future ocean
KIEL MARINE SCIENCES

Upwelling & isolation in oxygen-depleted anticyclonic modewater eddies
- and implications for nitrate cycling

J. Karstensen, F. Schütte, A. Pietri[2], G. Krahmann, B. Fiedler, D. Grundle, H. Hauss, A. Körtzinger, C.R. Löscher, P. Testor[2], N. Viera[3], M. Visbeck

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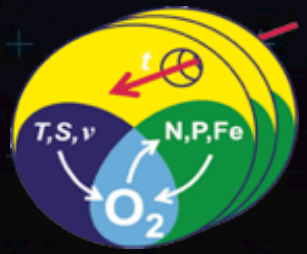

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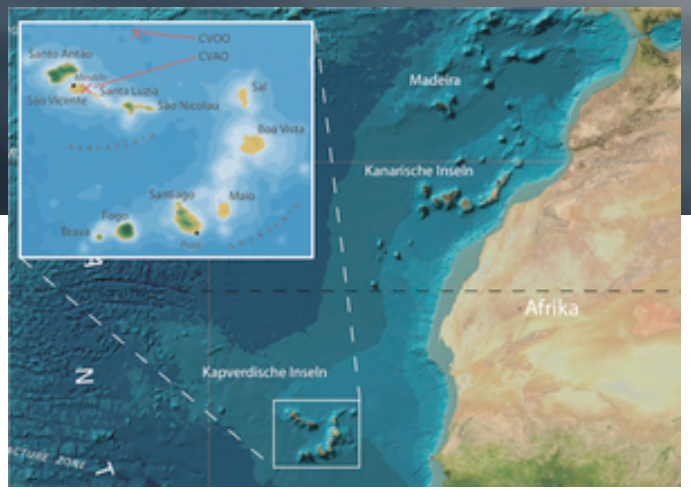
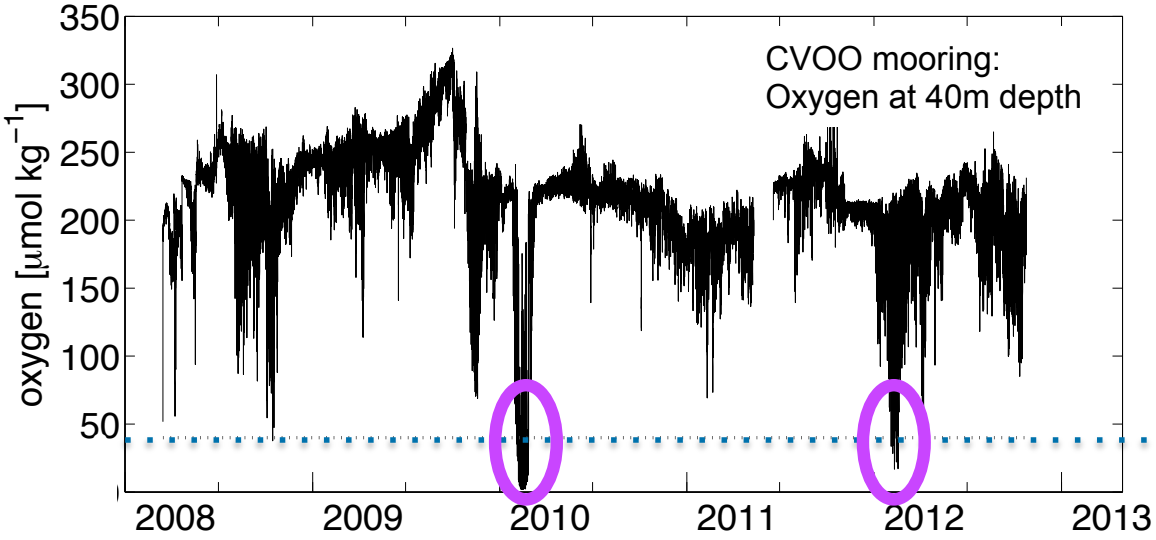
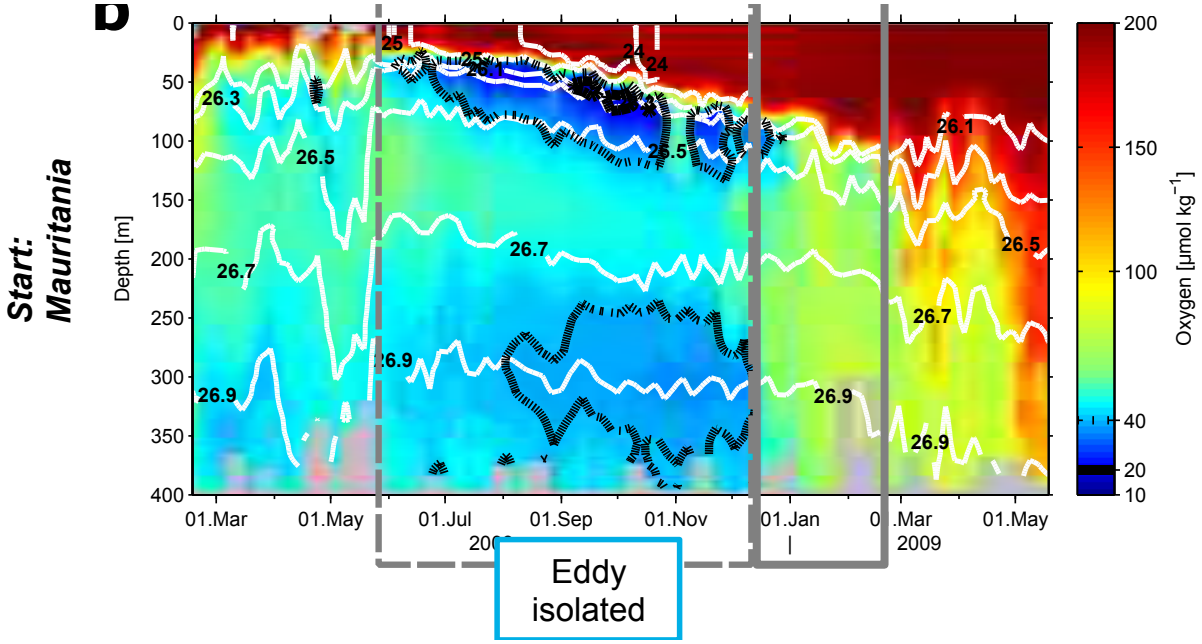
Low oxygen events at the eastern tropical Atlantic

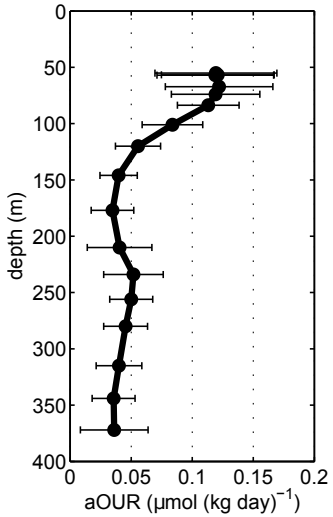


Karstensen et al. (2015)



North Atlantic OMZ





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Low oxygen eddies – open-ocean "dead-zones"

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Eddies show

High Productivity (and respiration)

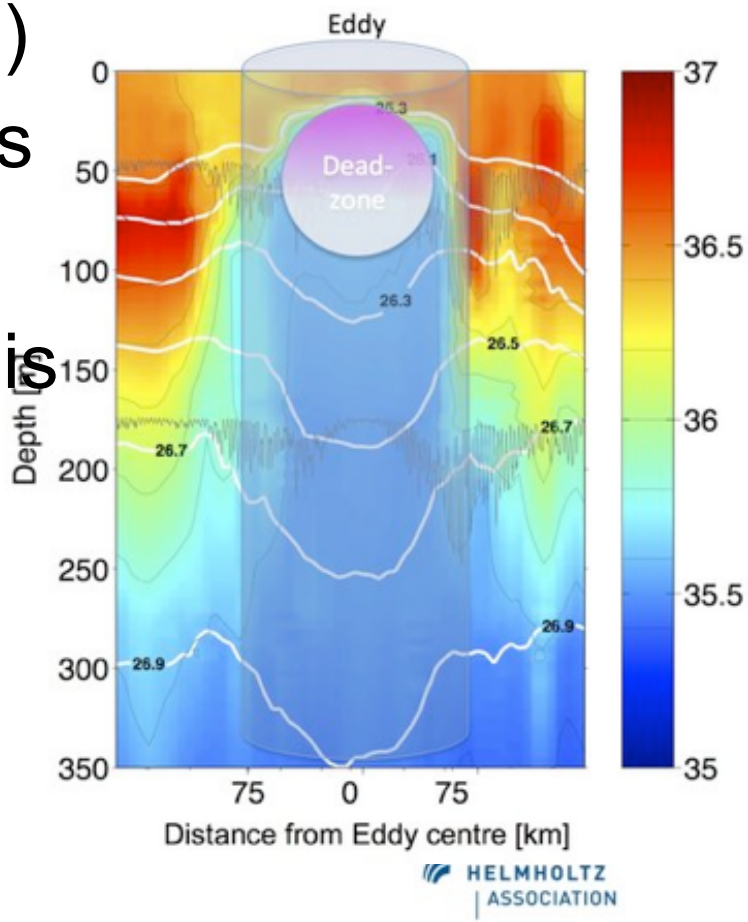
➔**Strong** Vertical flux of Nutrients

the afflux of oxygen into the core is minimal

➔**Weak** mixing

- Is this a contradiction?

Open Ocean "Dead-Zone"



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Low oxygen eddies – open-ocean "dead-zones"

GEOMAR

Eddies show

High Productivity (and respiration)

➔**Strong** Vertical flux of Nutri

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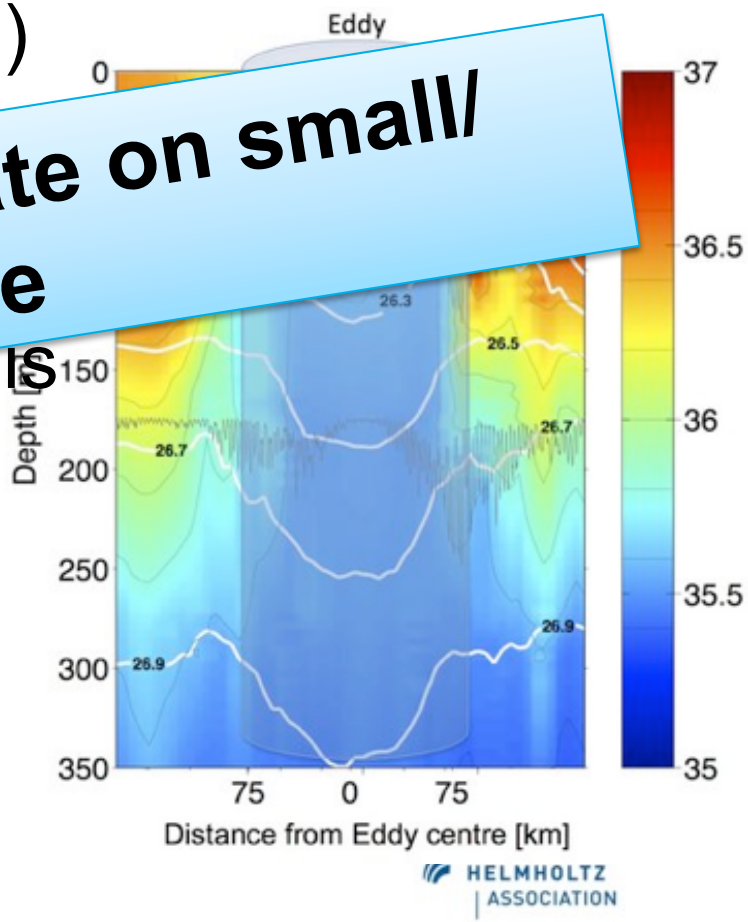
• Is this a contradiction?

