THE INTERANNUAL VARIABILITY OF THE INDONESIAN THROUGHFLOW from 20 years of repeat XBT data

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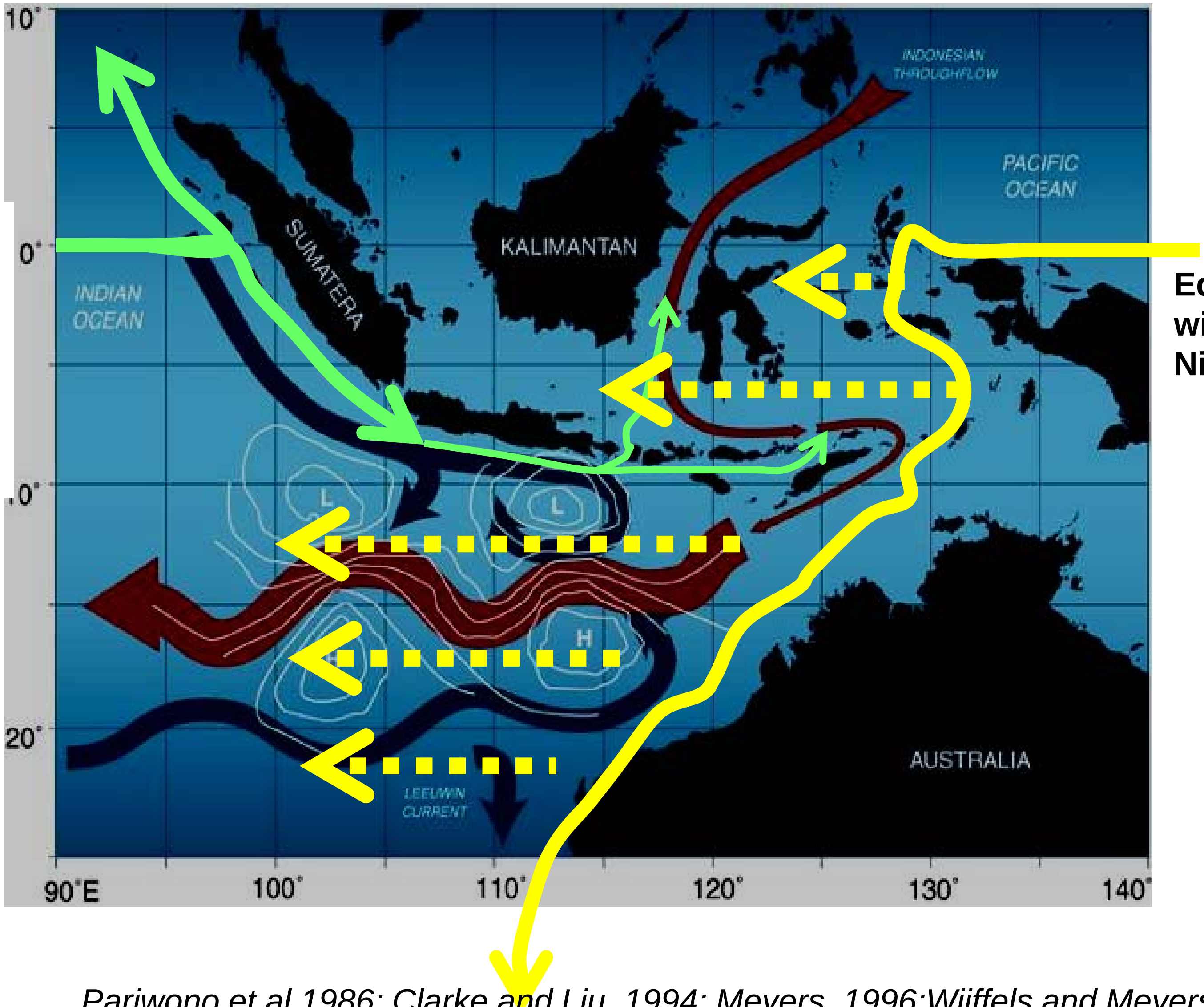
THANKS to: volunteer observers and ship operators

Australian Bureau of Meteorology

CSIRO

Interannual ocean variability in this region is strong! Meyers (1996) showed it is as large at the annual cycle

