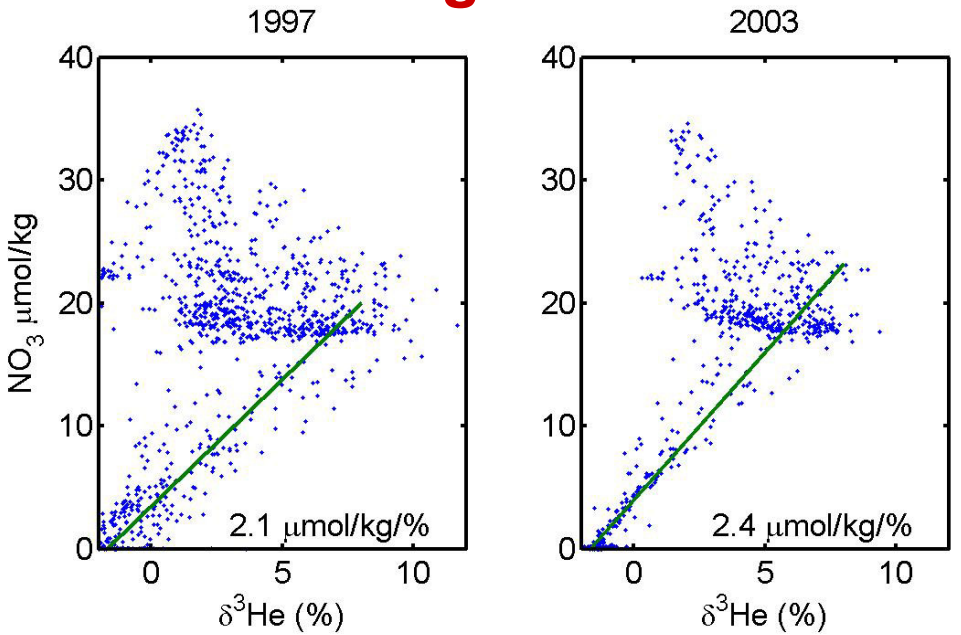
A good test…

The NO_3:^{3}He Slope is rotating counter-clockwise with time due to the evolving ^{3}He distribution