Processes have to operate on small/ submesoscale

Open Ocean "Dead-Zone"



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“Dead-zone” eddy hunt experiment

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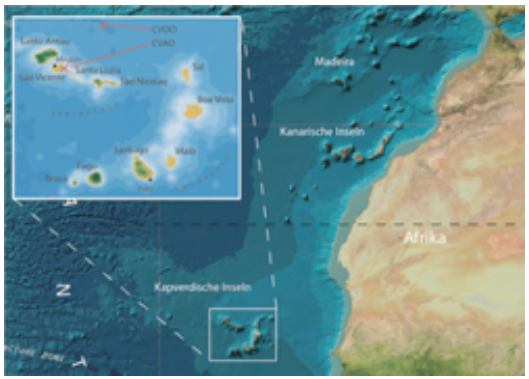
- Design of a meso/submesoscale experiment using gliders, ships, floats, satellite



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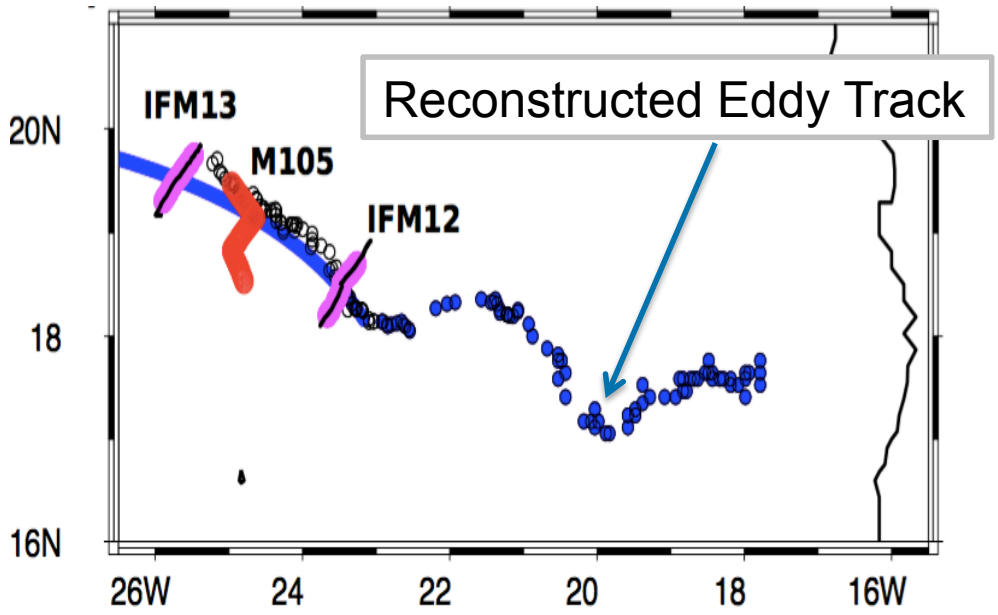
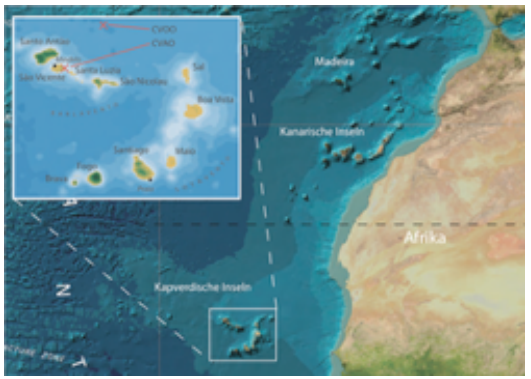
“Dead-zone” eddy hunt experiment

GEOMAR

- Design of a meso/submesoscale experiment using gliders, ships, floats, satellite
- Satellite/float “eddy detection system”
- Multiple surveys of one low oxygen eddy from February 2014 to April 2014





$T_{IFM12}=0$
Glider (IFM12)

$T_{M105}=T_{IFM12}$ + 6 weeks
Ship (M105)

$T_{M105}=T_{IFM12}$ + 9 weeks
Glider (IFM13)

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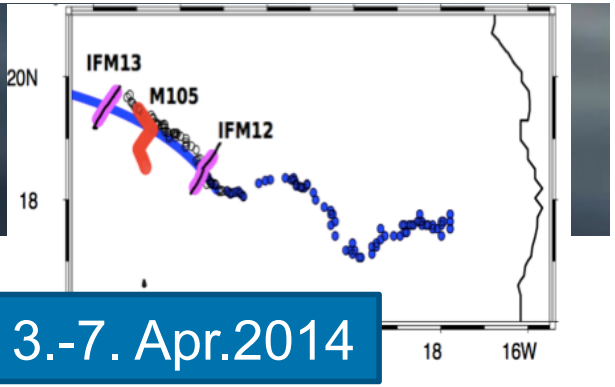
Oxygen evolution in eddy



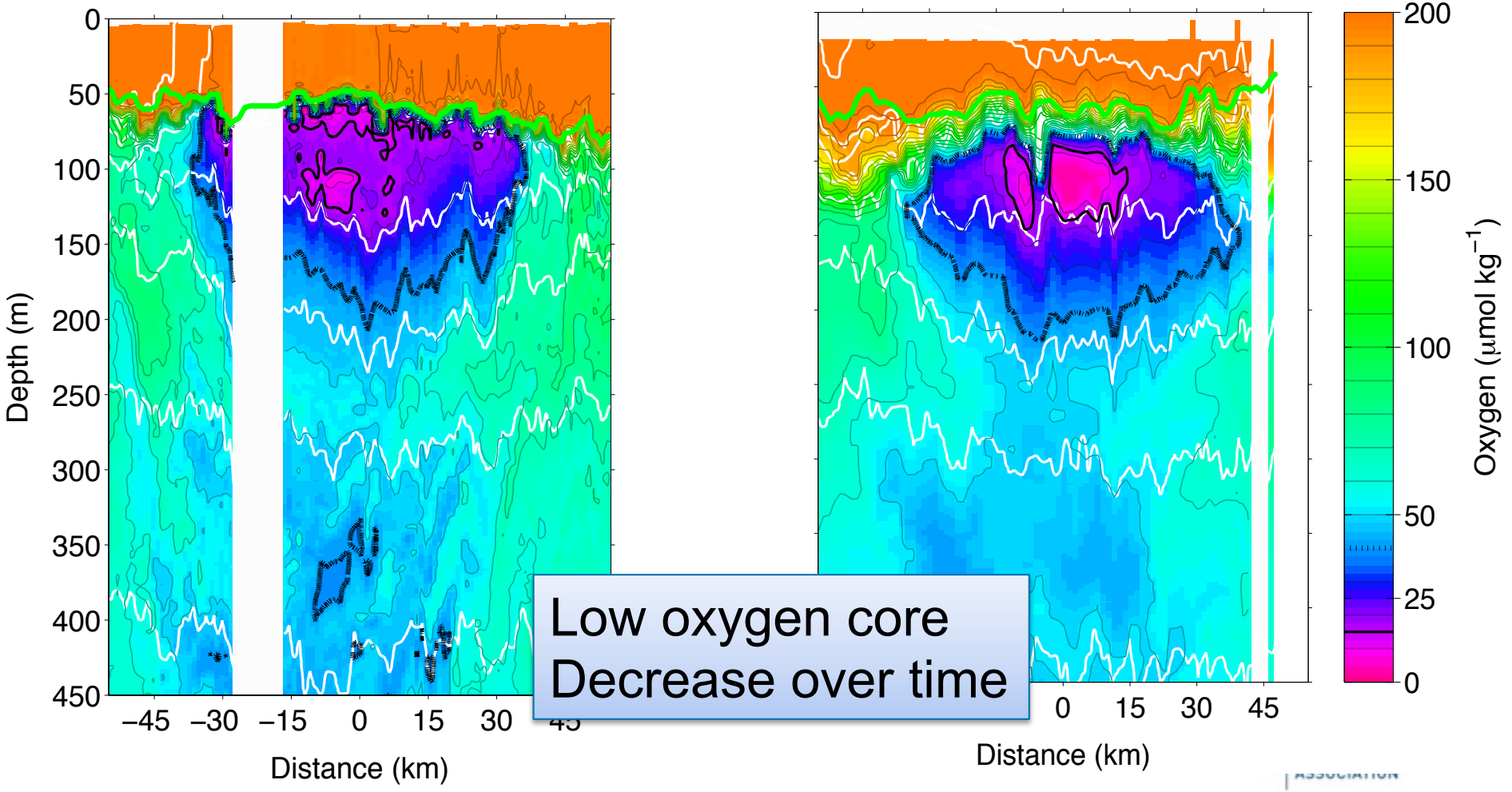
3.-10. Feb. 2014

2 month

3.-7. Apr.2014

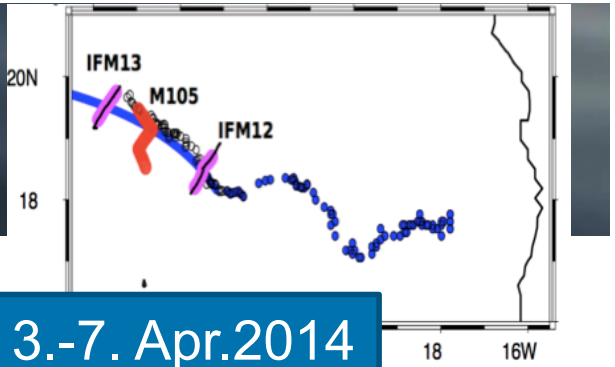
Glider ifm12

Glider ifm13



Low oxygen core
Decrease over time

Turbidity (particle)



3.-10. Feb. 2014

2 month

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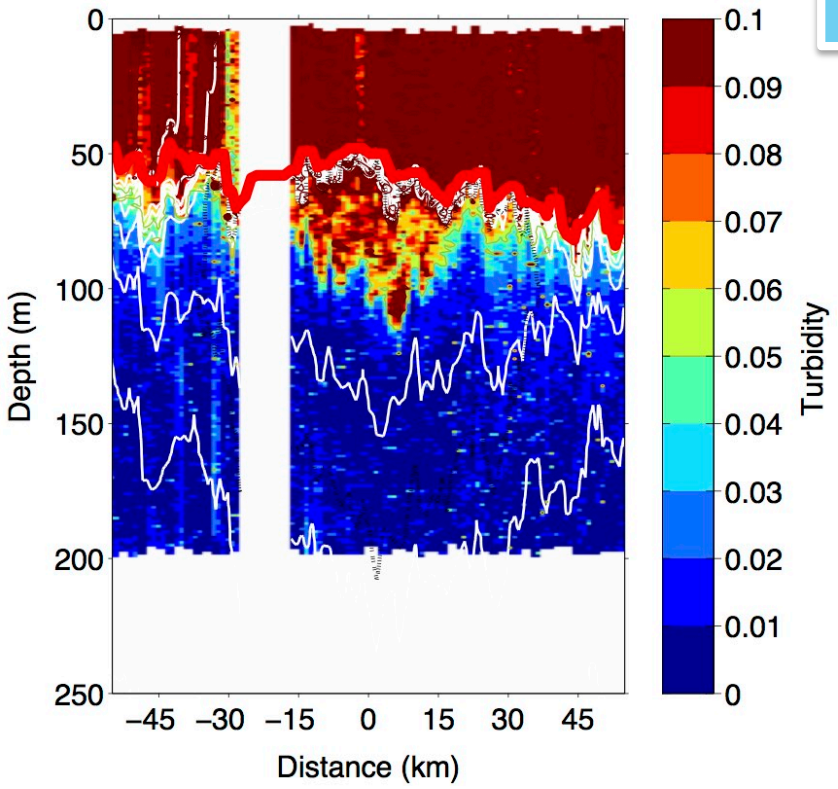
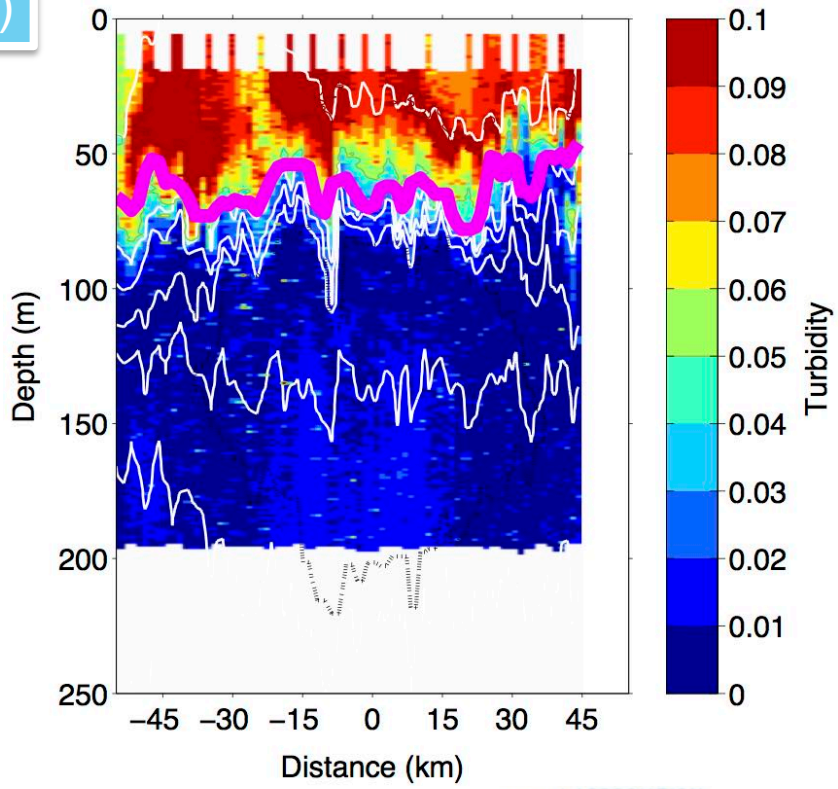
Turbidity (uncal. NTU)