Equatorial Indian Ocean wind energy: Indian Ocean Dipole

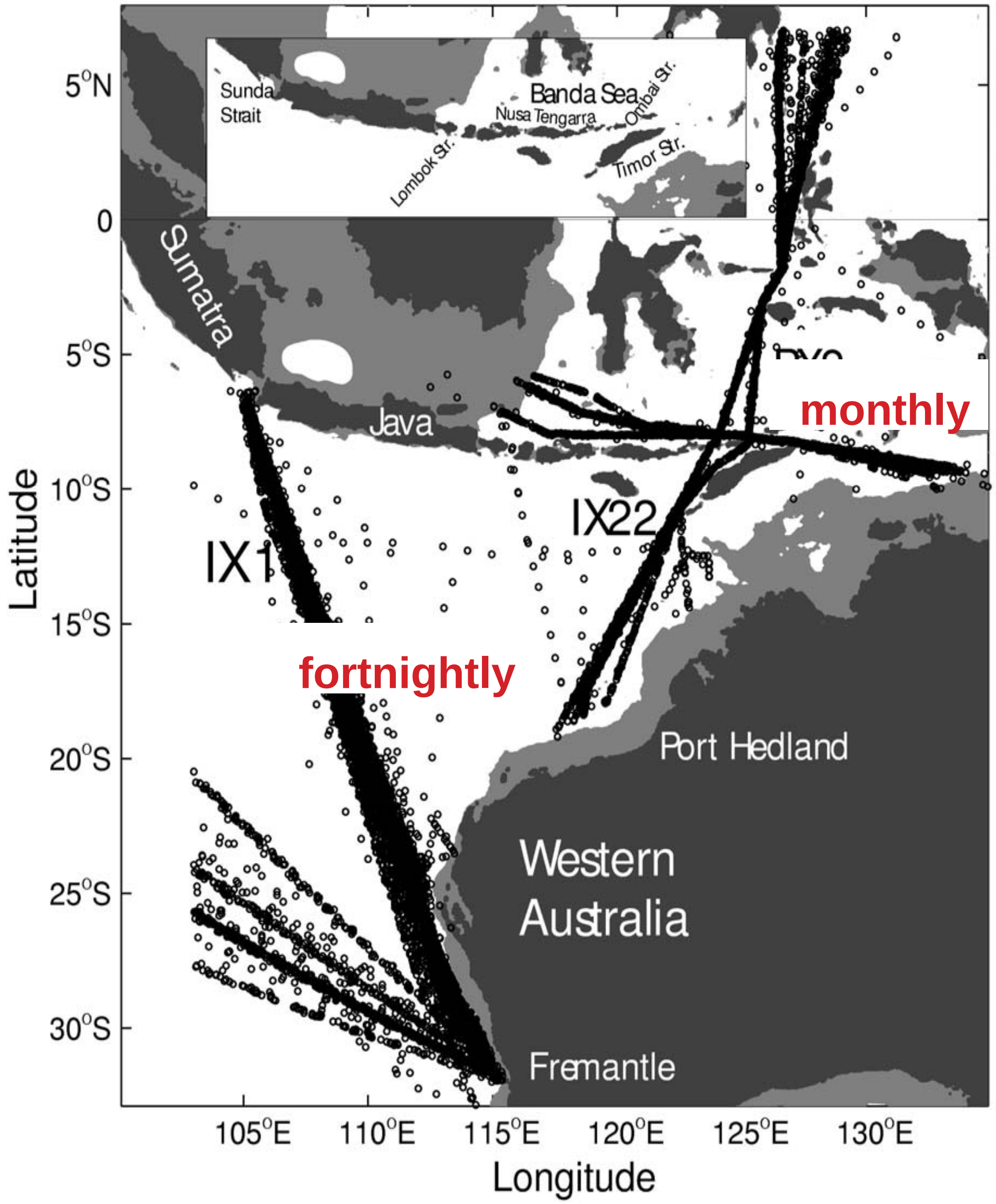


Equatorial Pacific wind energy (El Nino)

Pariwono et al 1986; Clarke and Liu, 1994; Meyers, 1996;Wijffels and Meyers, 2004.

