The Challenges of Life at the Mesoscale and Submesoscale

Adrian Martin, Roz Pidcock,

John Allen, Stuart Painter, Meric Srokosz

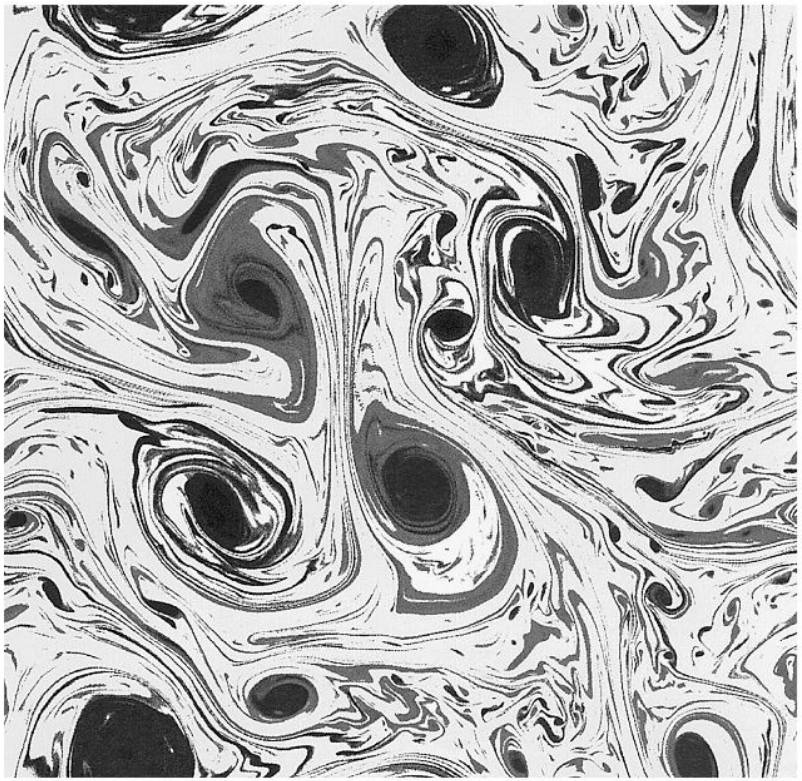
National
Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

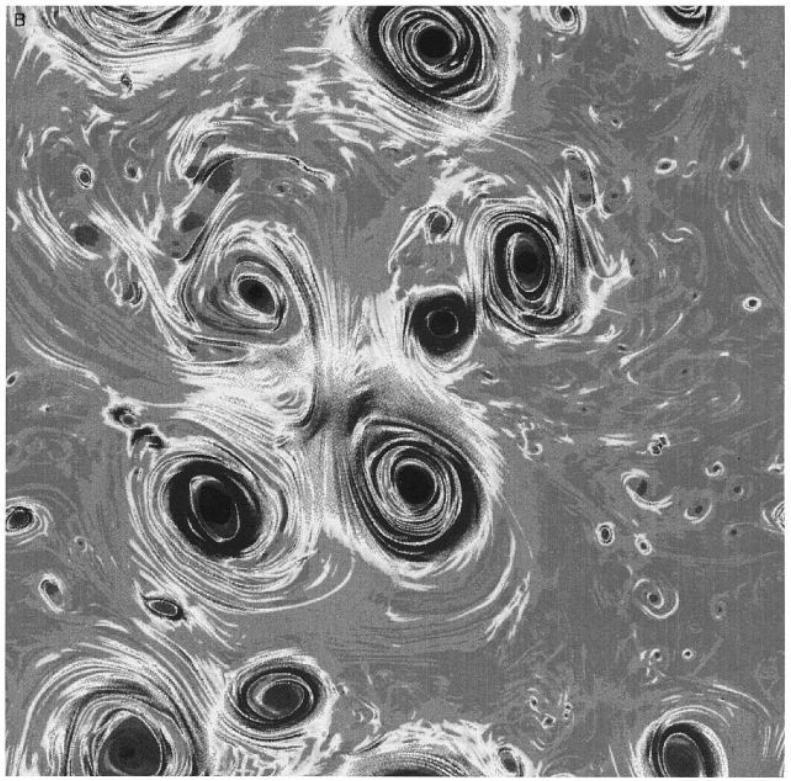
University of
Portsmouth

Motivation

- Mesoscale and sub-mesoscale processes may provide important nutrient fluxes to the surface
- Field measurements have focussed on individual mesoscale features
- Models suggest dynamics involving multiple features are important

Motivation





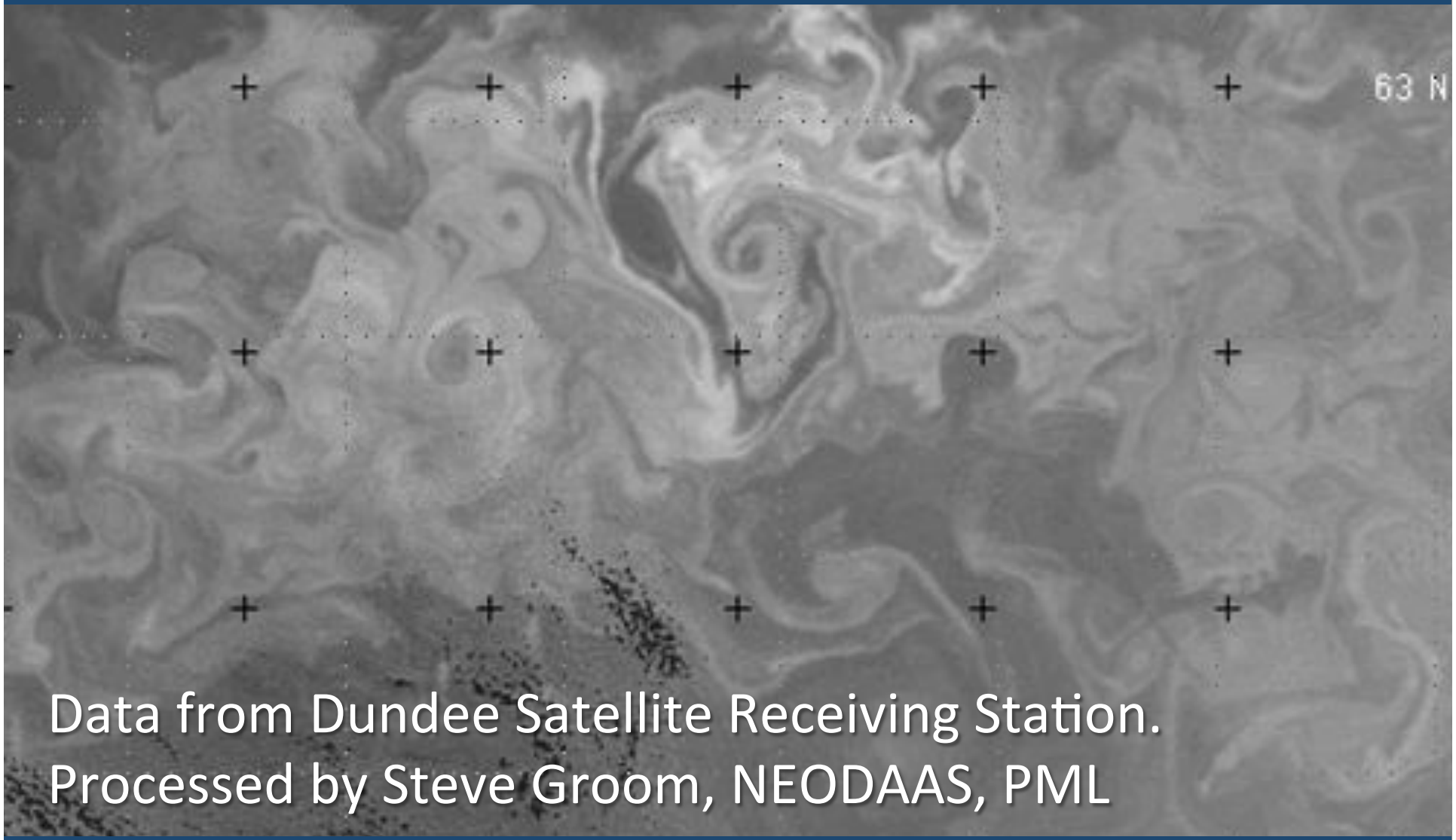
An exact criterion for the stirring properties
of nearly two-dimensional turbulence

B.L. Hua *, P. Klein

Physica D 113 (1998) 98–110

adrian.martin@noc.ac.uk

Real life is messy too



Data from Dundee Satellite Receiving Station.
Processed by Steve Groom, NEODAAS, PML

adrian.martin@noc.ac.uk

Questions

- How important is the ‘messy stuff’?
- How can we quantify it *in situ*?