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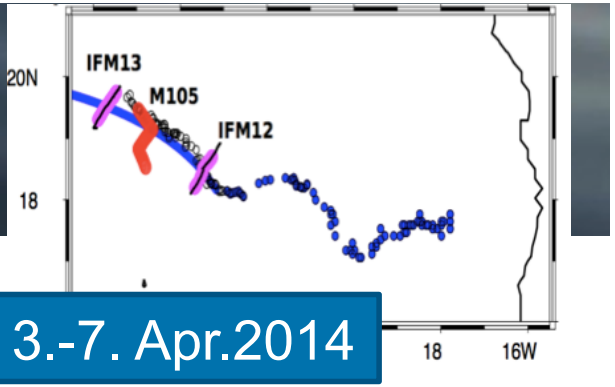
Turbidity (particle)



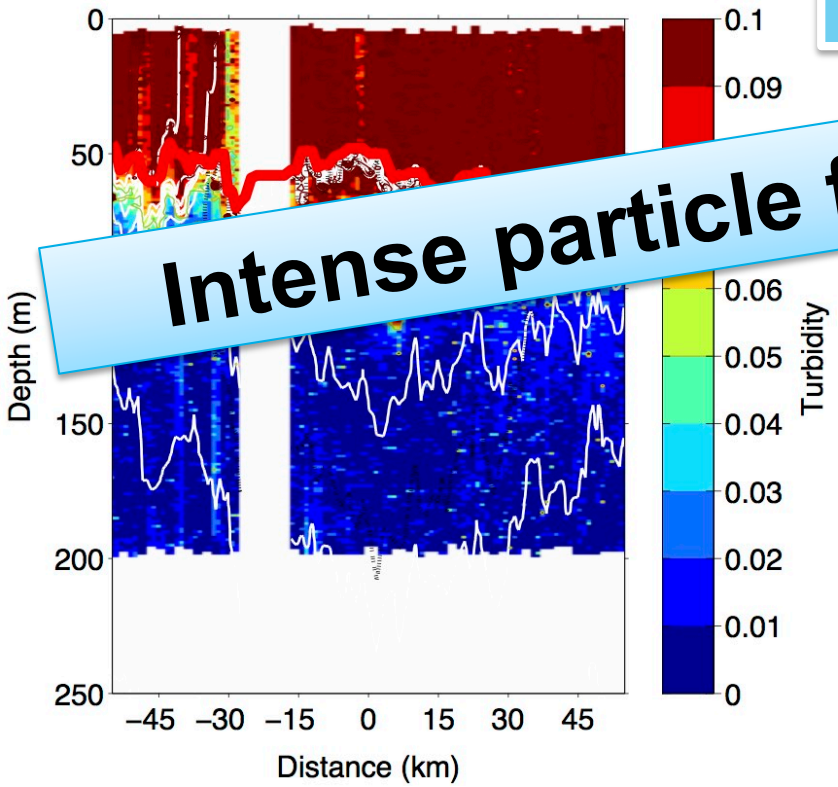
3.-10. Feb. 2014

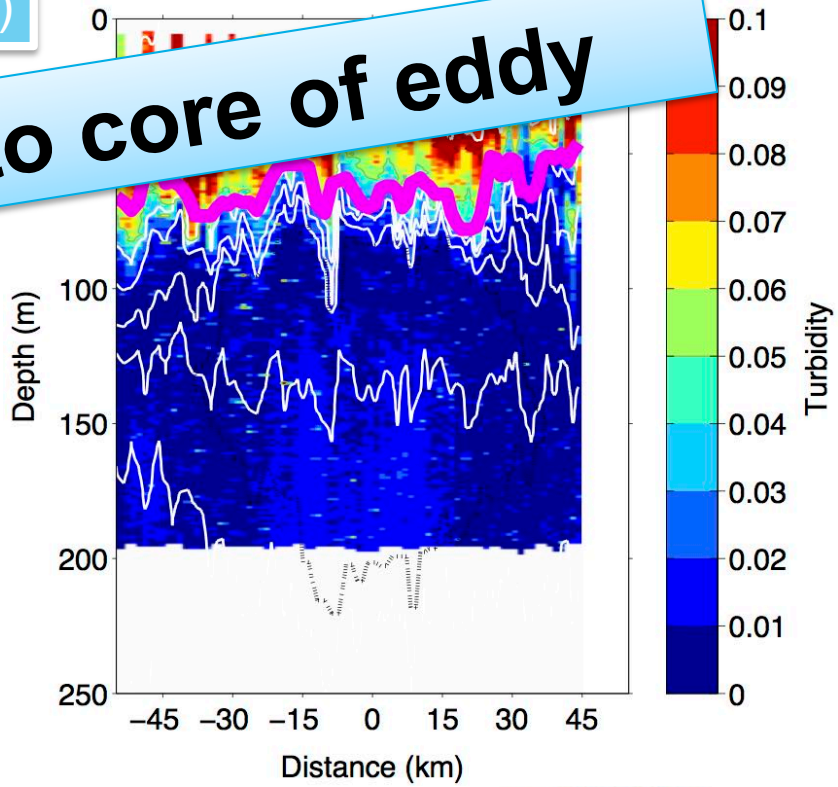
2 month

3.-7. Apr.2014

Turbidity (uncal. NTU)

Intense particle flux into core of eddy





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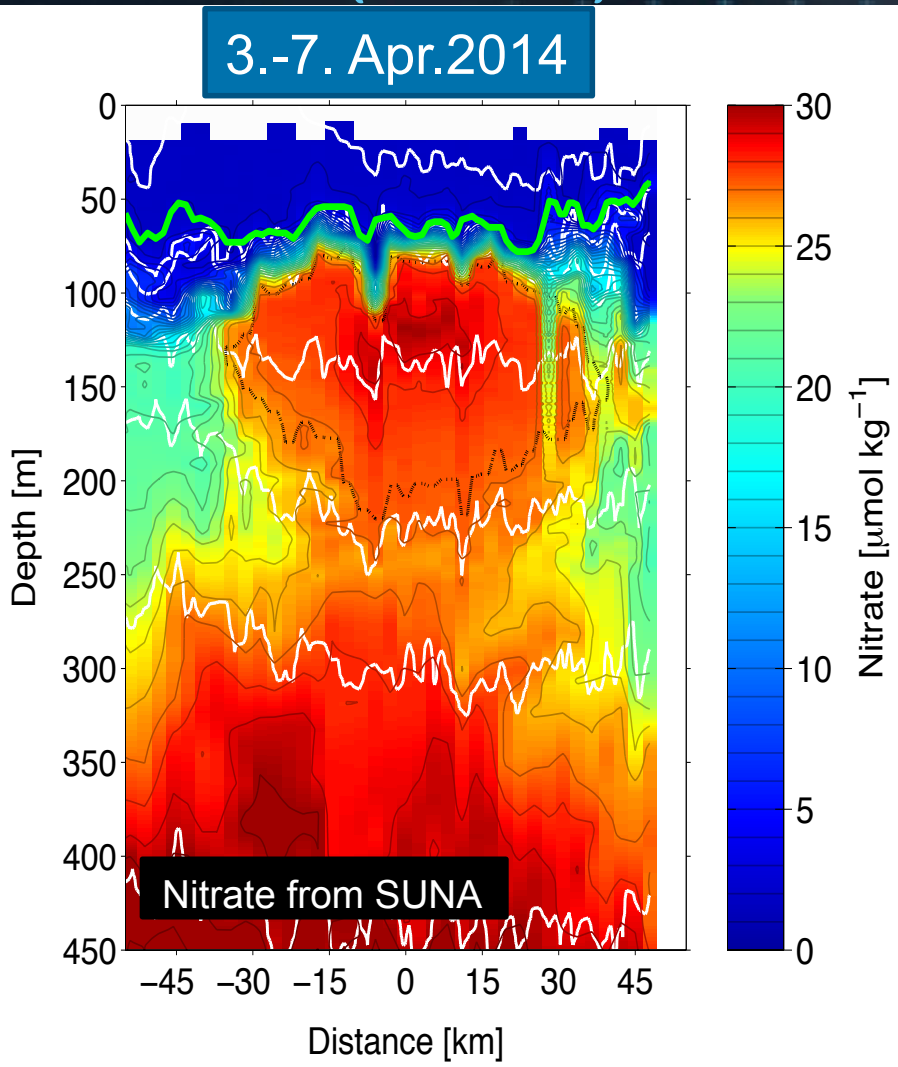
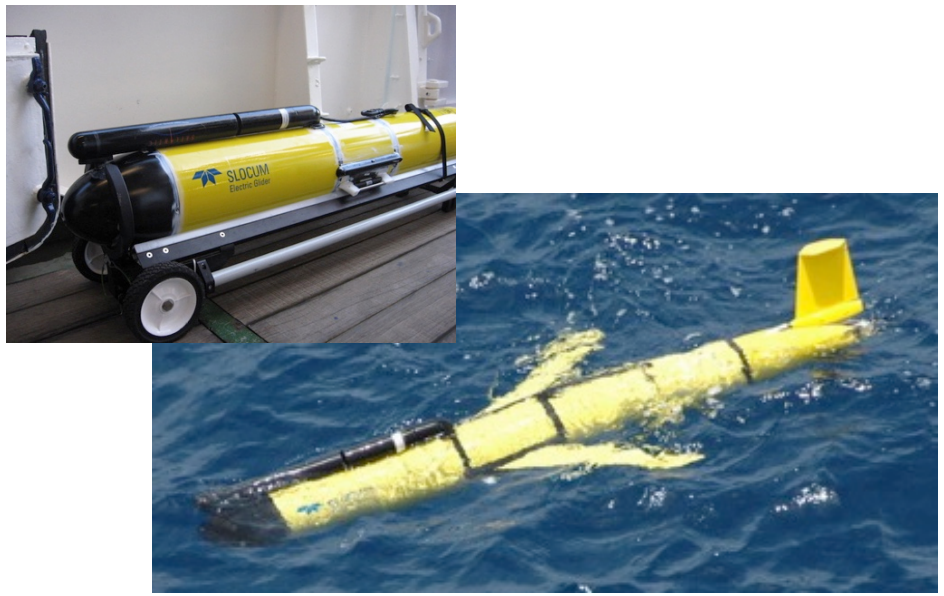
Nitrate (SUNA)





- Advice from Florent Besson (LOV)
- SUNA pre-calibration (NaCl)
- Data QC: comparison with bottle samples
- Problems:
  - Communication with Satlantic!
  - Initially wrong spectra – generated 5µmol/kg offset!

Nitrate (SUNA) & Apparent oxygen utilization

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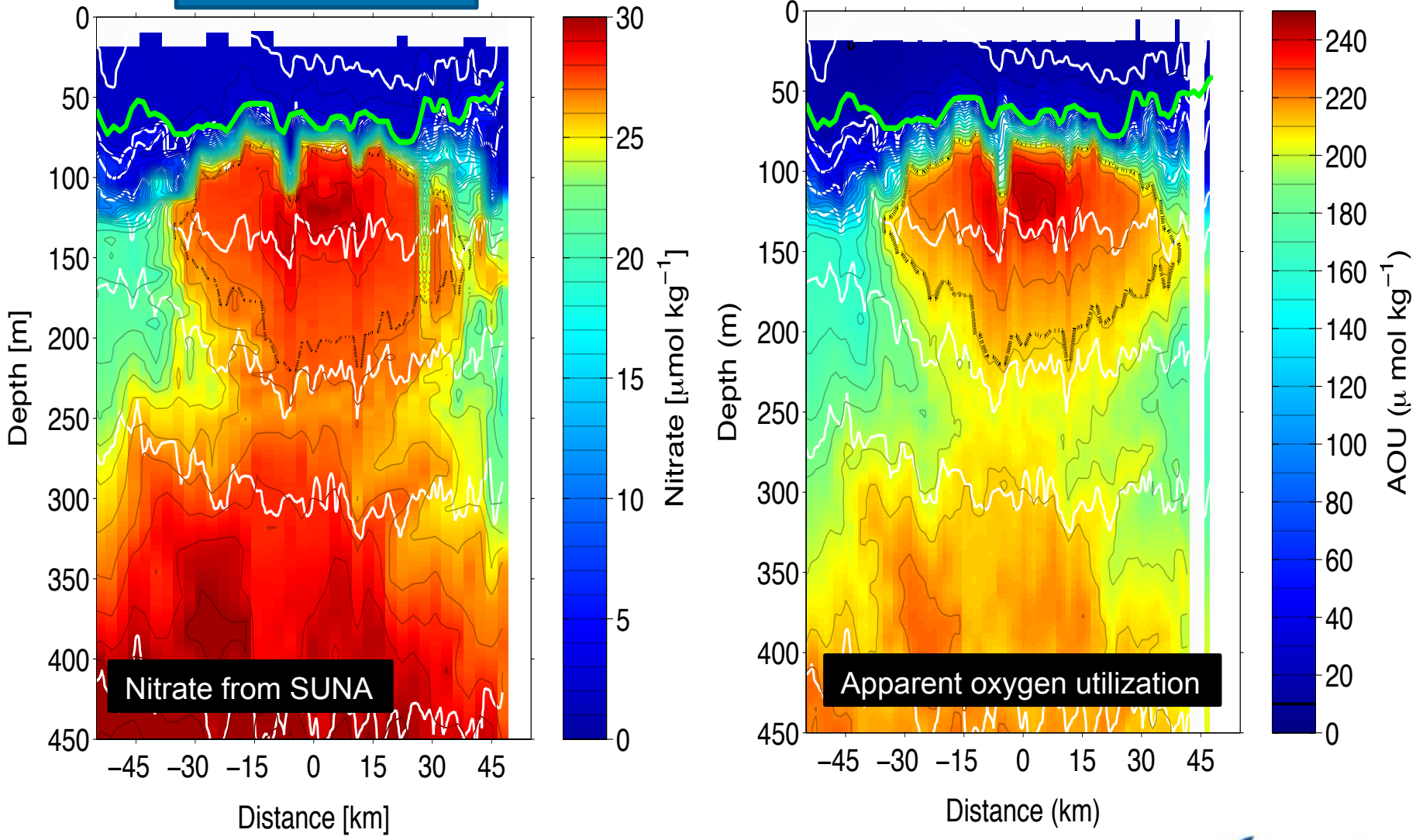
3.-7. Apr.2014