Frequently Repeated XBT lines:

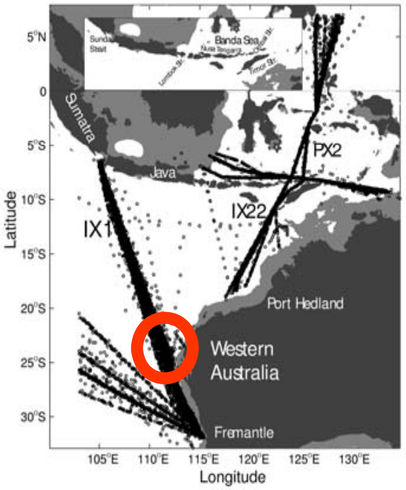
- 1984-present
- More than > 20 years of consistent data collection!
- low spatial resolution (~1degree)
- require substantial averaging due to internal tides - especially east of 115E

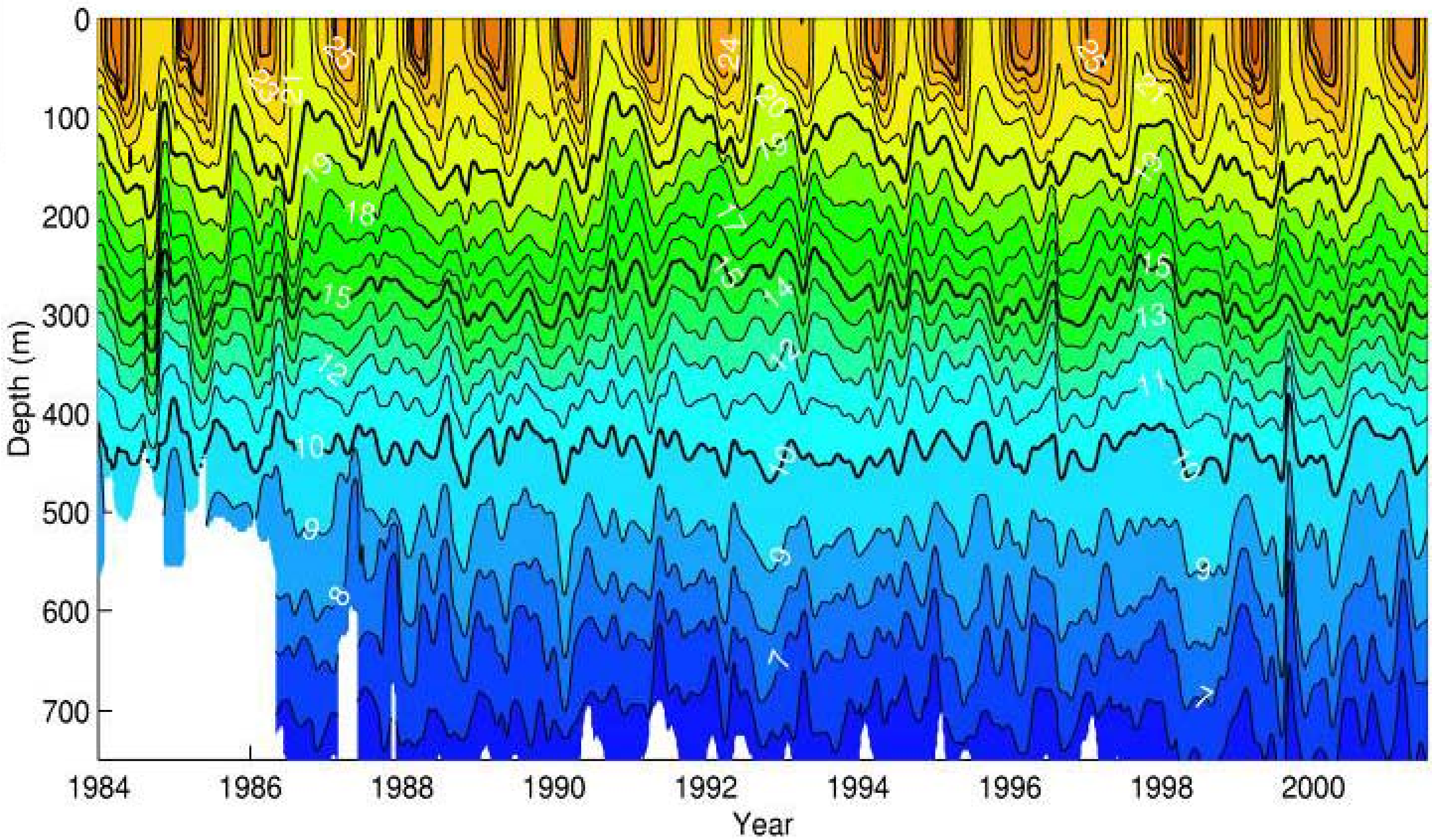


Analysis

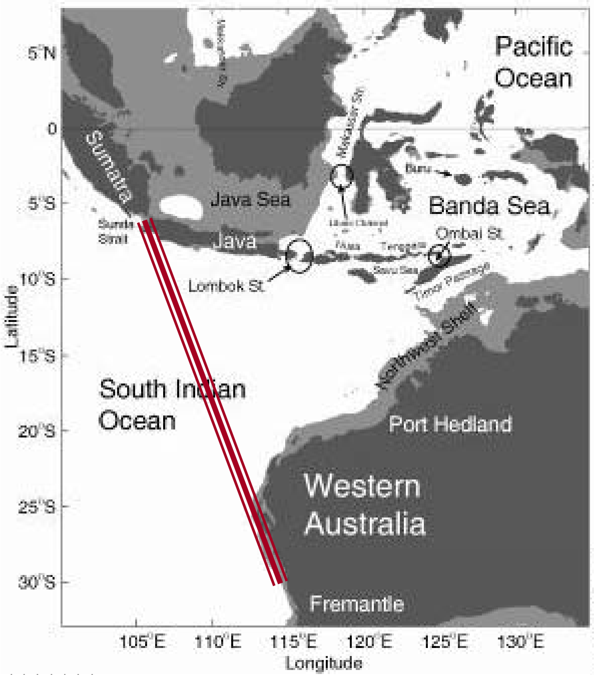
- data are all quality controlled by expert inspection and vertically filtered to a 5m grid
- mean and seasonal cycle fitted on a 50km grid along each XBT line to a quadratic spatial and seasonal harmonic model – care was taken to avoid mixing data across island chains
- residuals from the seasonal cycle were remapped with resolving timescales > 9 months
- density found using the CARS seasonally varying T/S relationship
- geostrophic velocity calculated relative to 750m or the bottom along each line
- Ekman velocity based on NCEP winds was linearly distributed over the mixed layer diagnosed from the XBT data

Temperature variability off Shark Bay, WA.