adrian.martin@noc.ac.uk

Model estimates

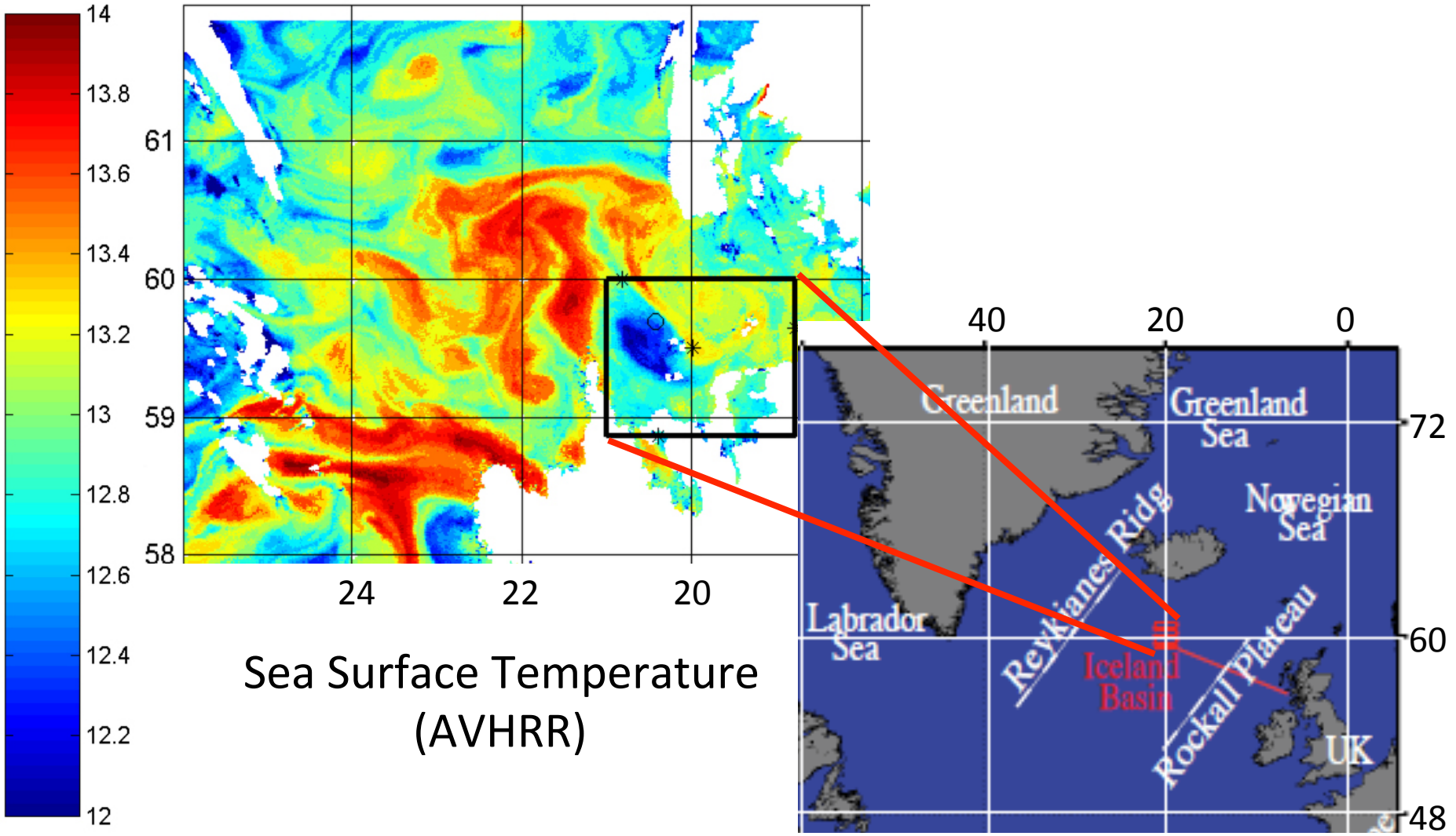
McGillicuddy et al. 2003 GBC

	OWSI
Horizontal transport[b]	−0.43 ± 0.19
Advection	−0.43 ± 0.19
Diffusion	0.00 ± 0.00
Vertical mixing[c]	1.76 ± 0.12
Convection	1.37 ± 0.09
Diffusion	0.39 ± 0.03
Vertical advection	0.14 ± 0.17
Annual new production	1.47 ± 0.02

mol N m^{-2} y^{-1}

adrian.martin@noc.ac.uk

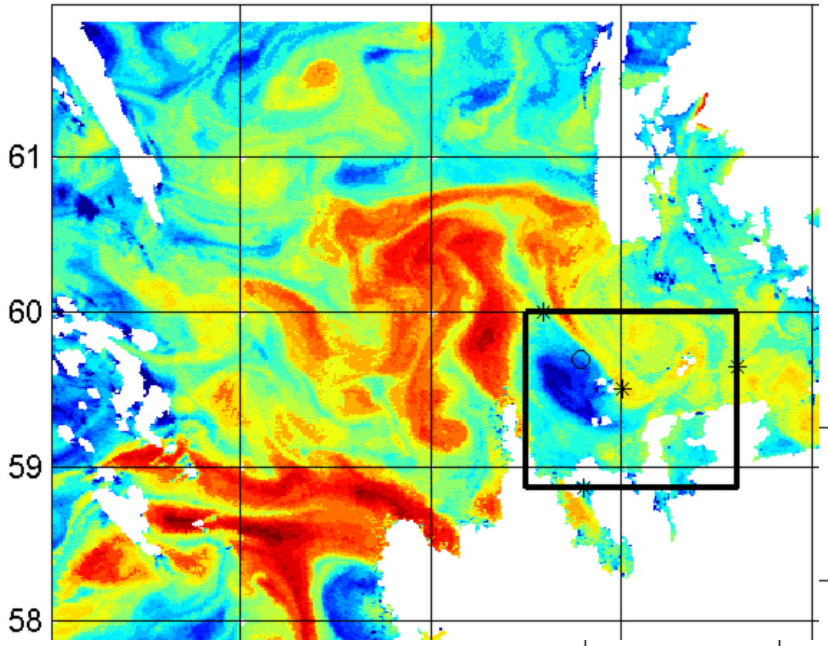
RRS Discovery cruise 321 – July-August 2007



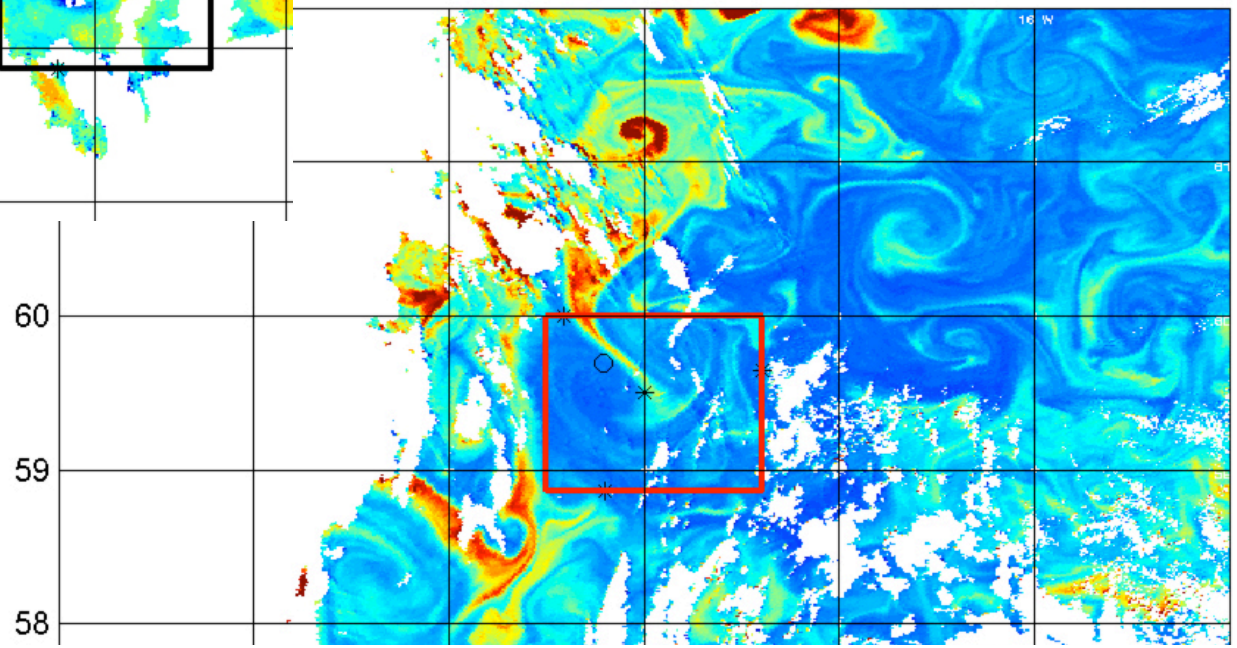
Sea Surface Temperature (AVHRR)

Life at the mesoscale
adrian.martin@noc.ac.uk

Context



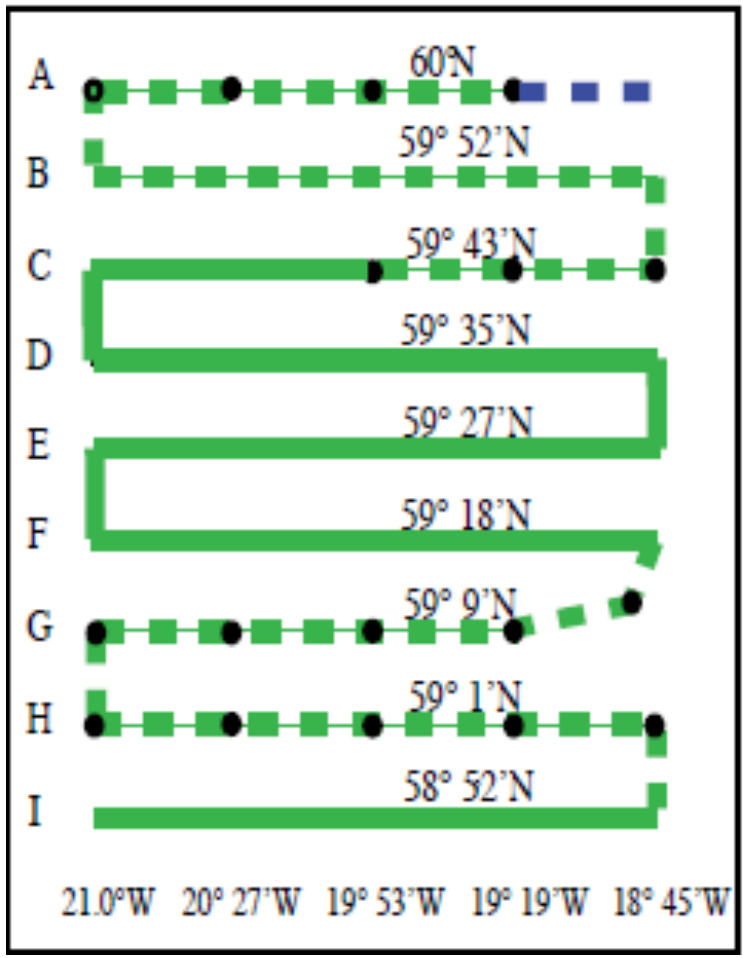
Sea Surface Temperature
(AVHRR)