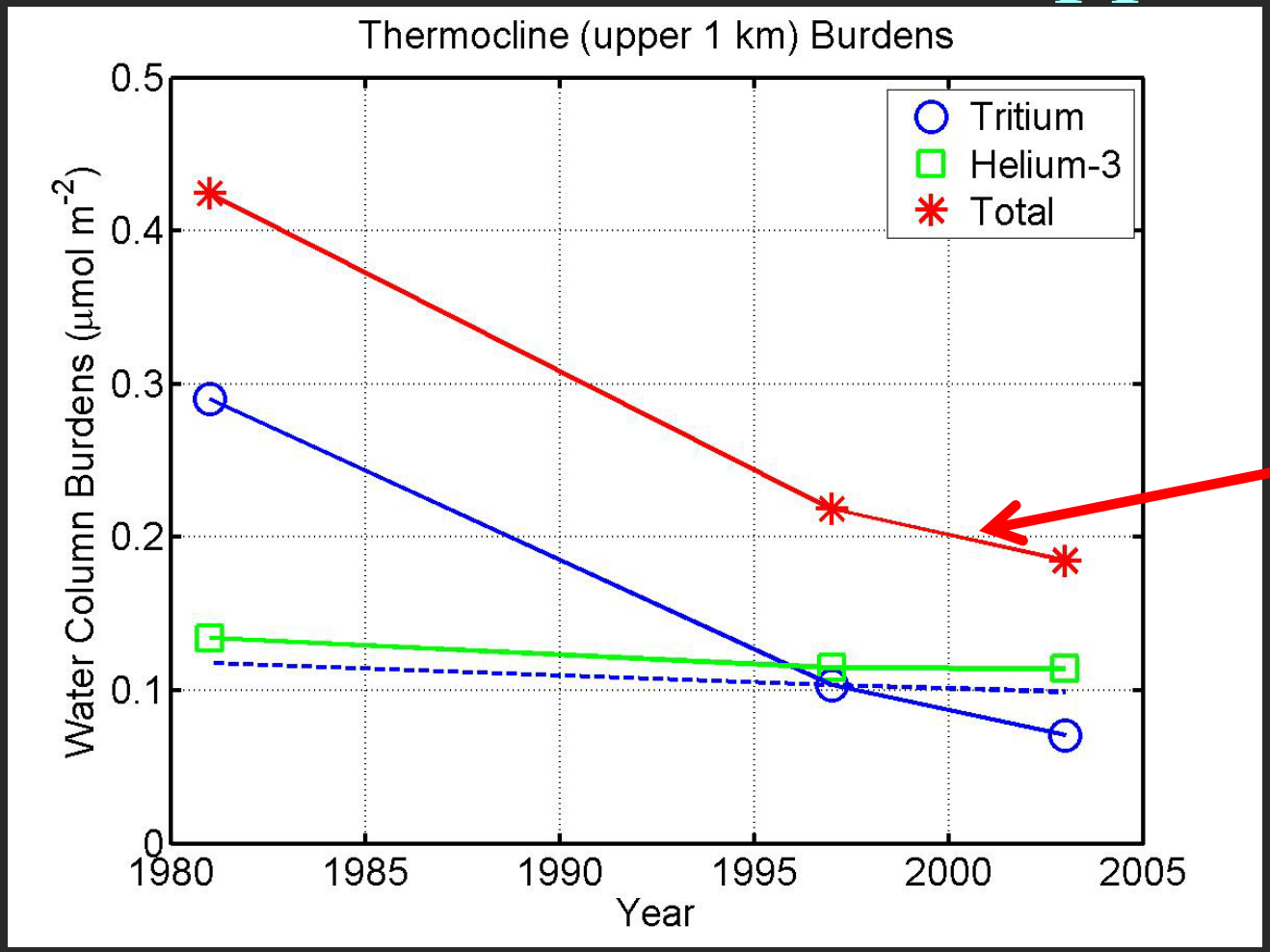




A 2-fold change over 2 decades



Is the ^{3}He flux supportable?