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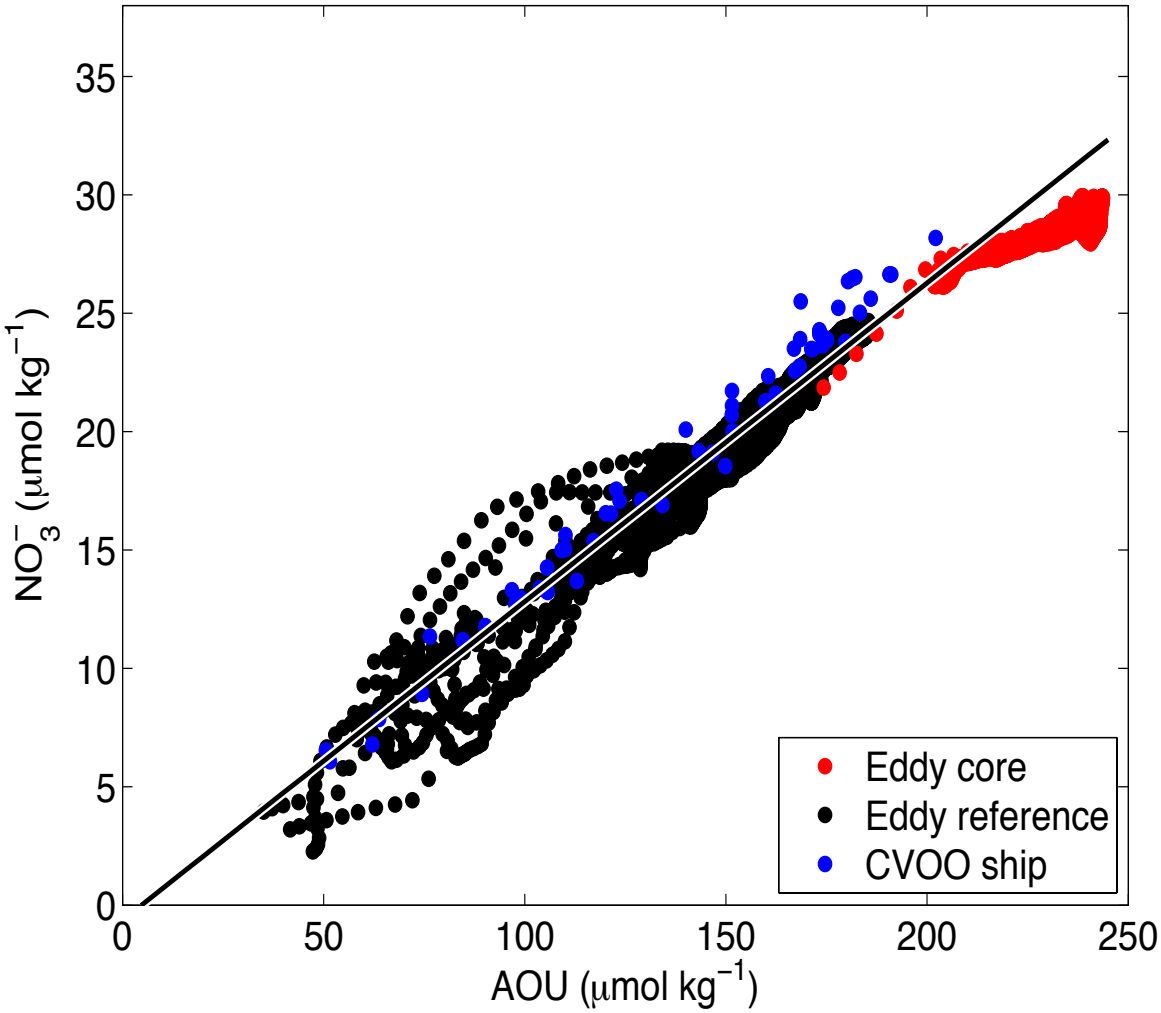
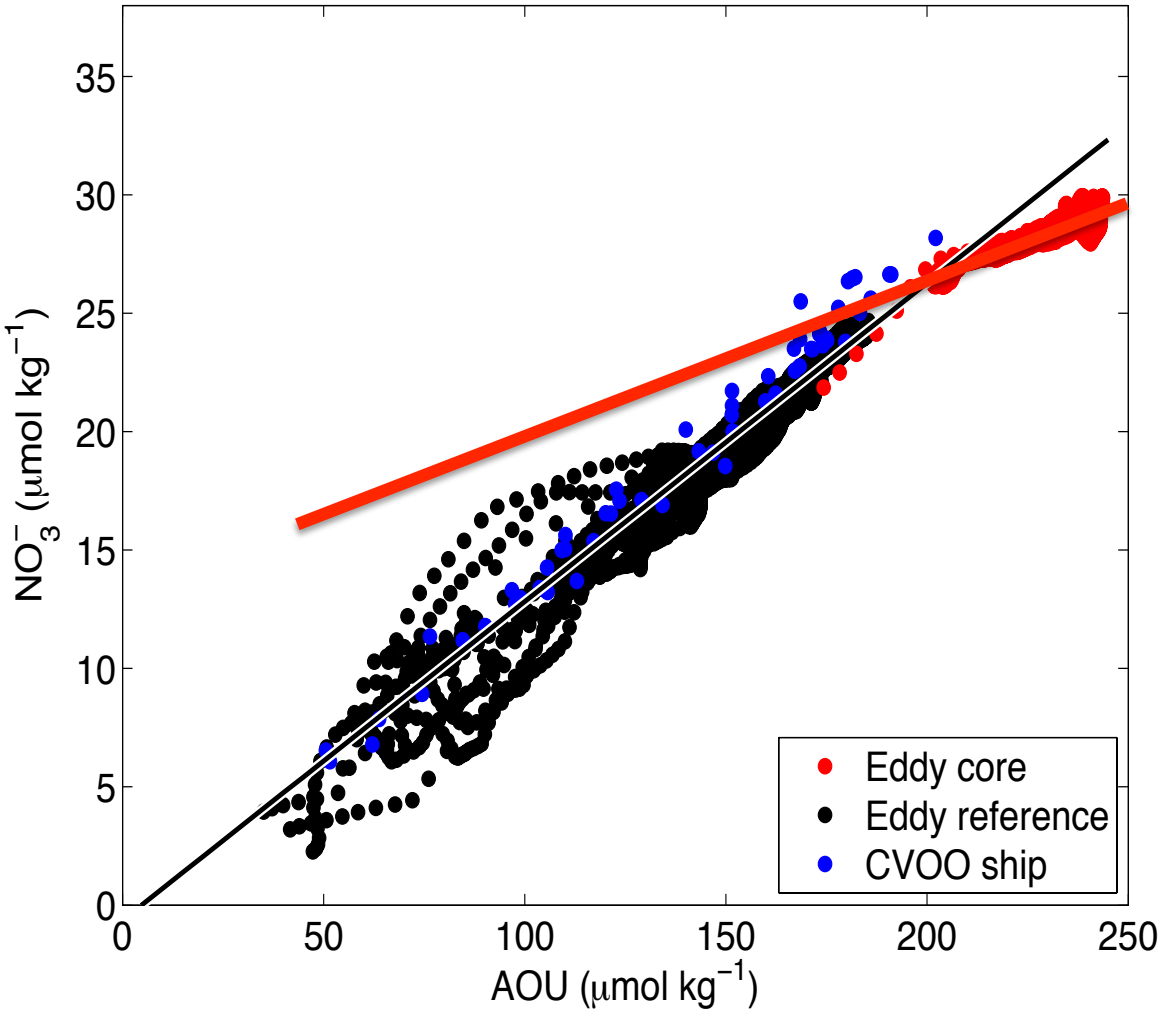
Nitrate (SUNA) & Apparent oxygen utilization



Redfield AOU:N (138:16 = ~9)
Outside eddy = 8
Mauritanian coast = 9

Nitrate (SUNA) & Apparent oxygen utilization



Redfield AOU:N
(138:16 = ~9)
Outside eddy = 8
Mauritanian coast = 9
Inside Eddy = 16

Why?

N cycling scheme: Decoupling Oxygen and Nitrate

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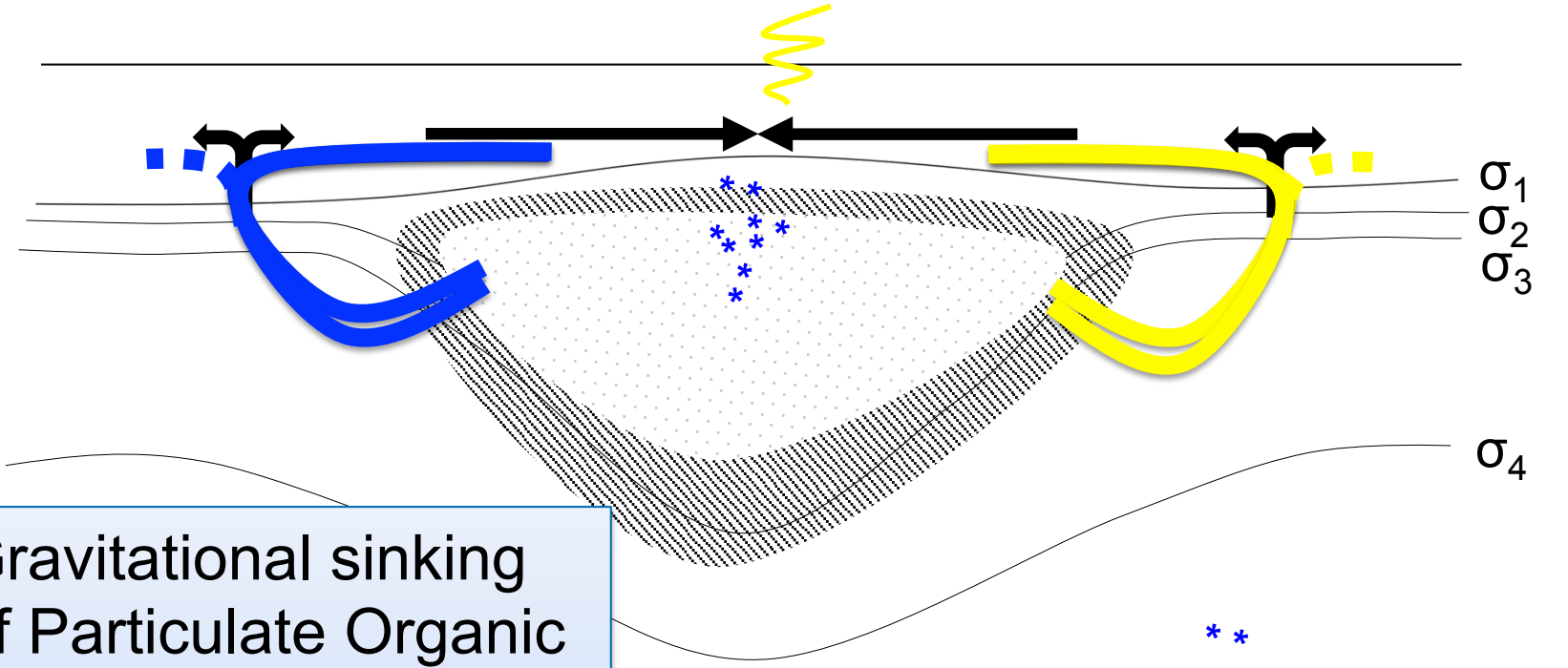

Gravitational sinking of Particulate Organic Nitrate (PON) is key!