Chlorophyll
(MODIS)

adrian.martin@noc.ac.uk

Estimating the mesoscale flux



Vertical velocities (w) calculated from Omega equation

SeaSoar equipped with SUV-6 nitrate sensor

Simultaneous 3D map of w and nitrate

adrian.martin@noc.ac.uk

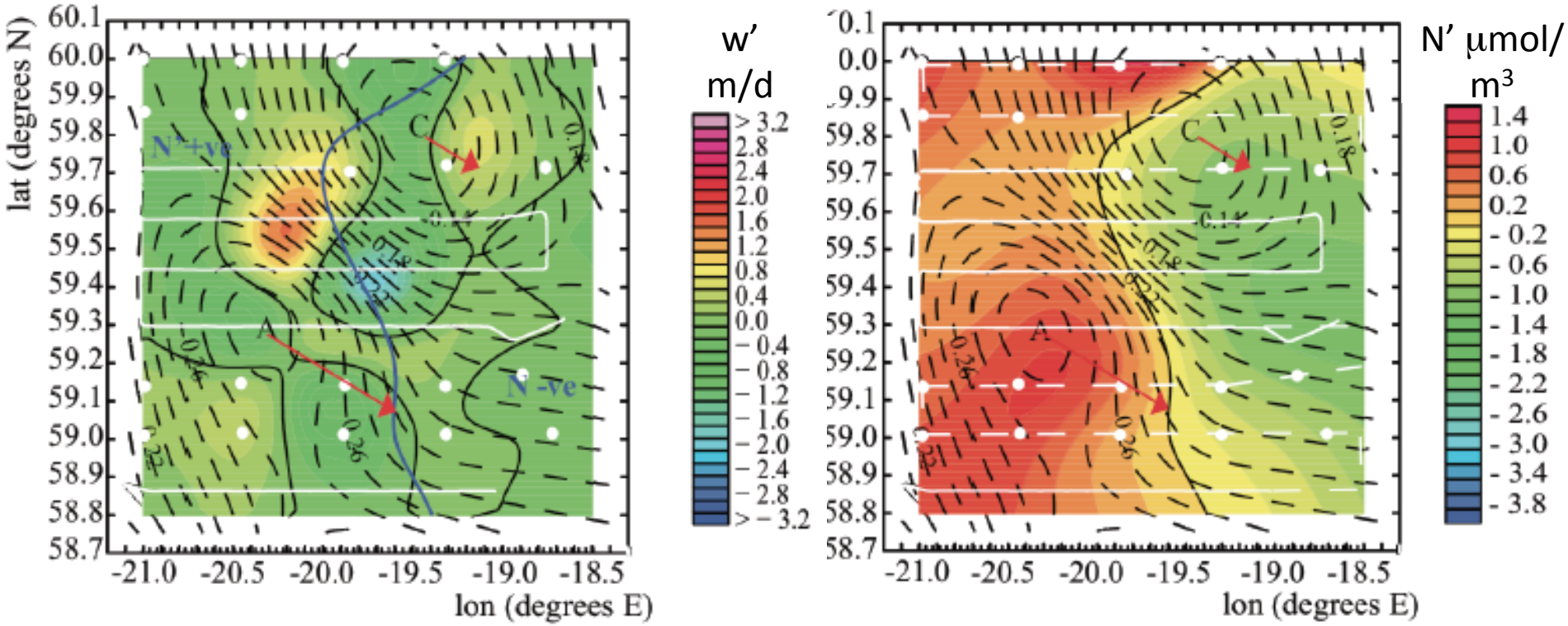
Fluxes

Flux estimates at 100m

	$\overline{w'N'}$	$w_{RMS}\bar{N}$	$\overline{wN}$
Naveira-Garabato et al., (2002)	- 0.04	-	-
Lapeyre & Klein (2006)	-	0.08	-
Present study	0.0069	0.02	- 1.54

All figures in (mol N m^{-2} yr^{-1}).

Complications #1



Nitrate and vertical velocity are not correlated

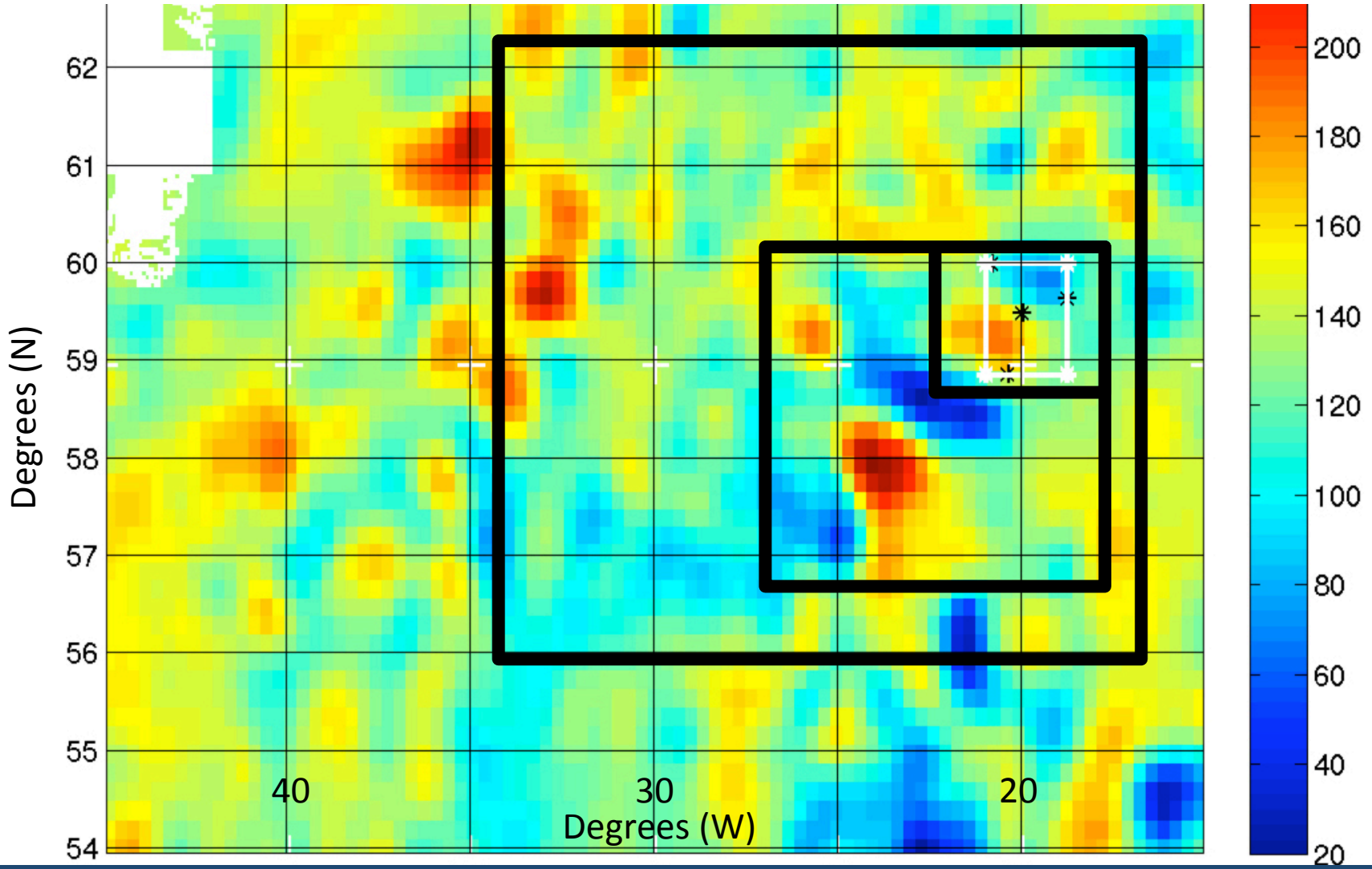
Complications #2

- **Mean vertical velocity for 'box' is non-zero:**

  <w>=0.23m/d

- **As a result the flux estimate is biased**
- **Need to calculate estimate over a region for which <w>=0**

How big a box do you need?