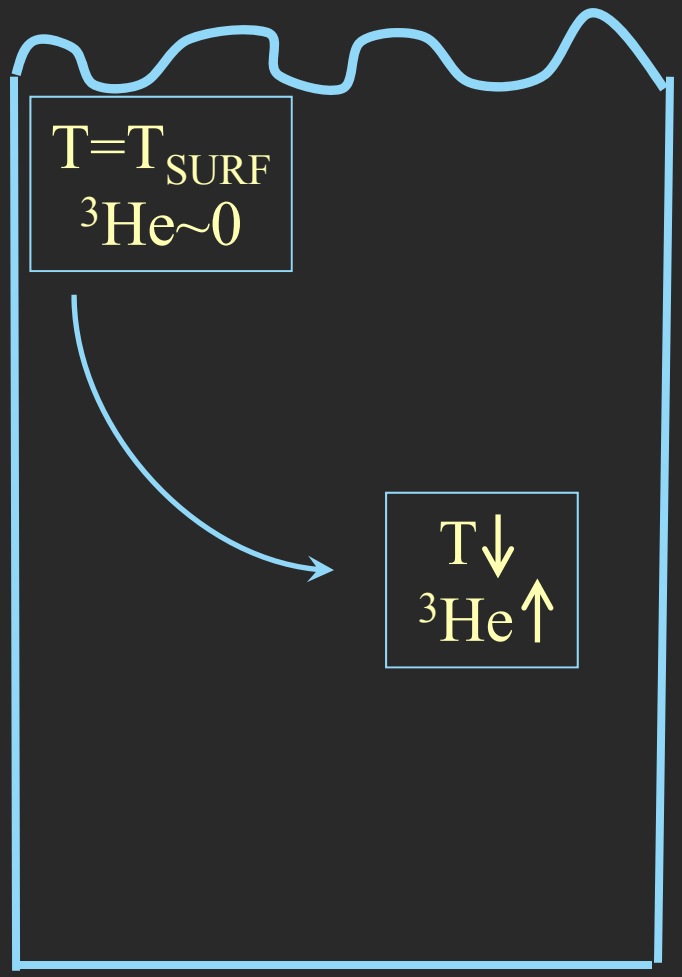
2 decades of inventory evolution

5.6 nmol m^{-2} y^{-1} = 0.18 amol m^{-2} s^{-1} over entire gyre

^{3}H + ^{3}He inventory change is equivalent to observed fluxes if outgassed over northern half of STG

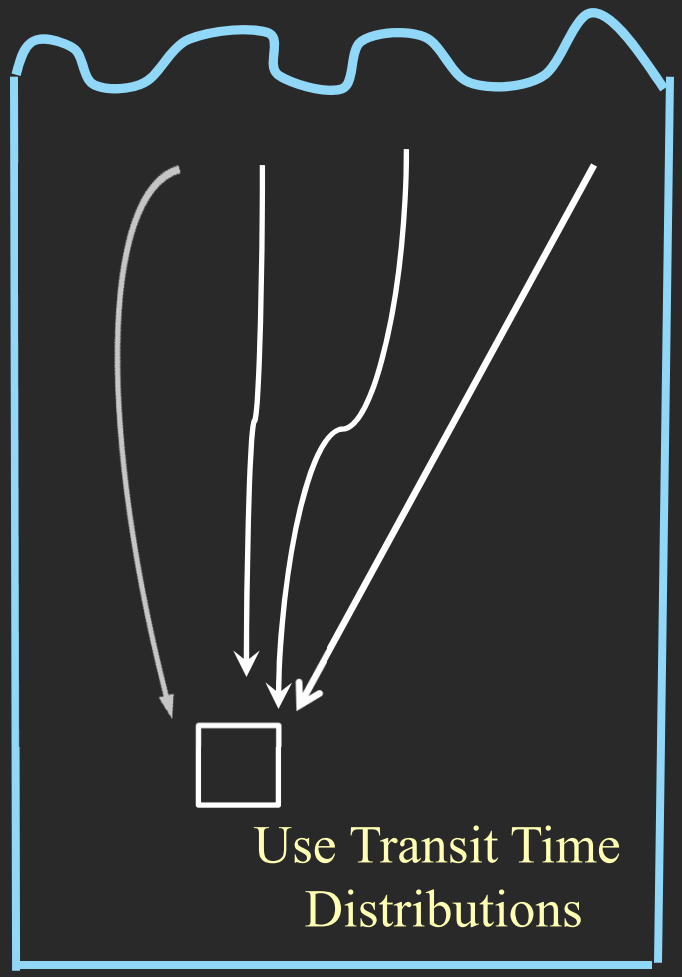
Export Production: AOUR

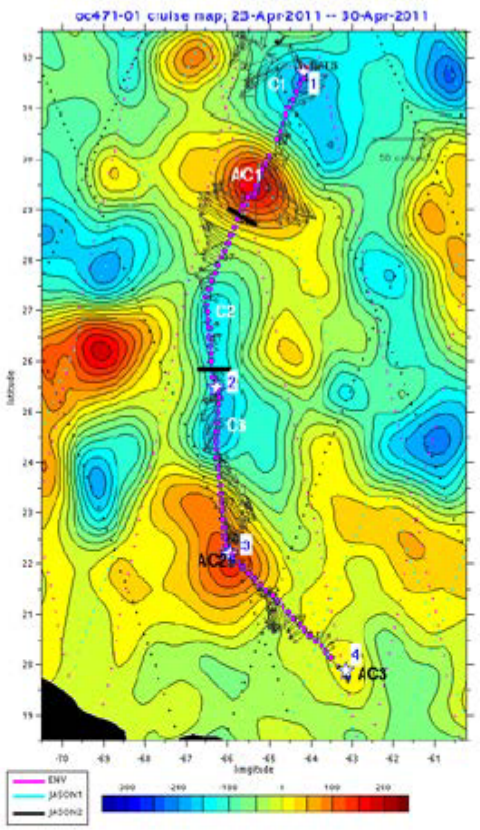
- Technique:
  - Respiration consumes O_2.
  - AOU = $[O2]_{sat} - [O2]_{meas}$ = measure of how much O_2 is consumed
  - Use T/^{3}He as clock to determine age of water
  - → Apparent Oxygen Utilization Rate
- Issues: Large spatial scale, When was the O_2 used? Below 500 m questions on Tritium source function.
- Annual export between 200 and 500 m = 2.1 ± 0.5 mol C m^{-2} y^{-1}