-> decouples local nitrate recycling from oxygen

PON flux

NO_3^- transport

Air/Sea oxygen flux

oxygen transport

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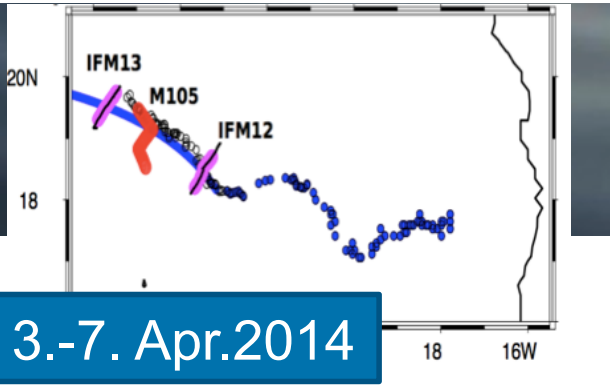
Salinity 9 weeks apart

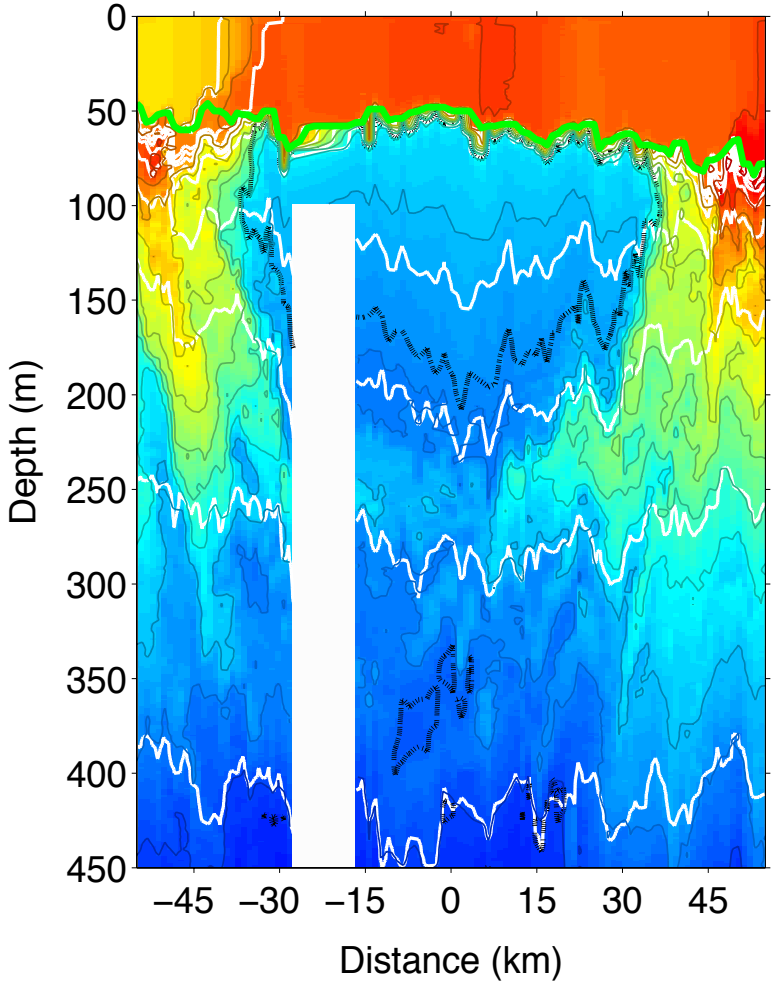


3.-10. Feb. 2014

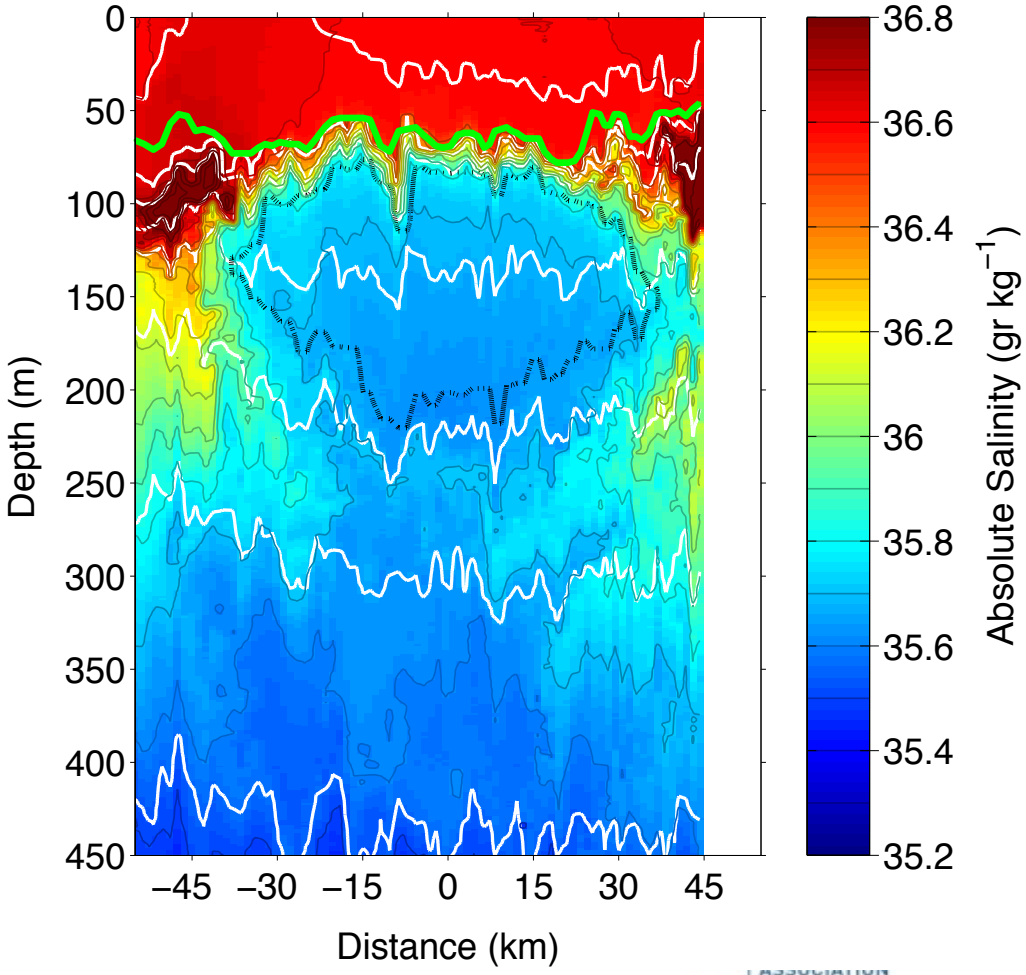
2 month

3.-7. Apr.2014

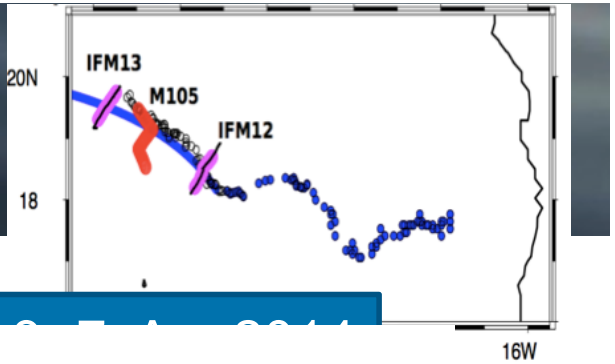
Glider ifm12



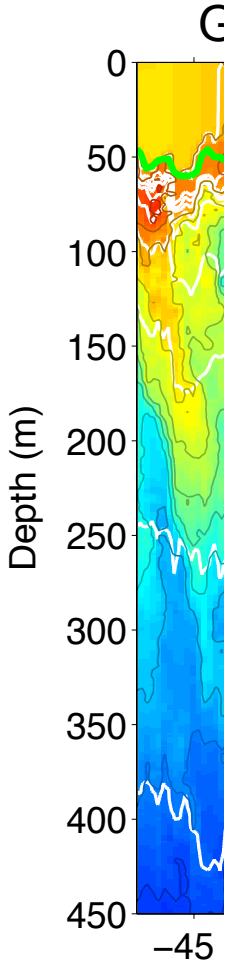
Glider ifm13