adrian.martin@noc.ac.uk

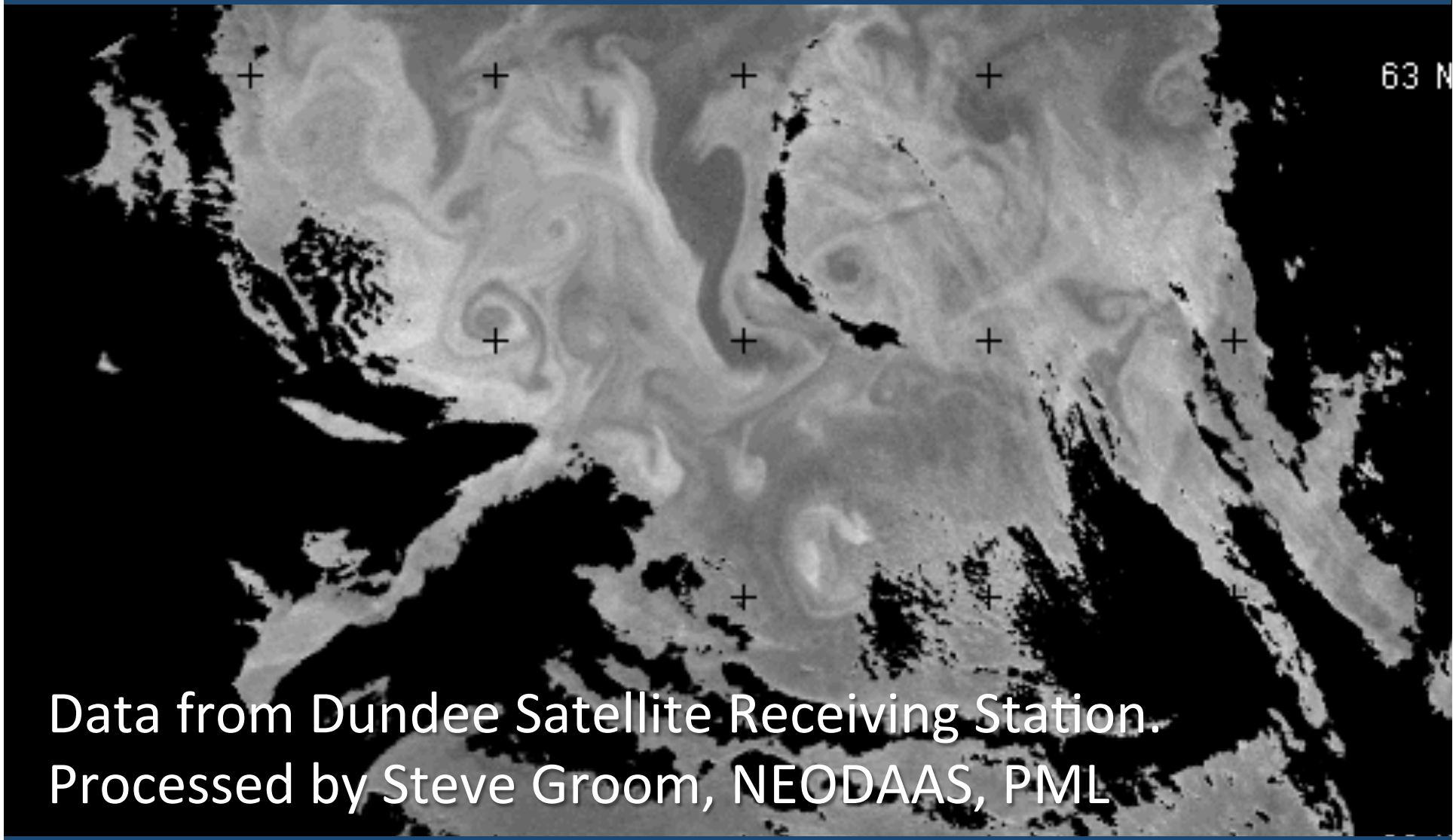
Summary

- We cannot accurately sample a region large enough to estimate the mesoscale nutrient flux
- We cannot rely on correlations between vertical velocities and nutrients
- We still have no observational estimate for the mesoscale nitrate flux in a typical square of ocean

adrian.martin@noc.ac.uk

The End

How messy is ‘messy’?



Data from Dundee Satellite Receiving Station.
Processed by Steve Groom, NEODAAS, PML

Life at the mesoscale
adrian.martin@noc.ac.uk

Budgeting nitrate and production

Table 6. Simulated Nitrate Budgets and Annual New Production at Four Different Sites in the North Atlantic[a]

	BATS	NABE	OWSI	EUMELI
Horizontal transport[b]	0.04 ± 0.01	0.23 ± 0.07	−0.43 ± 0.19	0.00 ± 0.01
Advection	0.04 ± 0.01	0.23 ± 0.07	−0.43 ± 0.19	0.00 ± 0.01
Diffusion	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Vertical mixing[c]	0.47 ± 0.04	1.32 ± 0.11	1.76 ± 0.12	0.05 ± 0.01
Convection	0.37 ± 0.03	1.02 ± 0.09	1.37 ± 0.09	0.00 ± 0.00
Diffusion	0.10 ± 0.01	0.30 ± 0.03	0.39 ± 0.03	0.05 ± 0.01
Vertical advection	0.12 ± 0.01	−0.09 ± 0.07	0.14 ± 0.17	0.05 ± 0.01
Annual new production	0.63 ± 0.04	1.48 ± 0.03	1.47 ± 0.02	0.10 ± 0.01

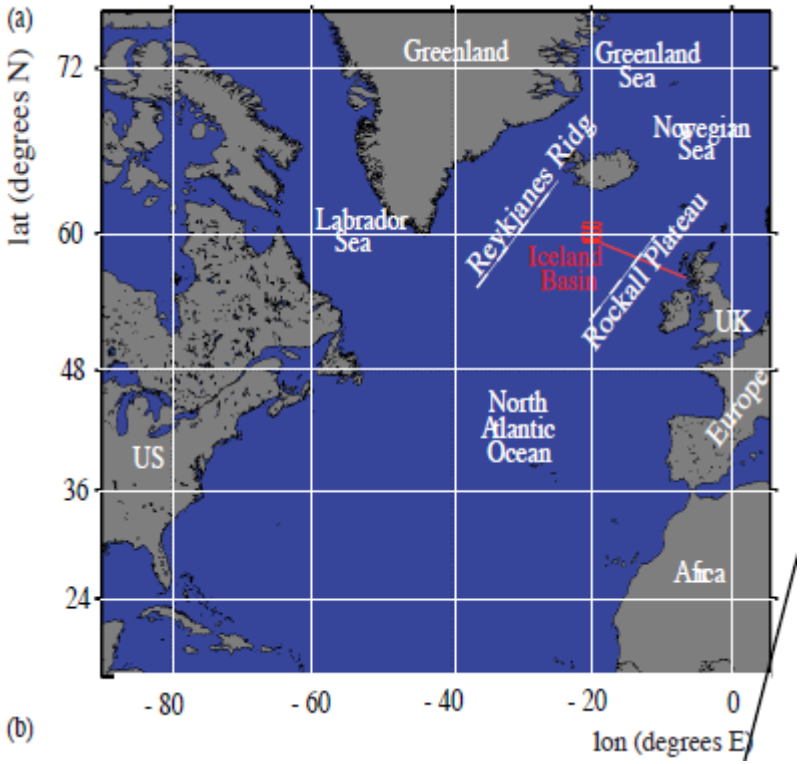
[a]Nitrate budgets and new production are in mol N m^{-2} yr^{-1}. Standard deviations are computed from yearly means and thus reflect interannual variability only.
[b]Horizontal transport is the sum of advection and diffusion.
[c]Vertical mixing is the sum of convection and diffusion.

McGillicuddy et al. 2003 GBC

	OWSI
Horizontal transport[b]	−0.43 ± 0.19
Advection	−0.43 ± 0.19
Diffusion	0.00 ± 0.00
Vertical mixing[c]	1.76 ± 0.12
Convection	1.37 ± 0.09
Diffusion	0.39 ± 0.03
Vertical advection	0.14 ± 0.17
Annual new production	1.47 ± 0.02

D321 – Iceland Basin 2007

- What scientific questions motivated the field experiment initially?
- What instruments were selected (and why) to conduct this experiment?
- What was the deployment strategy (orientation of the sections, spatial and temporal resolution of the data collection, ...)?
- Was satellite data used before/during/after the experiment?
- What challenges were encountered during
- the experiment (instrument failures, weather
- condition, presence of dynamical features not
- well captured by the deployment strategy
- (unexpected ones or expected features but with
- different scales, ...), scientific questions not well
- defined enough)?
- In light of the past experience and of the available technology or possible near future technology developments, how would the scientific questions be reformulated and how could a new experiment be designed to address these questions?



24 July-23 August 2007

D321 – Iceland Basin 2007

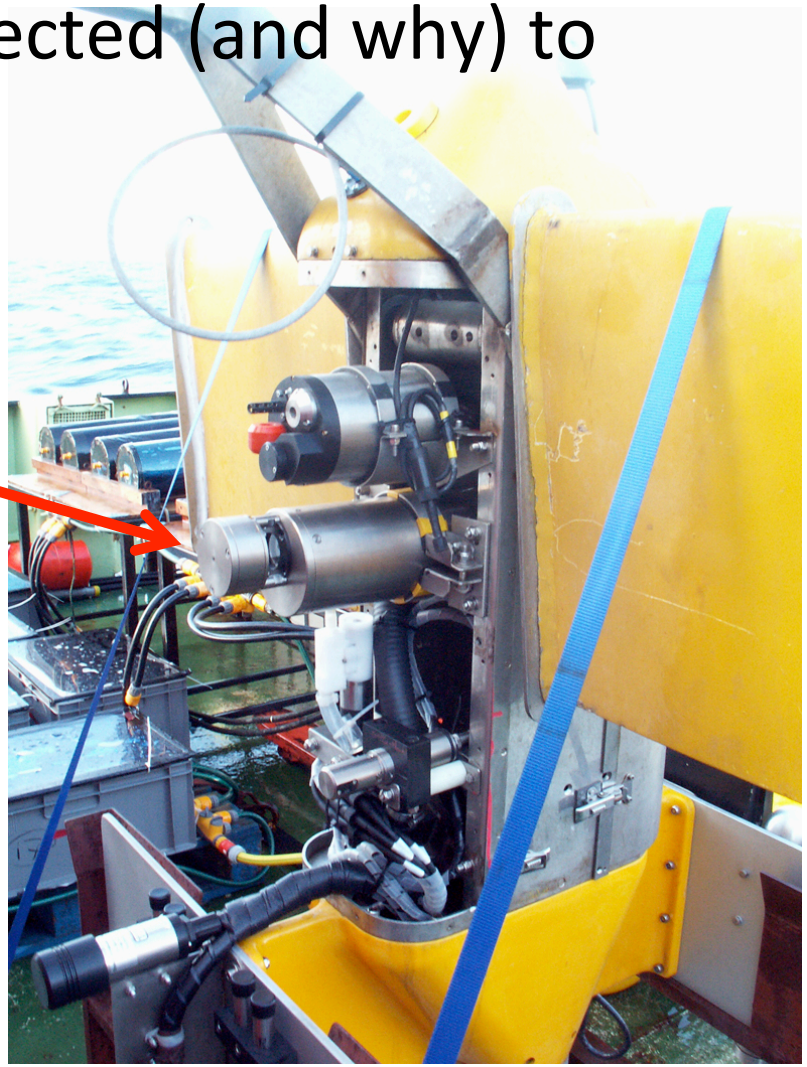
- What instruments were selected (and why) to conduct this experiment?