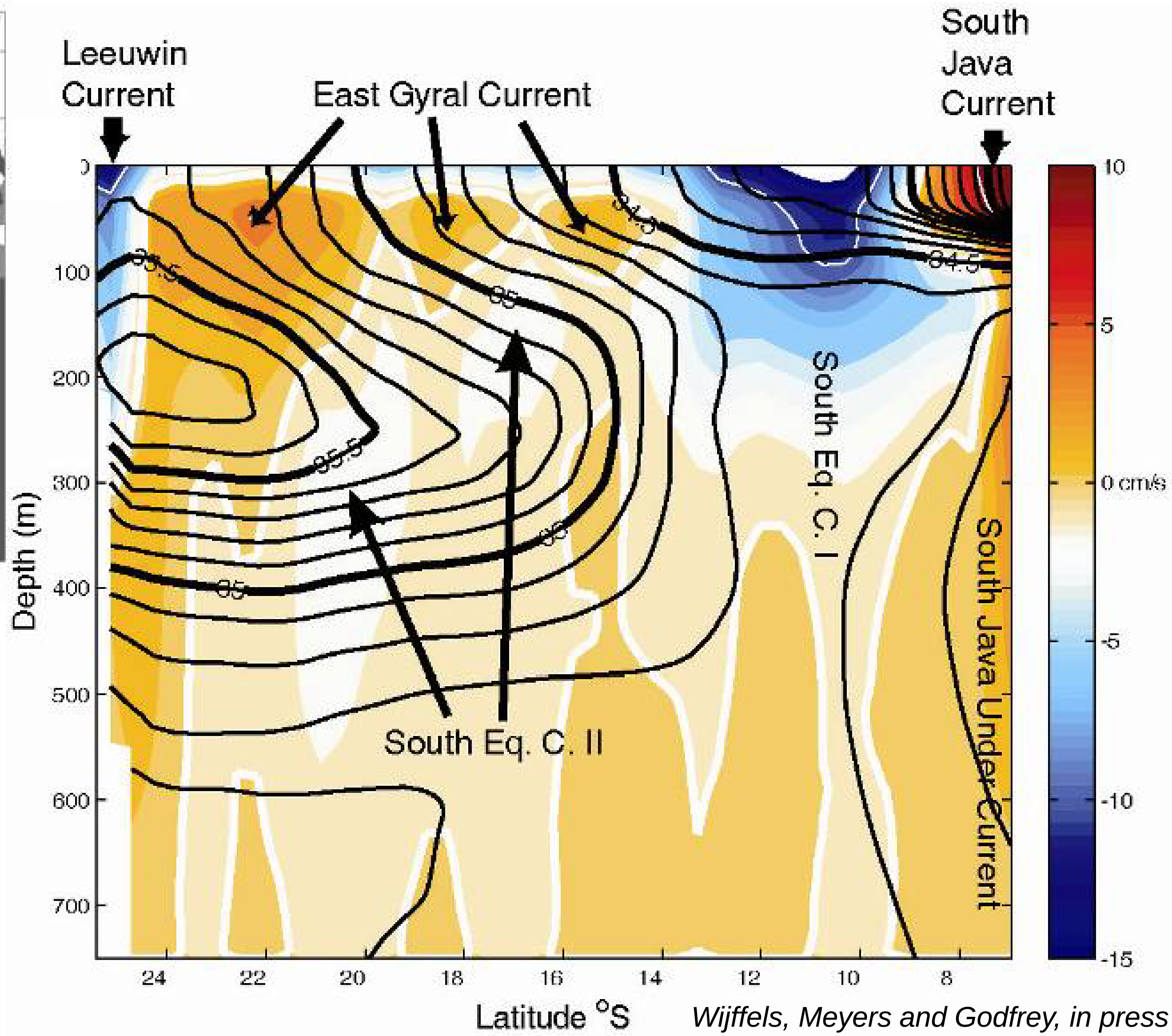




IX1 Total Velocity Structure: Fremantle – Sunda Strait

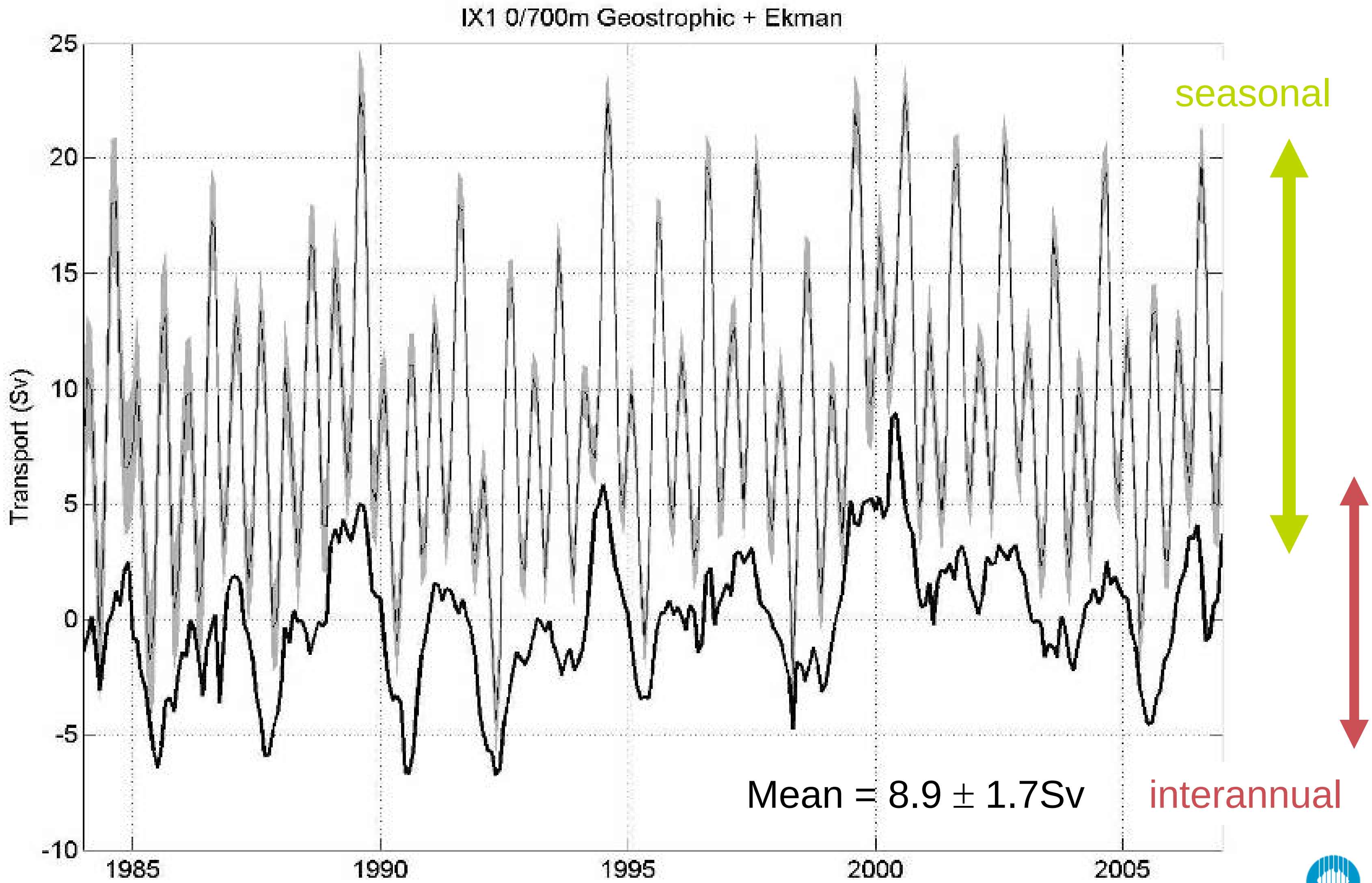


IX1