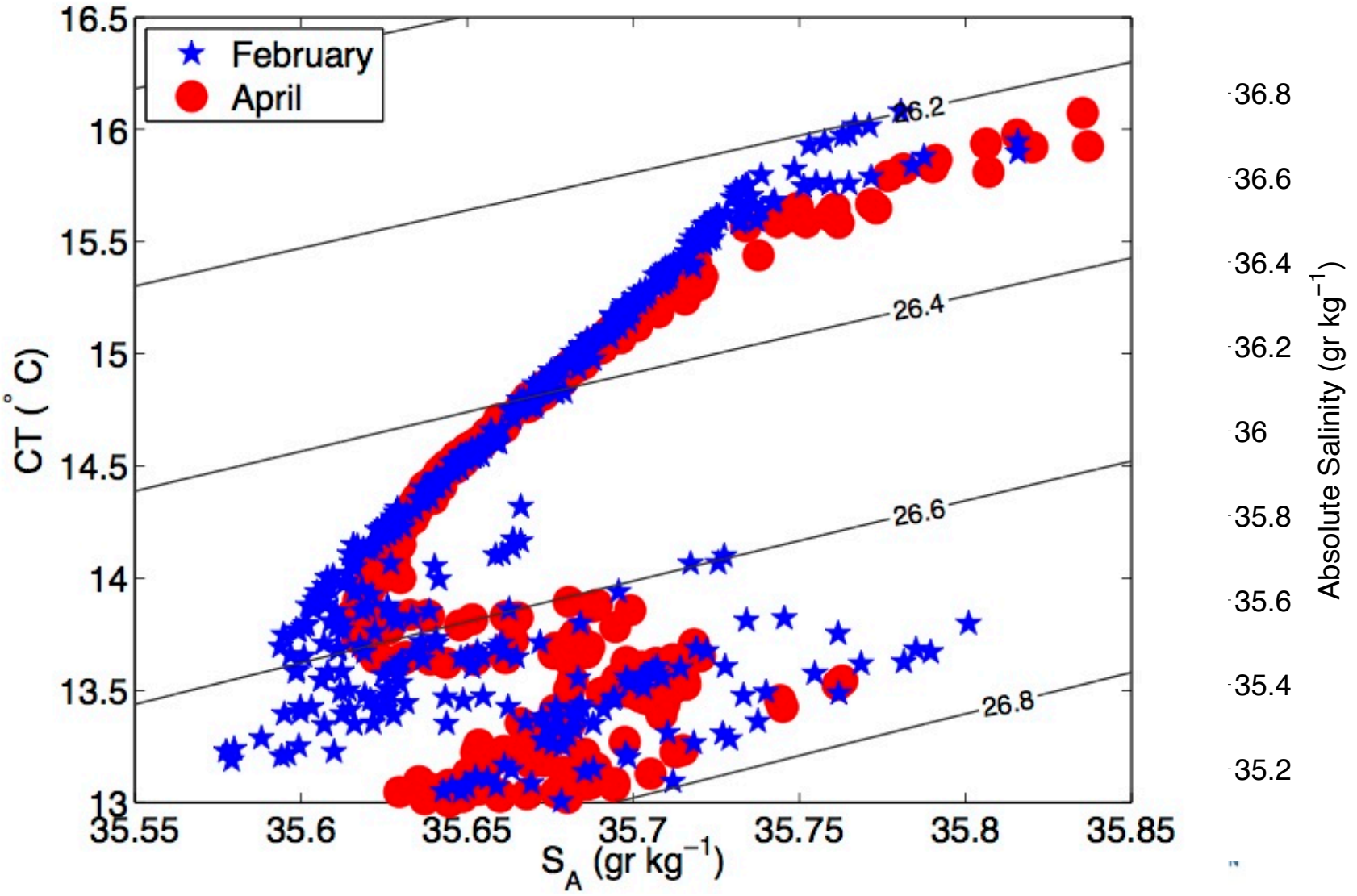


Salinity 9 weeks apart

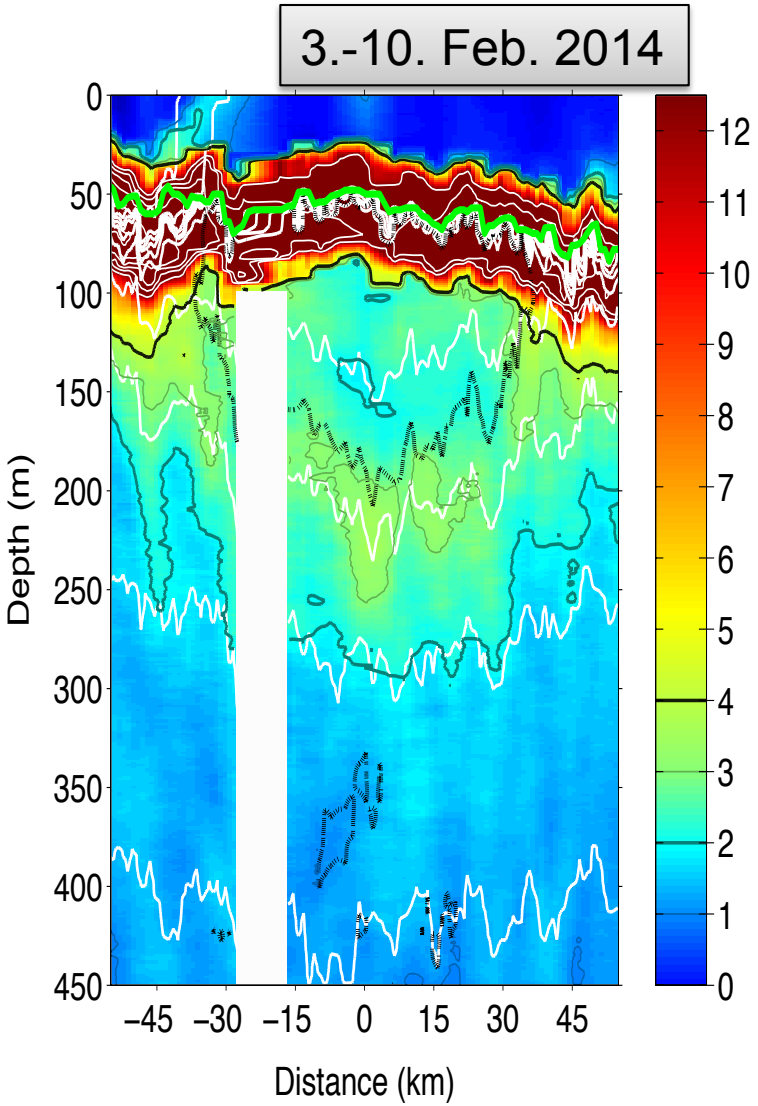


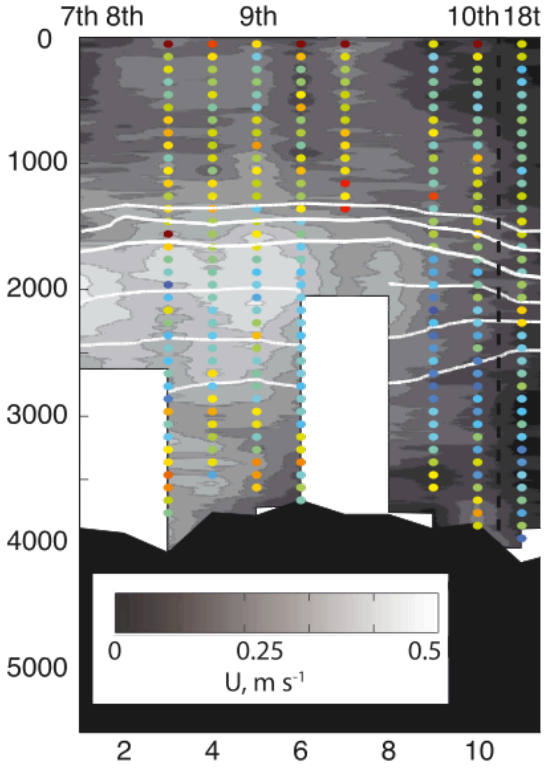
3.-

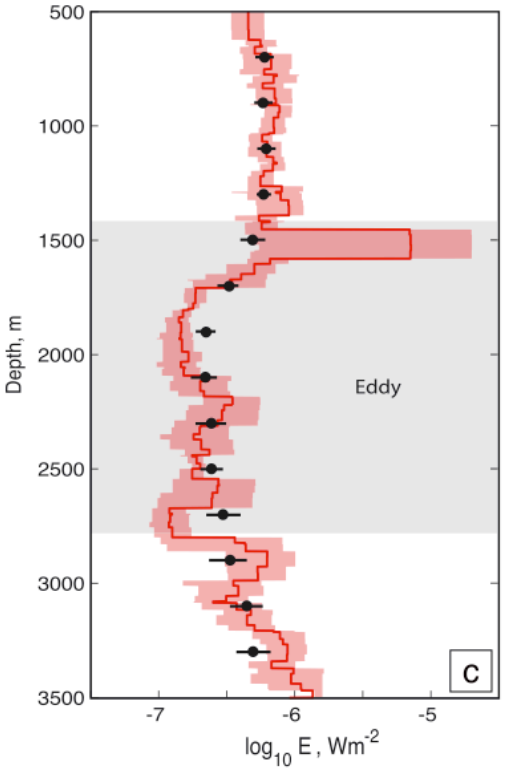




N^2 Buoyancy Frequency

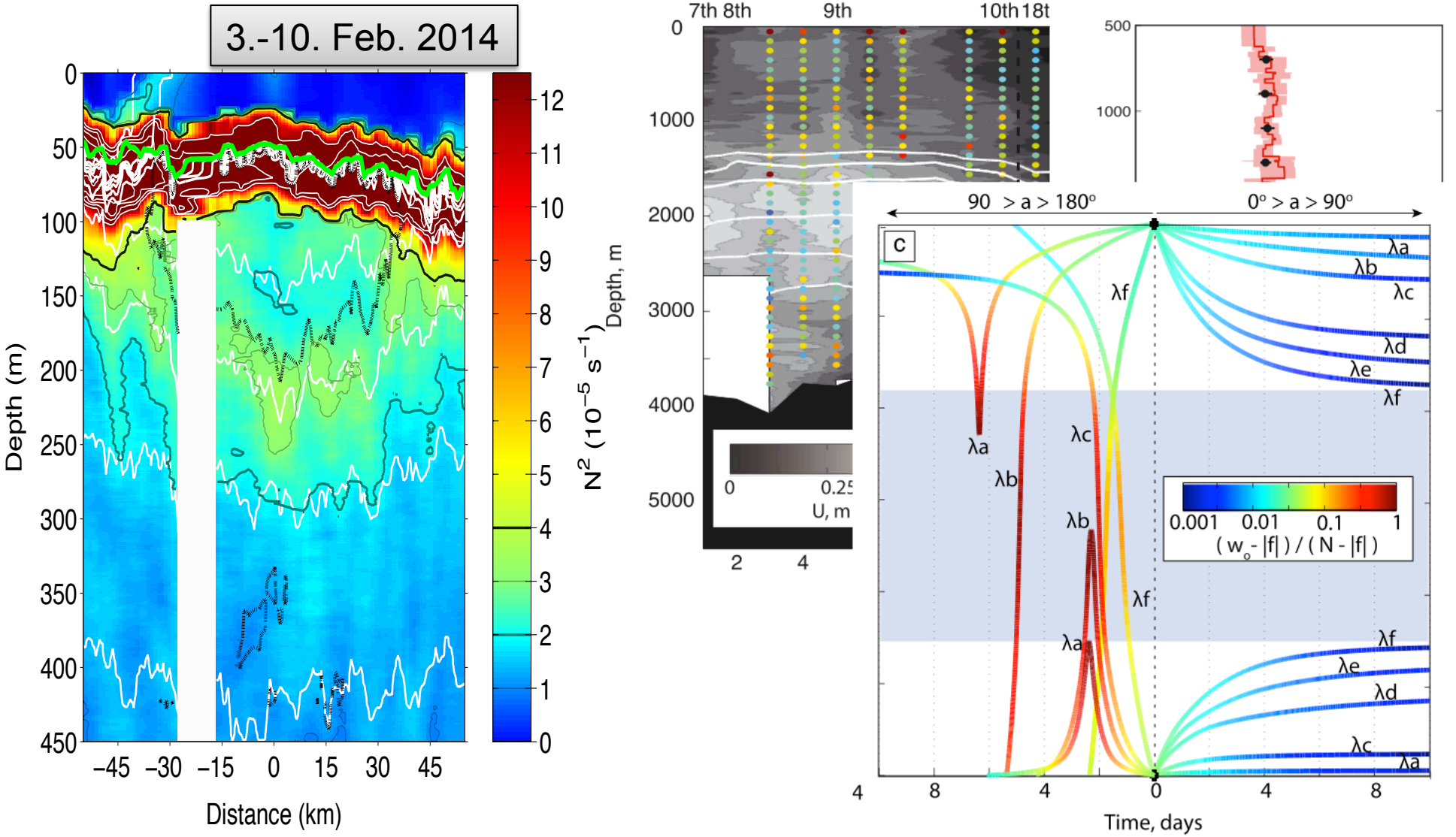






Sheen et al. 2015 (JGR); Kroll 1993 (JMR)

N^2 Buoyancy Frequency



Sheen et al. 2015 (JGR)

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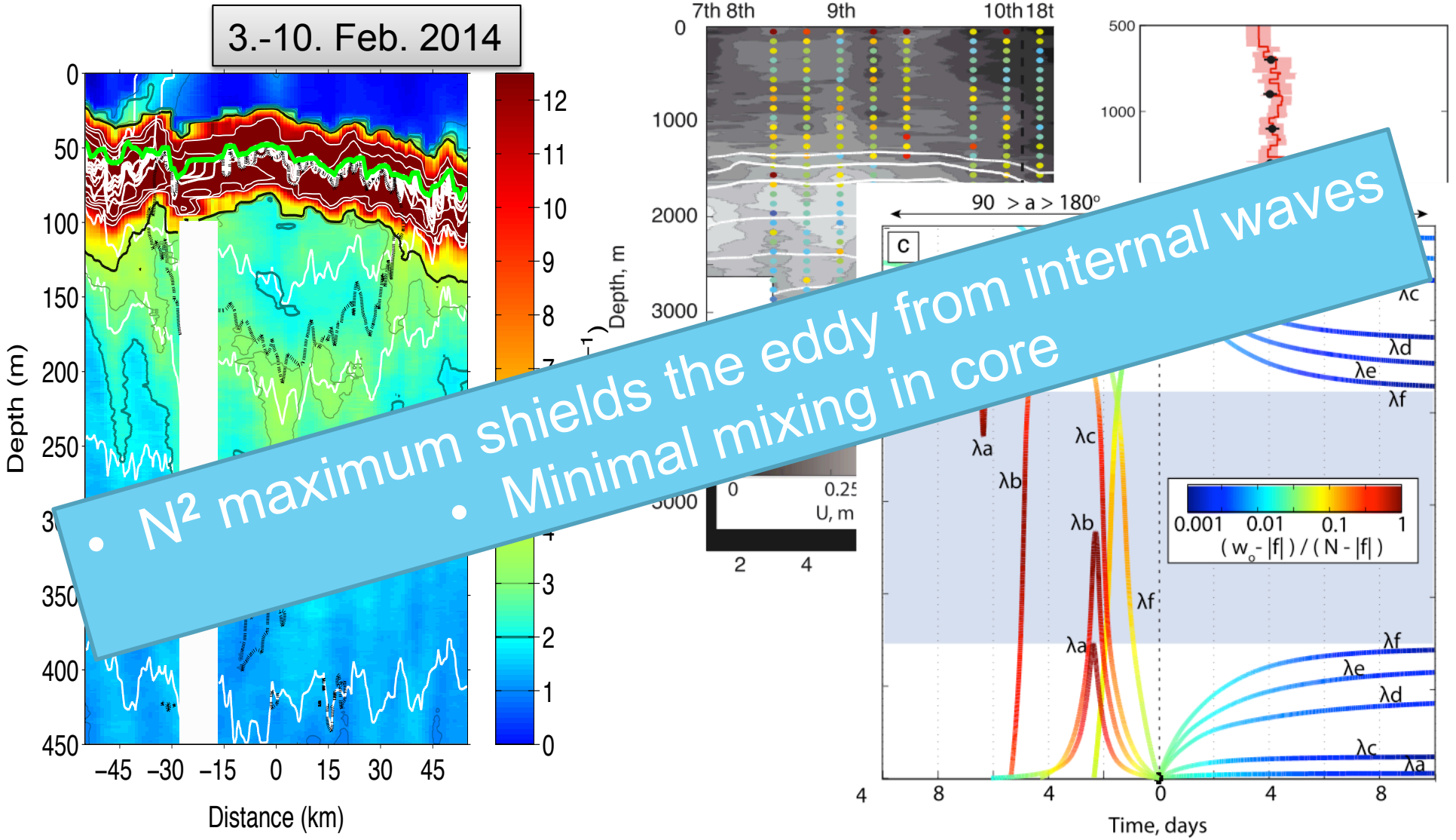
N^2 Buoyancy Frequency