SeaSoar equipped with

SUV-6 nitrate sensor

- simultaneous 3D map of hydrography and NO3
- high spatial resolution
- synoptic (8 kts / 15km/h)

Also CTD and bottle samples



STOP PRESS

D381 – 47N 16.5W – Oct 2012

- What was the deployment strategy?

2 SeaSoar surveys,

2 CTD surveys

130x130km box,

tracks ~14km

apart

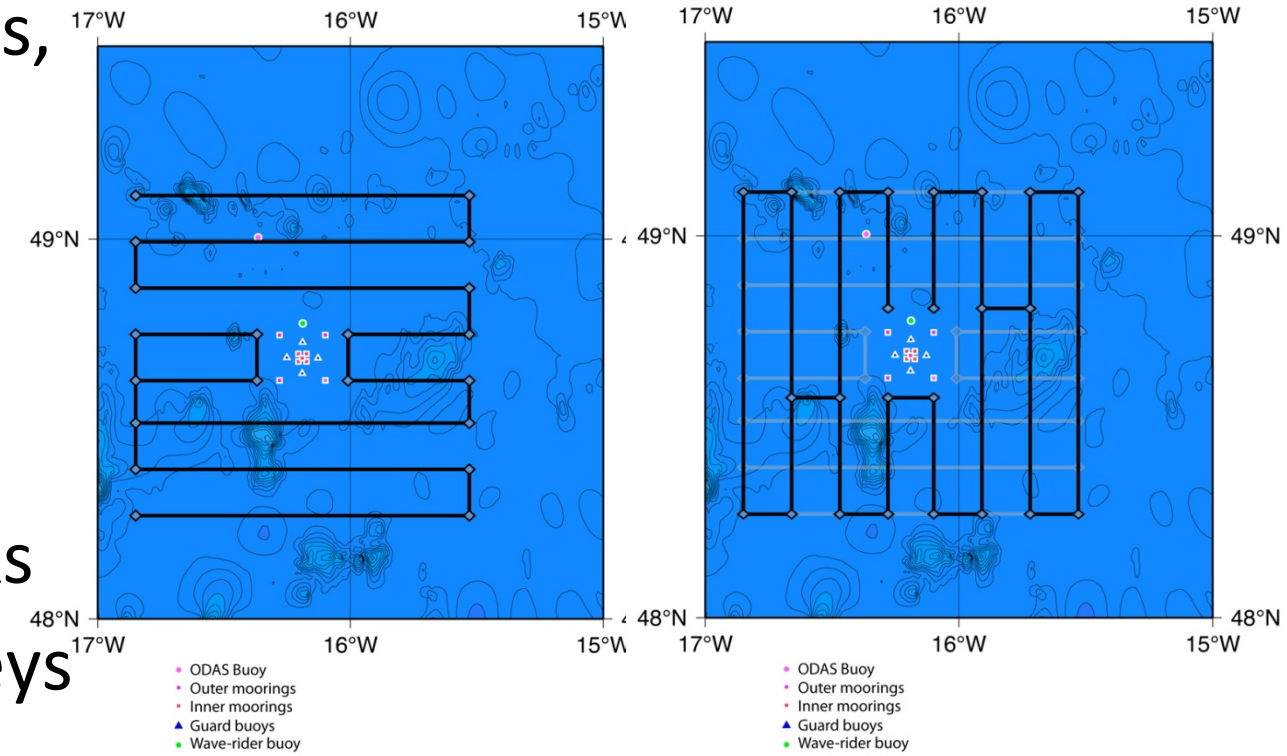
Orthogonal tracks

between surveys

Horiz. Resolution

2-4km SeaSoar,

~30km CTD



D321 – Iceland Basin 2007

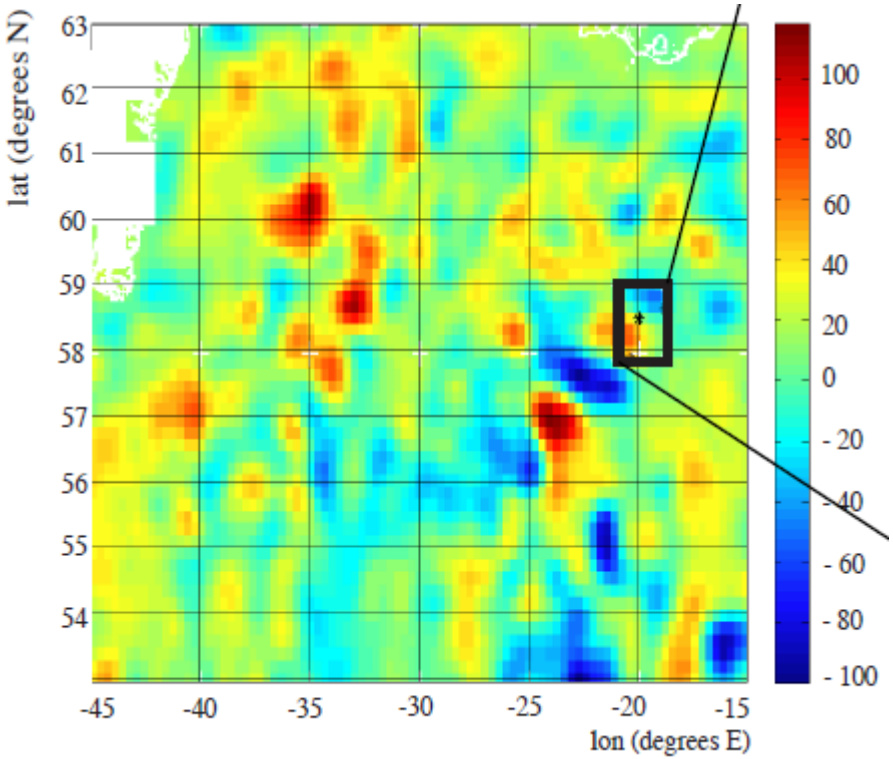
- Was satellite data used before/during after the experiment?

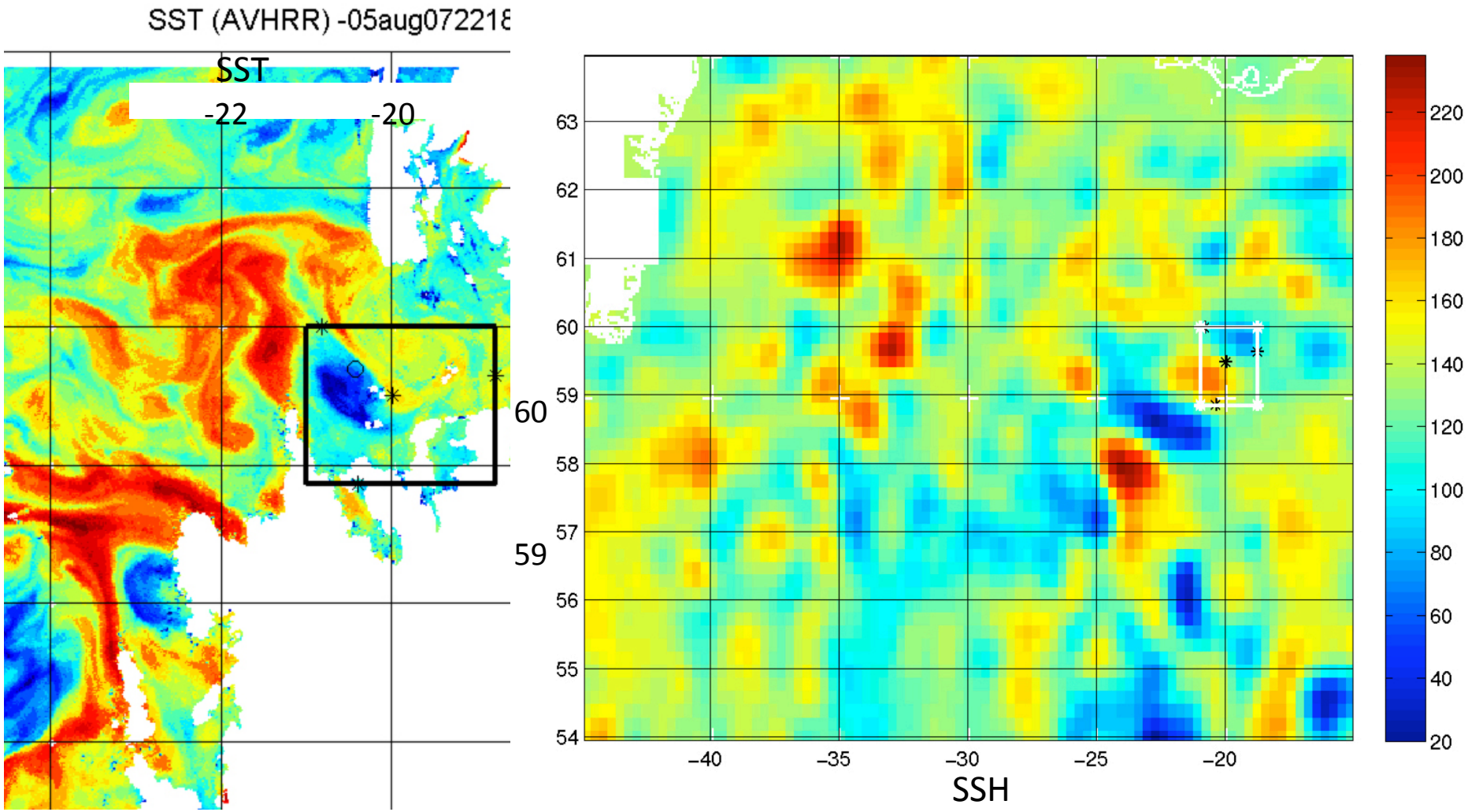
Yes but largely qualitative supporting role.