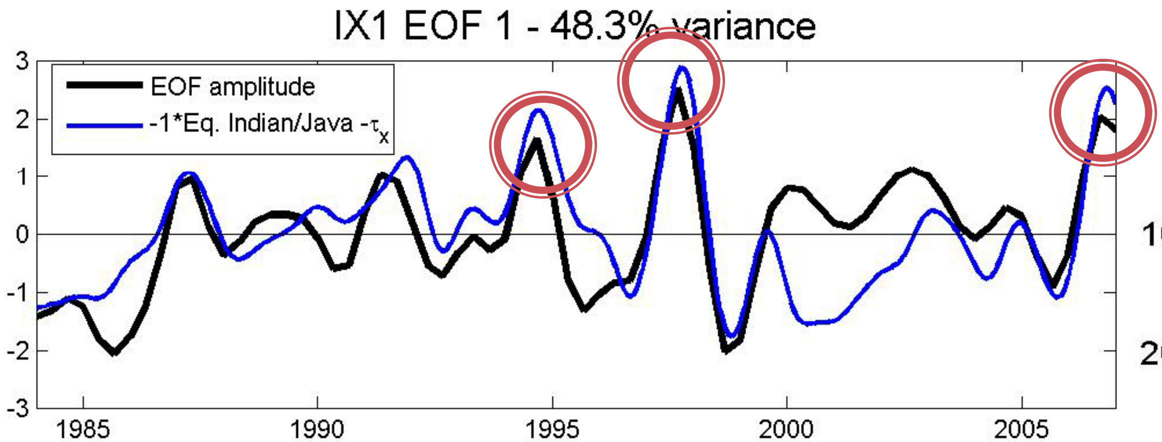


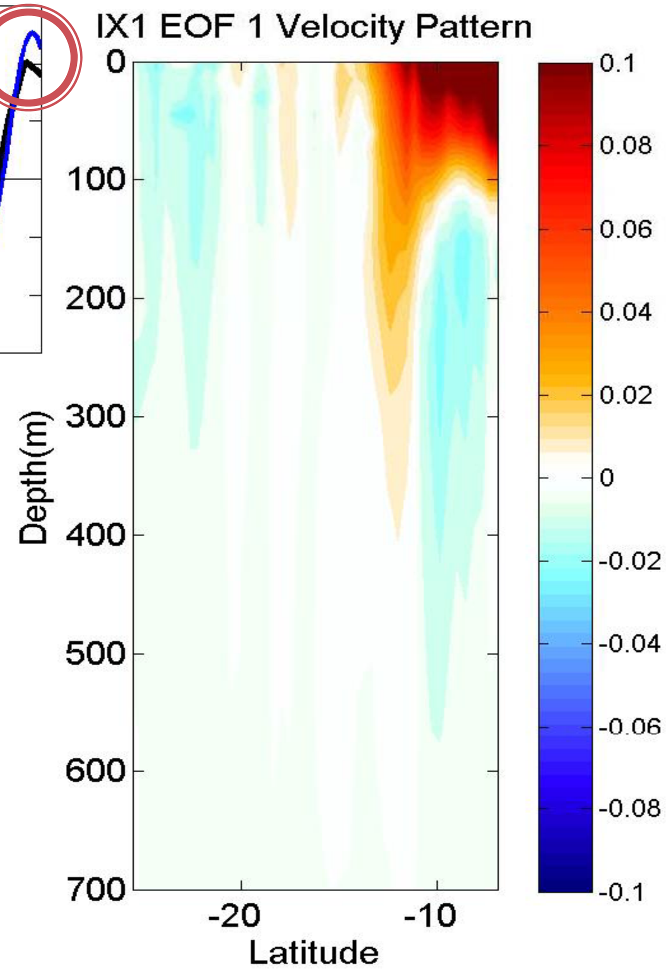
Wijffels, Meyers and Godfrey, in press

20 years of ITF transport variability IX1