- N^2 maximum shields the eddy from internal waves
- Minimal mixing in core

Sheen et al. 2015 (JGR)

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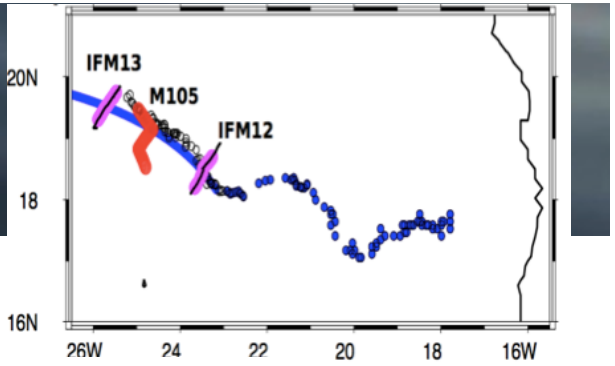
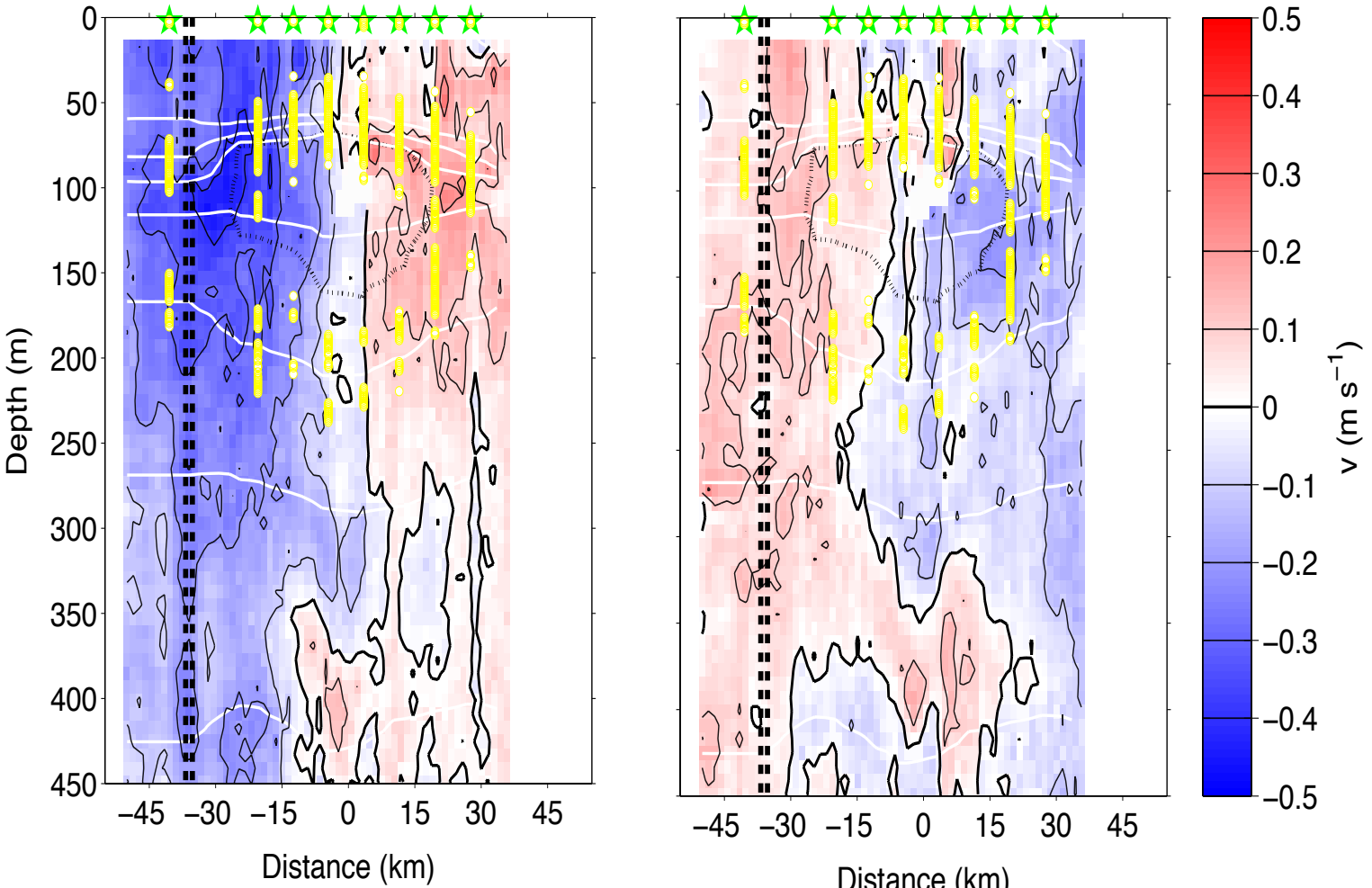
ADCP Velocity ship survey

18./19. Mar. 2014





Meridional Vel.

Zonal Vel.

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ADCP Velocity ship survey

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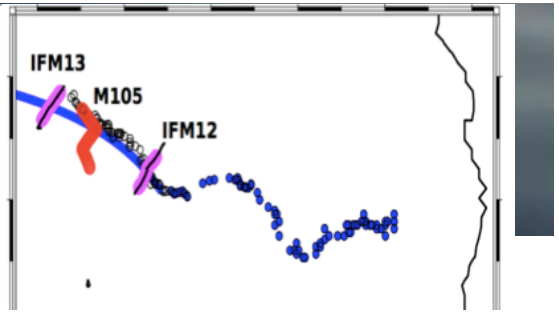
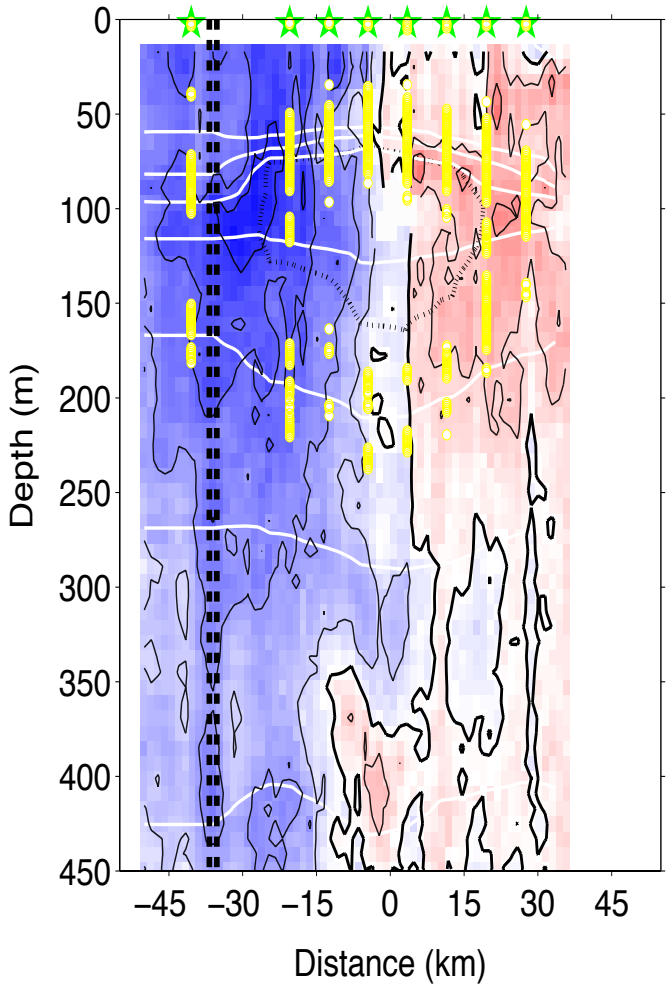
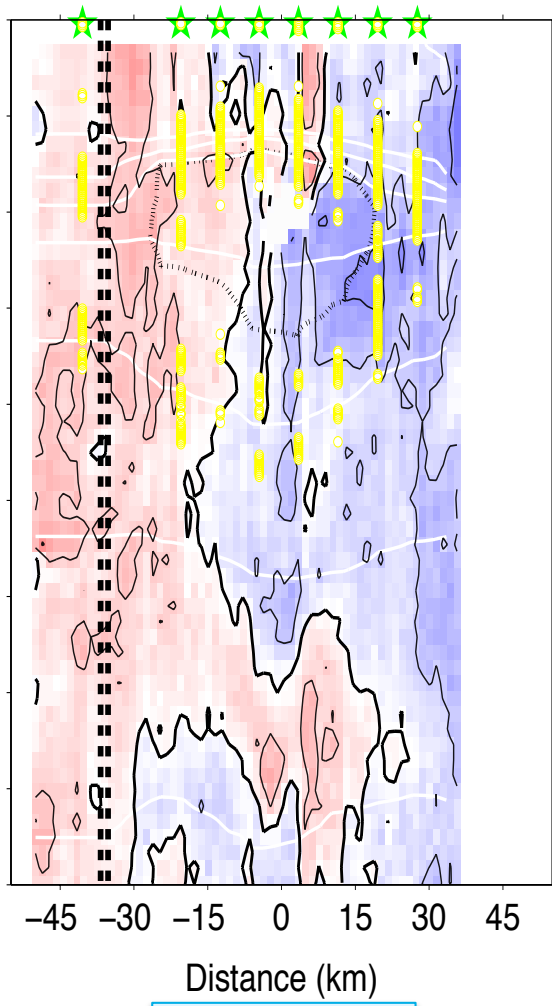


$U = U_0 + U'$

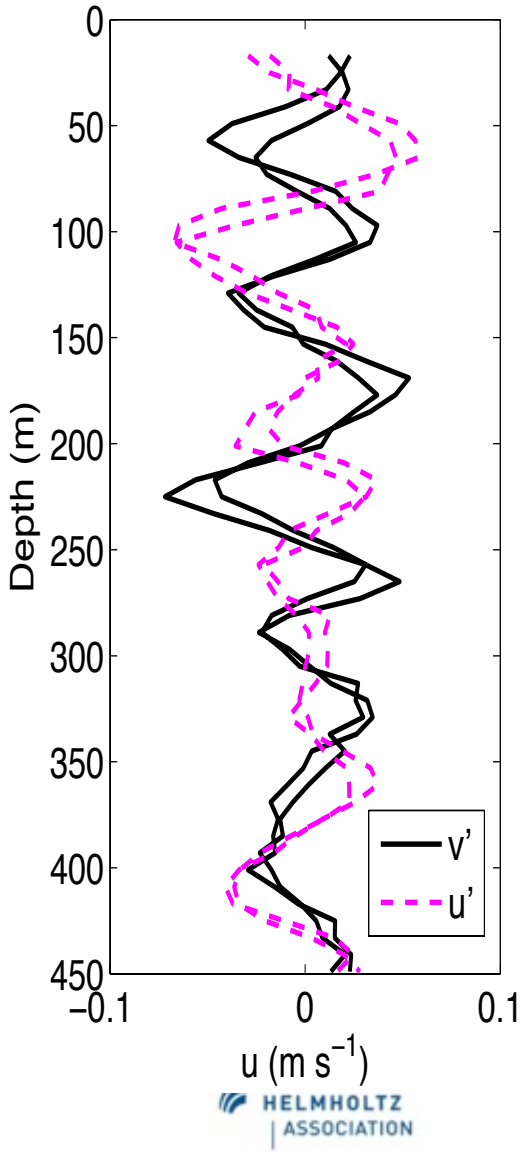
U_0: Apply 120m box car filter



Meridional Vel.



Zonal Vel.