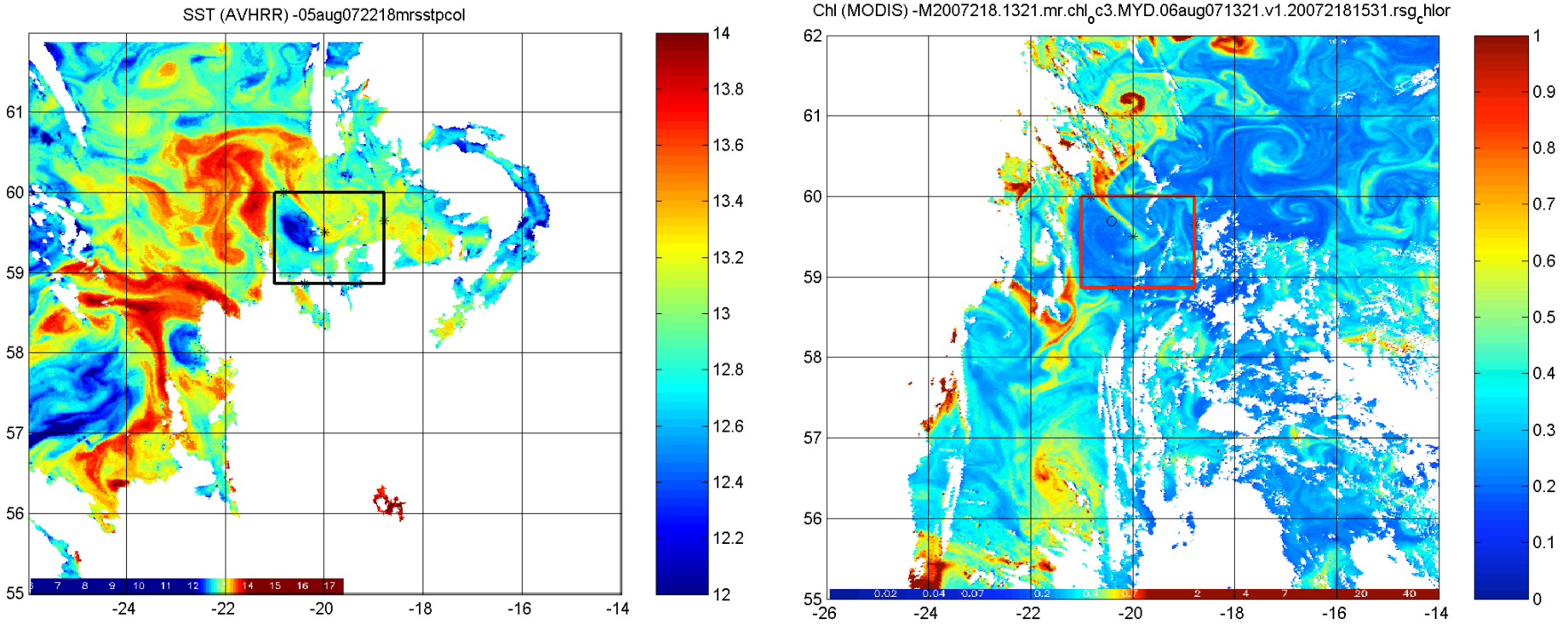
Identified dipole

Colour gave indication of strong jet

Altimetry backed up hydrography and ADCP in inferring movement of dipole

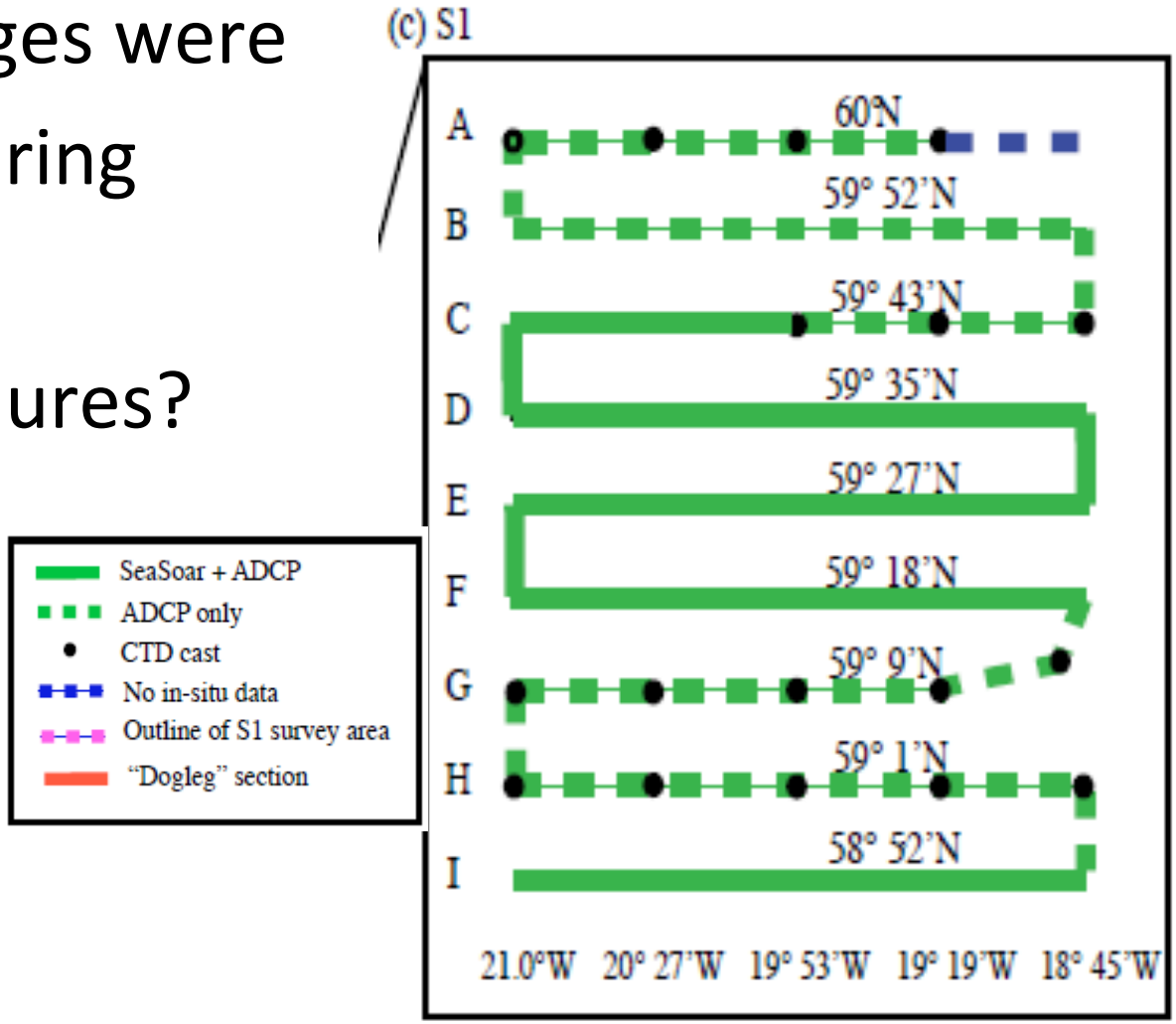



SST (AVHRR) -05aug072218
SST
-22
-20
60
59
63
62
61
60
59
58
57
56
55
54
−40
−35
−30
−25
−20
SSH
220
200
180
160
140
120
100
80
60
40
20


SST (AVHRR) -05aug072218mrsstpcol
61
60
59
58
57
56
55
-24
-22
-20
-18
-16
-14
14
13.8
13.6
13.4
13.2
13
12.8
12.6
12.4
12.2
12
Chl (MODIS) -M2007218.1321.mr.chl_oc3.MYD.06aug071321.v1.20072181531.rsg_chlor
62
61
60
59
58
57
56
55
-26
-24
-22
-20
-18
-16
-14
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

D321 – Iceland Basin 2007

- What challenges were encountered during the experiment
  - instrument failures?