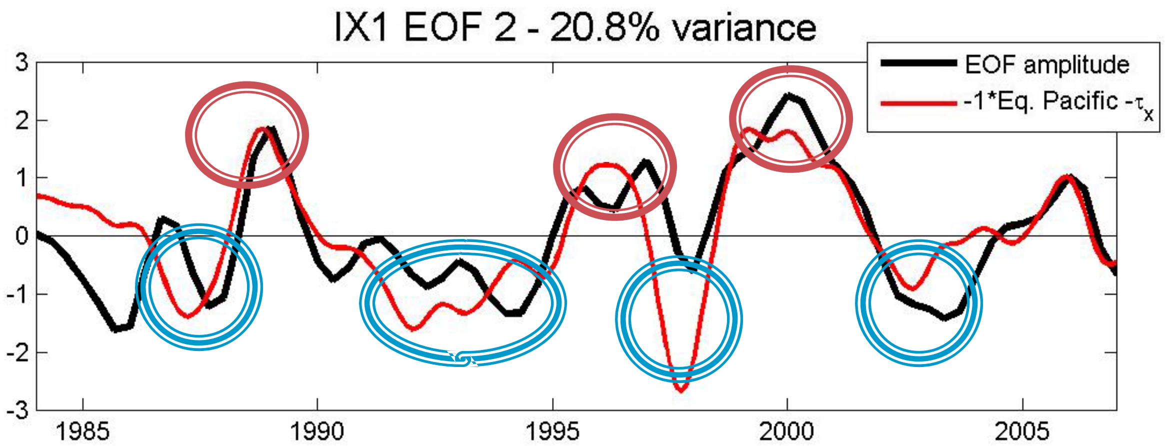
EOF 1 of Velocity Anomaly at IX1 – 48.3%

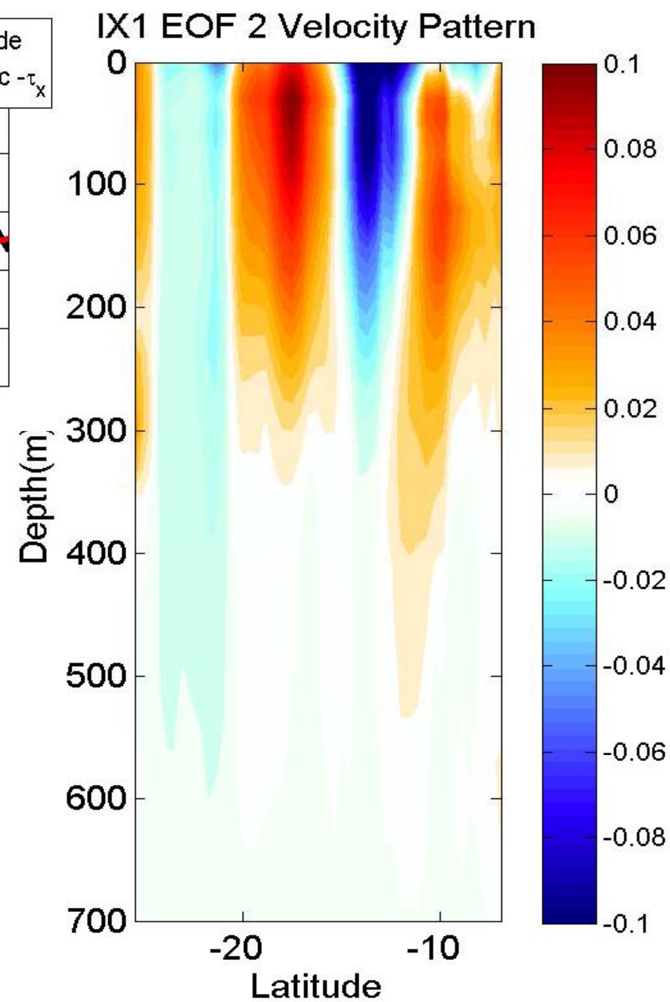




- tracks wind-stress in the Equatorial Indian and Java wave-guide
- dominated by Indian Ocean Dipole
- during cold phase – drop dynamic height off Java -> Throughflow increases
- note the reversal at depth