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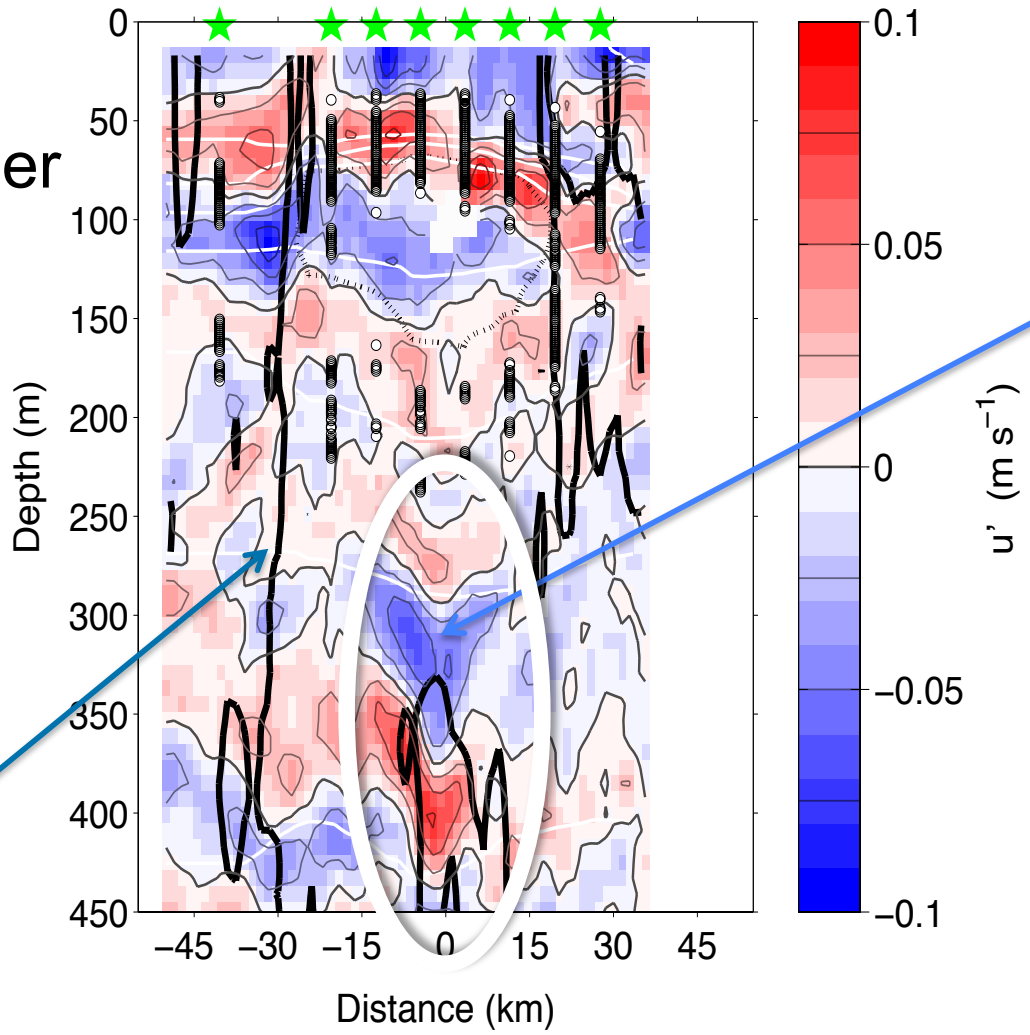
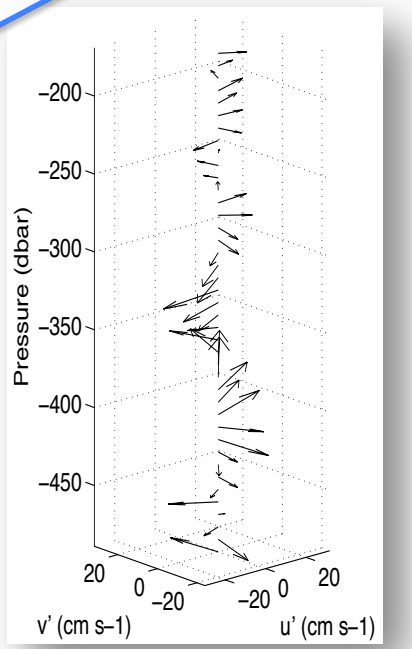
Near inertial waves (NIW)

"Inertial chimney" (Lee & Niiler 1998)



NIW pattern



$f_{eff} = f$

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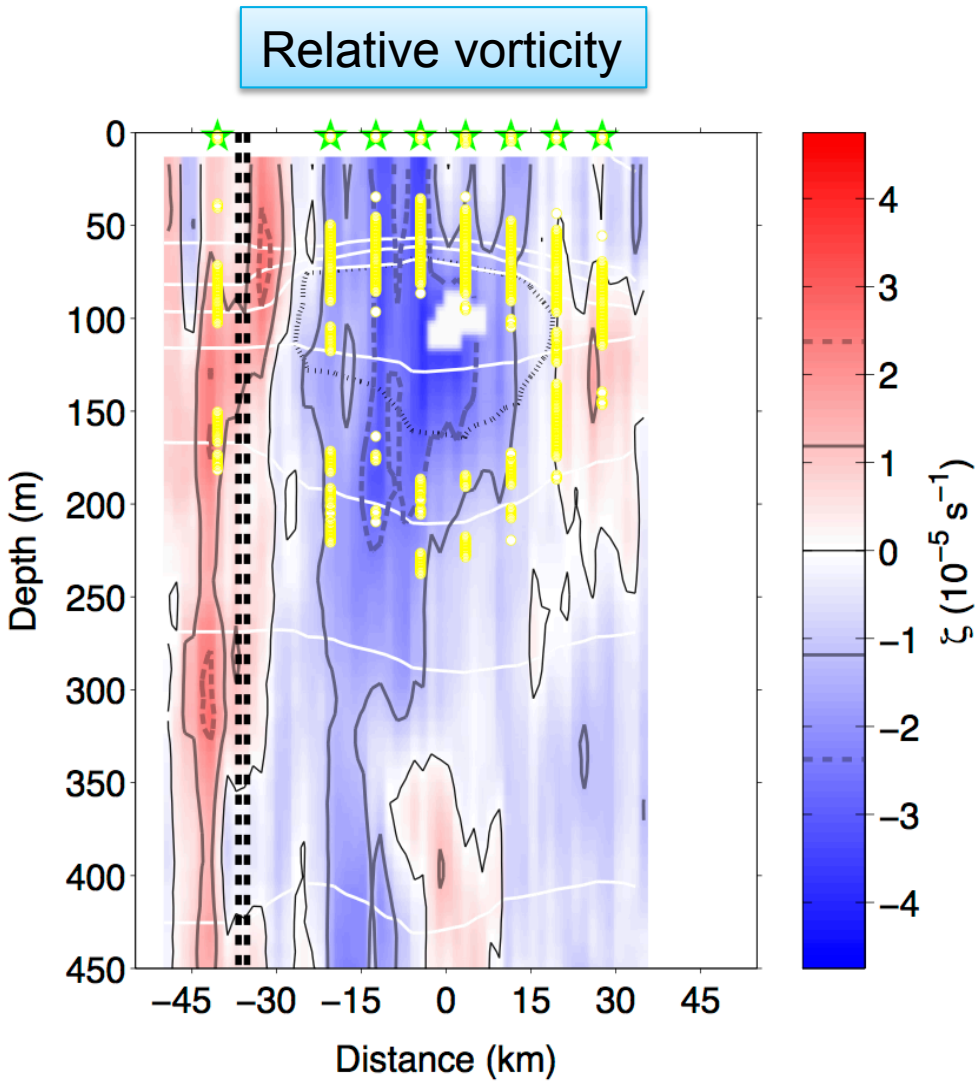
Vorticity structure



- Full rotation ~13 days
- Bu ~ 0.17 (flat lens)
- R_d ~ 25 km
- Ro > 0.3
- α ~ 7 (v_{rot}/v_{tranls})

Vorticity structure: effective planetary vorticity

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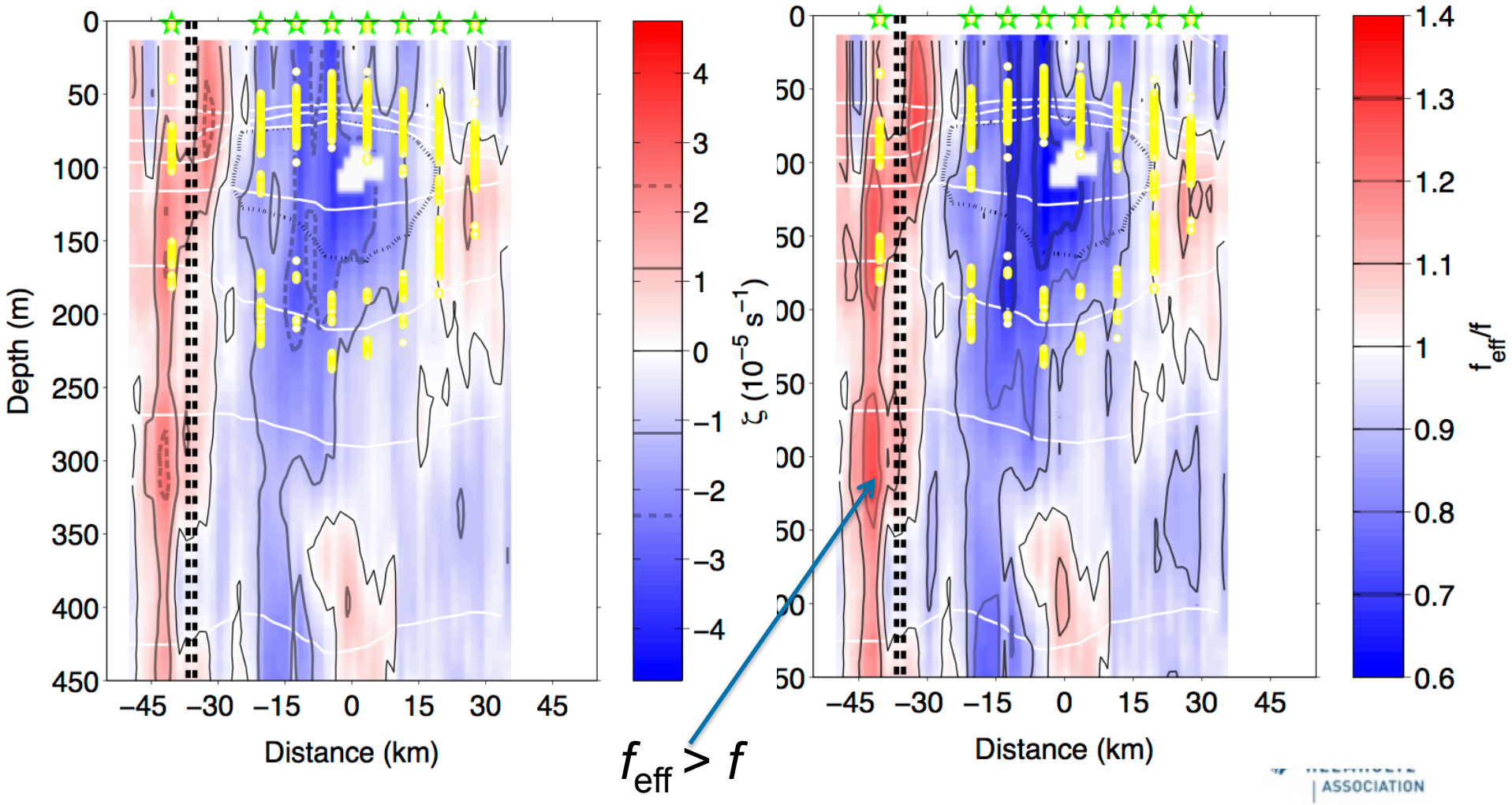
$f_{eff} = f + \zeta / 2$ *(e.g. Weller, 1982)*

f (18°N) = 4.4 10^{-5} [1/s]



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Summary

- First HR glider survey of “dead-zone” eddy
- This eddy was a “typical ACME” (80 km diameter, 0.4 m s-1 swirl vel., cold/fresh core, generated in eastern upwelling)
- N^2 maximum shield the core from internal wave field – reduced mixing in core – but could support erosion of core (Kroll 1993)
- Energetic zones are identified that may support enhanced vertical mixing – one underneath the eddy, one close to the mixed layer -> vertical nutrient flux
- Recycling of NO_3 via PON decouples N and O, resulting in high AOU:N ratios

Further reading on "Eddy hunt" experiment

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Löscher, C. et al.: Hidden biosphere in an oxygen-deficient Atlantic open-ocean eddy: future implications of ocean deoxygenation on primary production in the eastern tropical North Atlantic, Biogeosciences, 12, 2015

Hauss, H. et al.: Dead zone or oasis in the open ocean? Zooplankton distribution and migration in low-oxygen modewater eddies, Biogeosciences, 13, 2016.

Fischer, G. et al.: Bathypelagic particle flux signatures from a suboxic eddy in the oligotrophic tropical North Atlantic: production, sedimentation and preservation, Biogeosciences, 13, 2016.

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Schütte, F., et al.: Characterization of "dead-zone" eddies in the tropical Northeast Atlantic Ocean, Biogeosciences Discuss.,, in review, 2016.

Karstensen, J., et al.: Upwelling and isolation in oxygen-depleted anticyclonic modewater eddies and implications for nitrate cycling, Biogeosciences Discuss., in review, 2016.

Grundle, D. et al.: Extreme N2O activity in an oxygenated ocean, Nature Scientific reports, revision submitted, 2016

Genomic

Zooplankton behaviour

Particle fluxes

Nutrient & carbon cycling

Occurrence & Characteristic

Submesoscale processes

Nitrogen cycling

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