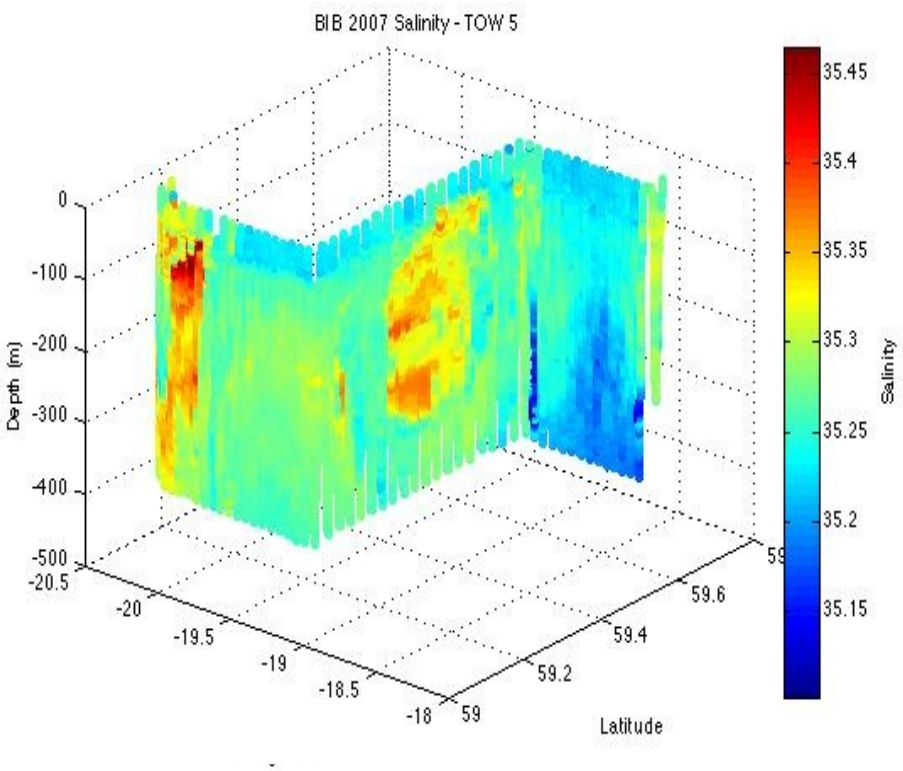
D321 – Iceland Basin 2007

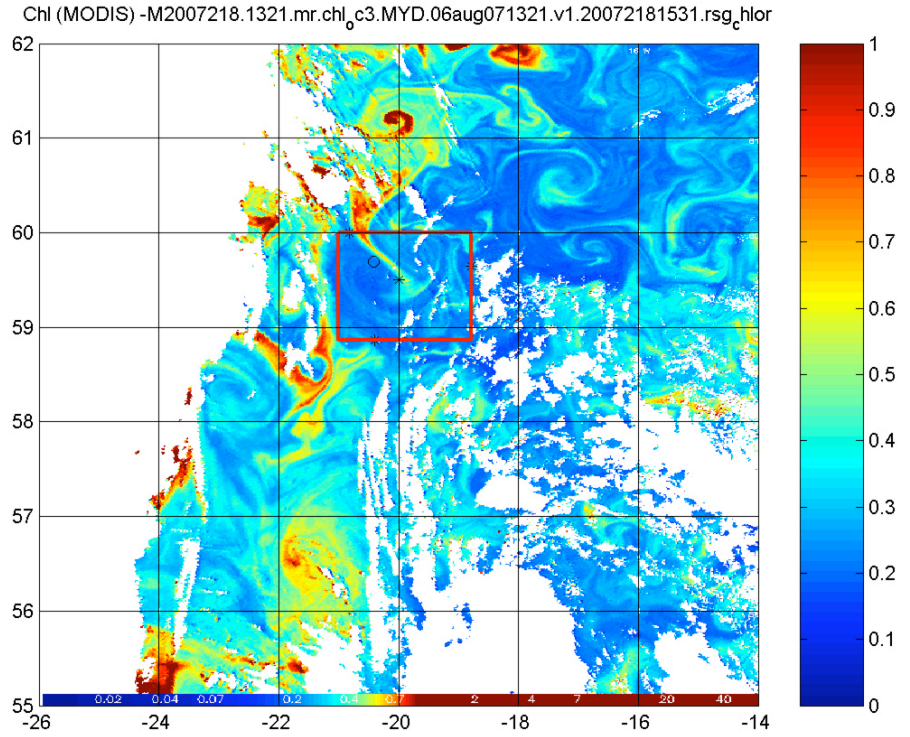
- What challenges were encountered during the experiment - presence of dynamical features not well sampled

Not the obvious answer

- dipole was well sampled...

Filaments


BIB 2007 Salinity - TOW 5
Depth (m)
0
-100
-200
-300
-400
-500
-20.5
-20
-19.5
-19
-18.5
-18
59
59.2
59.4
59.6
Latitude
35.45
35.4
35.35
35.3
35.25
35.2
35.15
Salinity


Chl (MODIS) -M2007218.1321.mr.chl_oc3.MYD.06aug071321.v1.20072181531.rsg_chlor
62
61
60
59
58
57
56
55
-26
-24
-22
-20
-18
-16
-14
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

D321 – Iceland Basin 2007

- What challenges were encountered during the experiment - presence of dynamical features not well sampled

How big does a box need to be to do a budget?

i.e. How big a box is needed for sum of vertical velocities to be near zero? ....

Allen et al. "Diagnosing vertical velocities with the QG omega equation: an examination of the errors due to sampling strategy", 2001. Deep Sea Research (1), **48**, 315-346

Table 1. Values of $\overline{N}$, $\overline{w}$, $\overline{w'N'}$ and $\overline{wN}$ at 50 m and 98 m for S1.

	50 m	98 m
$\overline{N}$ (mmol m^{-3})	9.13	11.28
$\overline{w}$ (m day^{-1})	-0.23	- 0.38
$\overline{w'N'}$ (mol N m^{-2} yr^{-1})	+ 0.0082	+ 0.0069
$\overline{w'N'}$ (mmol N m^{-2} day^{-1})	+ 0.022	+ 0.019
$\overline{wN}$ (mol N m^{-2} yr^{-1})	- 0.76	- 1.54
$\overline{wN}$ (mmol N m^{-2} day^{-1})	- 2.08	- 4.2

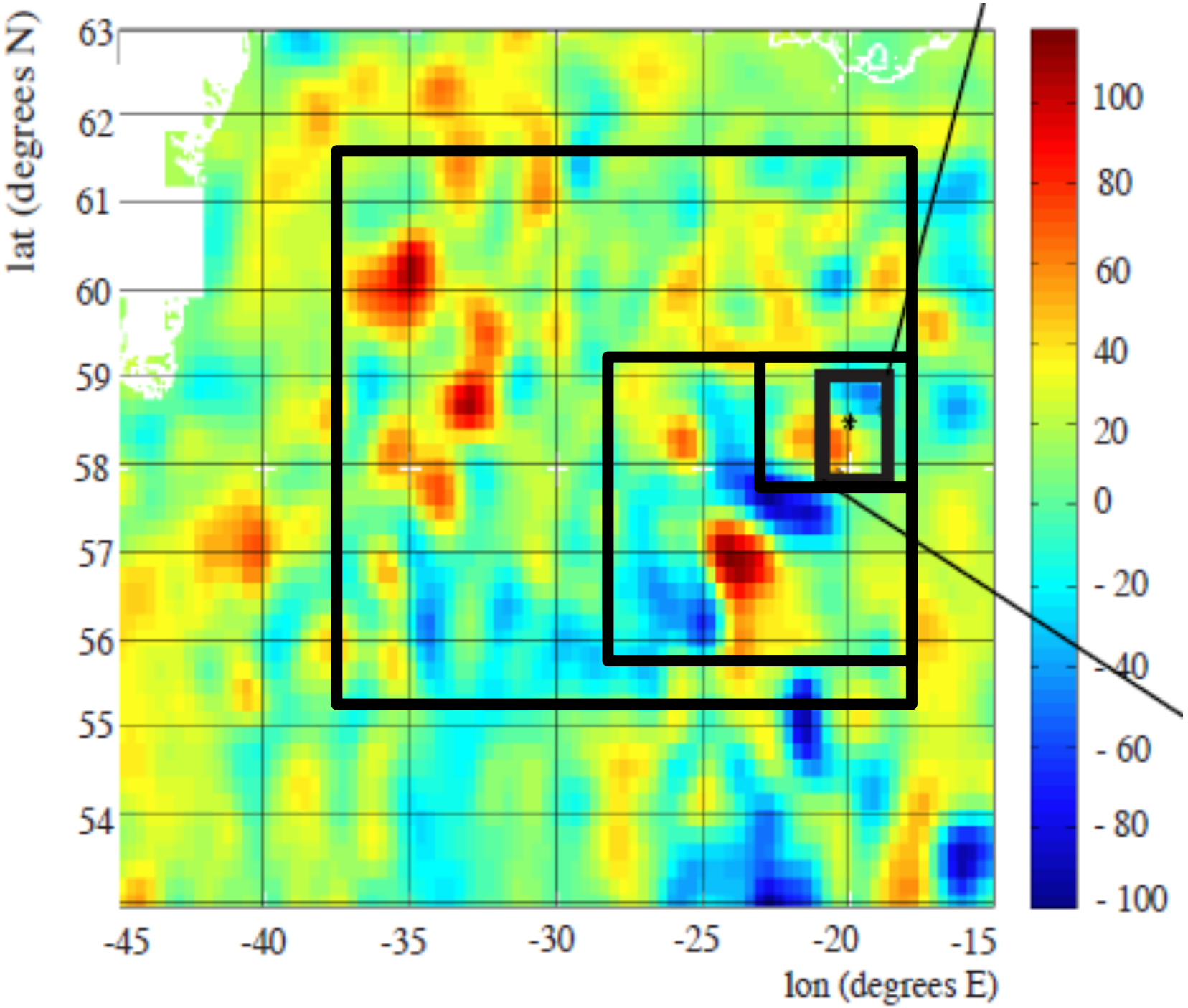
Table 2. Literature comparison of areal mean mesoscale nitrate flux rates.