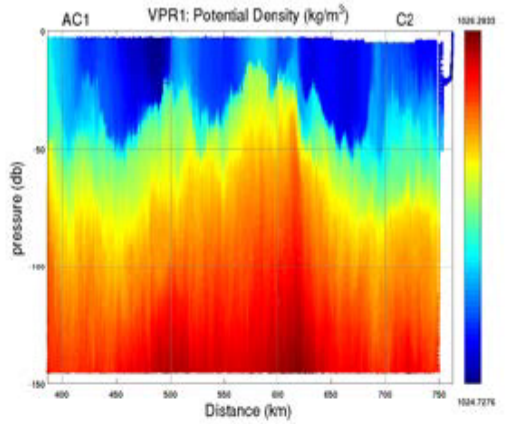


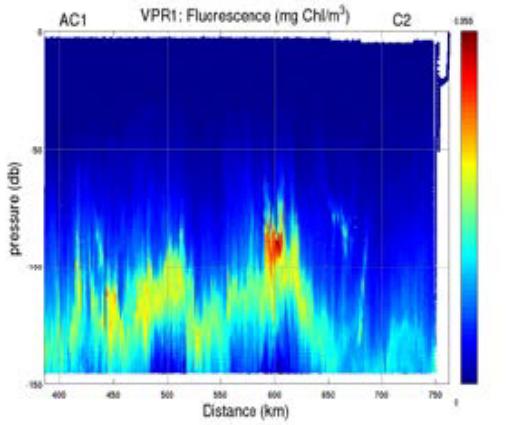
Export Production: AOUR

- Technique:
  - Respiration consumes O_2.
  - AOU = $[O2]_{sat} - [O2]_{meas}$ = measure of how much O_2 is consumed
  - Use $T/^3He$ as clock to determine age of water
  - → Apparent Oxygen Utilization Rate
- Issues: Large spatial scale, When was the O_2 used? Below 500 m questions on Tritium source function.
- Annual export between 200 and 500 m = 2.1 ± 0.5 mol C m^{-2} y^{-1}









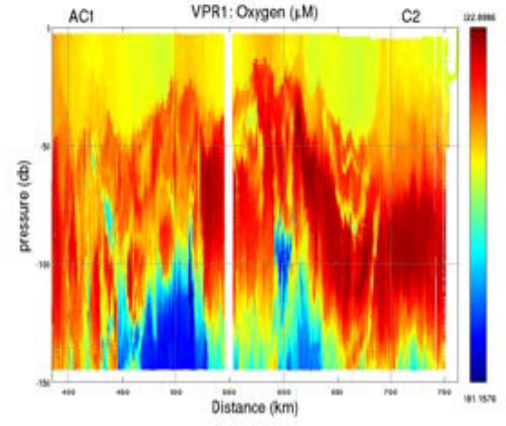


Figure X. OC471 cruise track overlayed on sea level anomaly (mm). Hydrographic stations indicated by stars, and XBTs as magenta dots. Velocity vectors derived from a vertical average (0-240m) of shipboard ADCP measurements. Endpoints of the VPR data shown on the right are indicated by bold line segments between AC1 and C2. Alongtrack resolution of the 0-140m undulations of the VPR is ca. 2km.