	$\overline{w'N'}$	$w_{RMS}\overline{N}$	$\overline{wN}$
Naveira-Garabato et al., (2002)	- 0.04 *	-	-
Lapeyre & Klein (2006)	-	0.08 *	-
Present study	0.0069 **	0.02 *	- 1.54 *

All figures in (mol N m^{-2} yr^{-1}).

* net flux at 100 m

** net flux at 98 m


lat (degrees N)
63
62
61
60
59
58
57
56
55
54
-45
-40
-35
-30
-25
-20
-15
lon (degrees E)
100
80
60
40
20
0
- 20
- 40
- 60
- 80
- 100

D321 – Iceland Basin 2007

- What challenges were encountered during the experiment - presence of dynamical features not well sampled

How can cruise results be scaled up?

Dipole not immediately amenable to SQG ...

...need to take deeper structure into account...

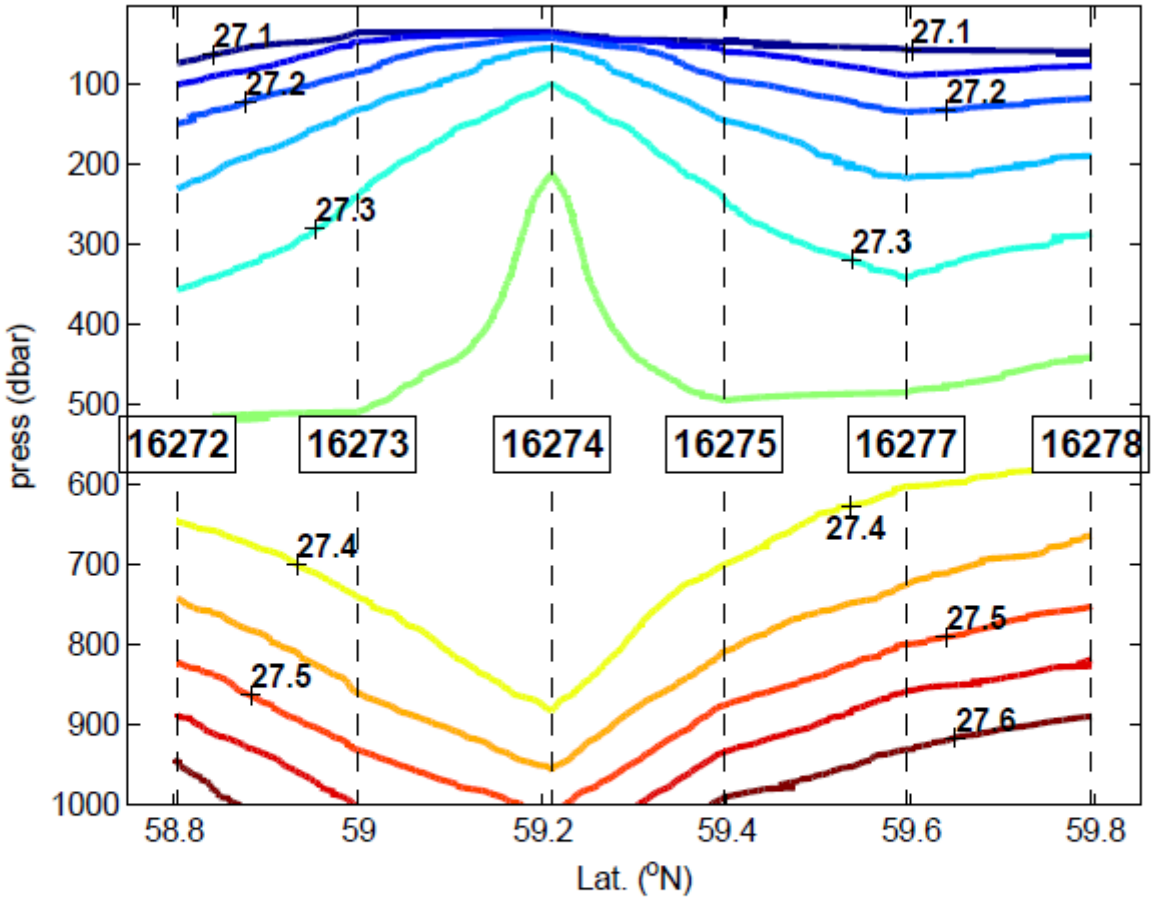


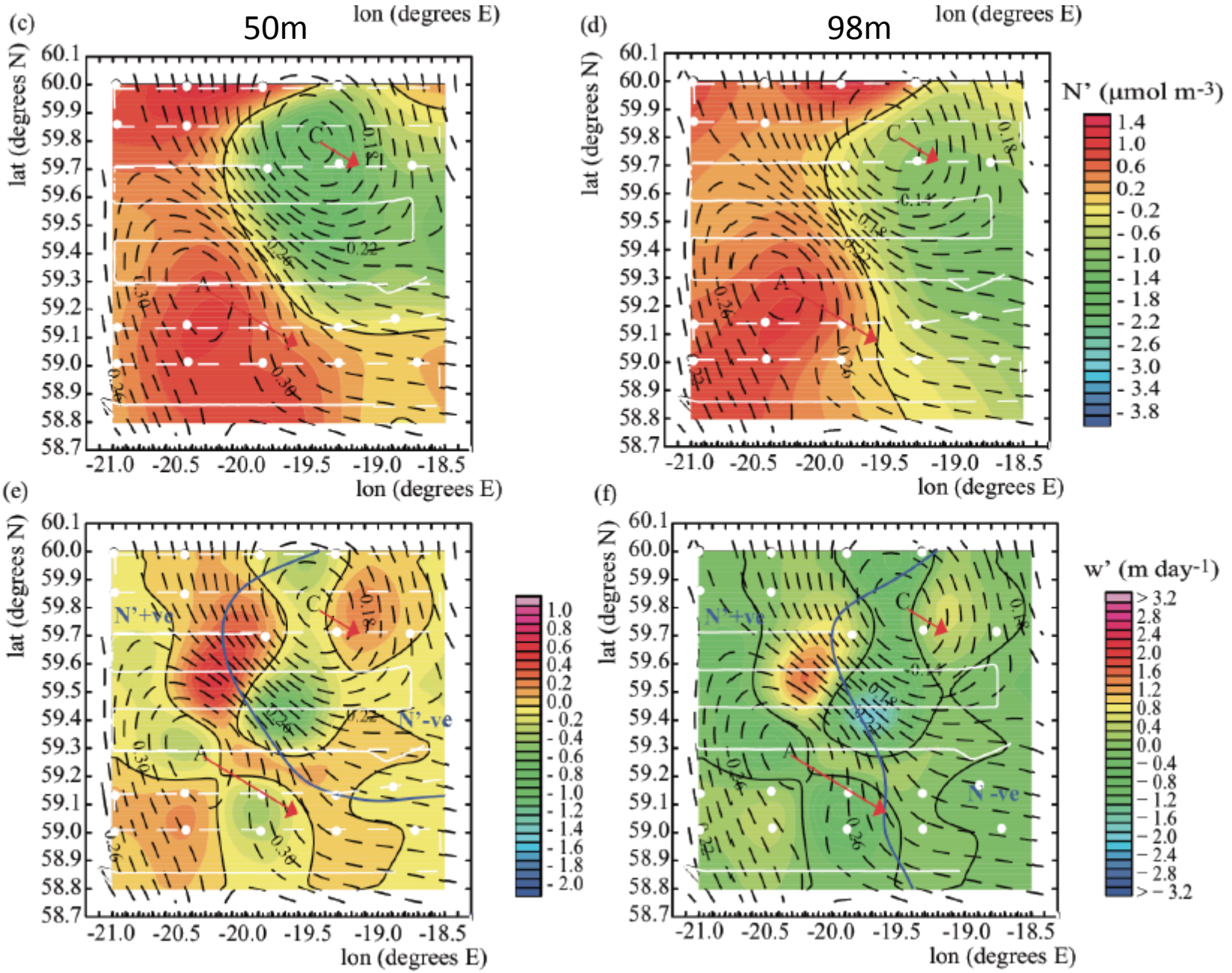
FIGURE 4.2: A contoured cross section of potential density (σ_o contours are shown every 0.05 kg m^{-3}) through the mode-water eddy core from conductivity-temperature-depth (CTD) stations 16272 to 16278 from survey two (see Figure 4.1 for station locations). σ_o is potential density calculated with respect to 0 dbar pressure minus 1000 kg m^{-3}. The position of each CTD station is indicated.

Forryan, PhD thesis, 2011

D321 – Iceland Basin 2007

- What challenges were encountered during the experiment – correlations

Vertical velocity and nitrate field were not...



Pidcock et al., in preparation

D321 – Iceland Basin 2007

- In light of the past experience (practice, acquired knowledge) and of the available technology or possible near future technology developments, how would the scientific questions be reformulated and how could a new experiment be designed to address these questions?

SeaSoar and SUV-6 now a proven key tool

Gliders too slow

…. need a fleet and a novel deployment/ management structure (Leonard 2008 ???)

SQG needs thought in environment with mode water eddies

2 ships needed? But only one SeaSoar-SUV6 combination extant