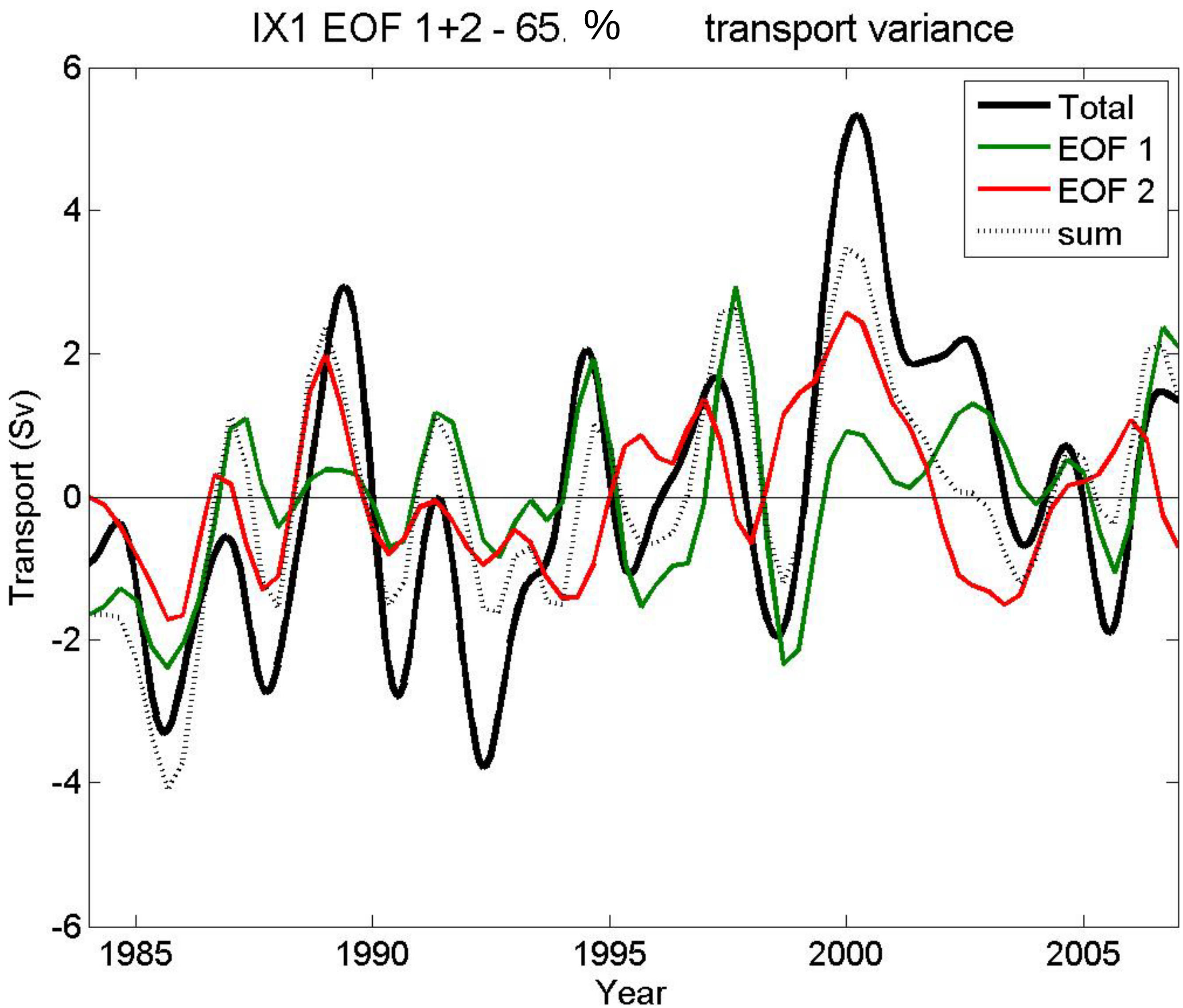
EOF 2 of Velocity Anomaly at IX1 – 20.8%





- tracks wind-stress in the Equatorial Pacific -> dominated by ENSO
- during warm phase – increase dynamic height south of 12°S – moves SEC southwards
- Leeuwin Current increases

Total transport variability



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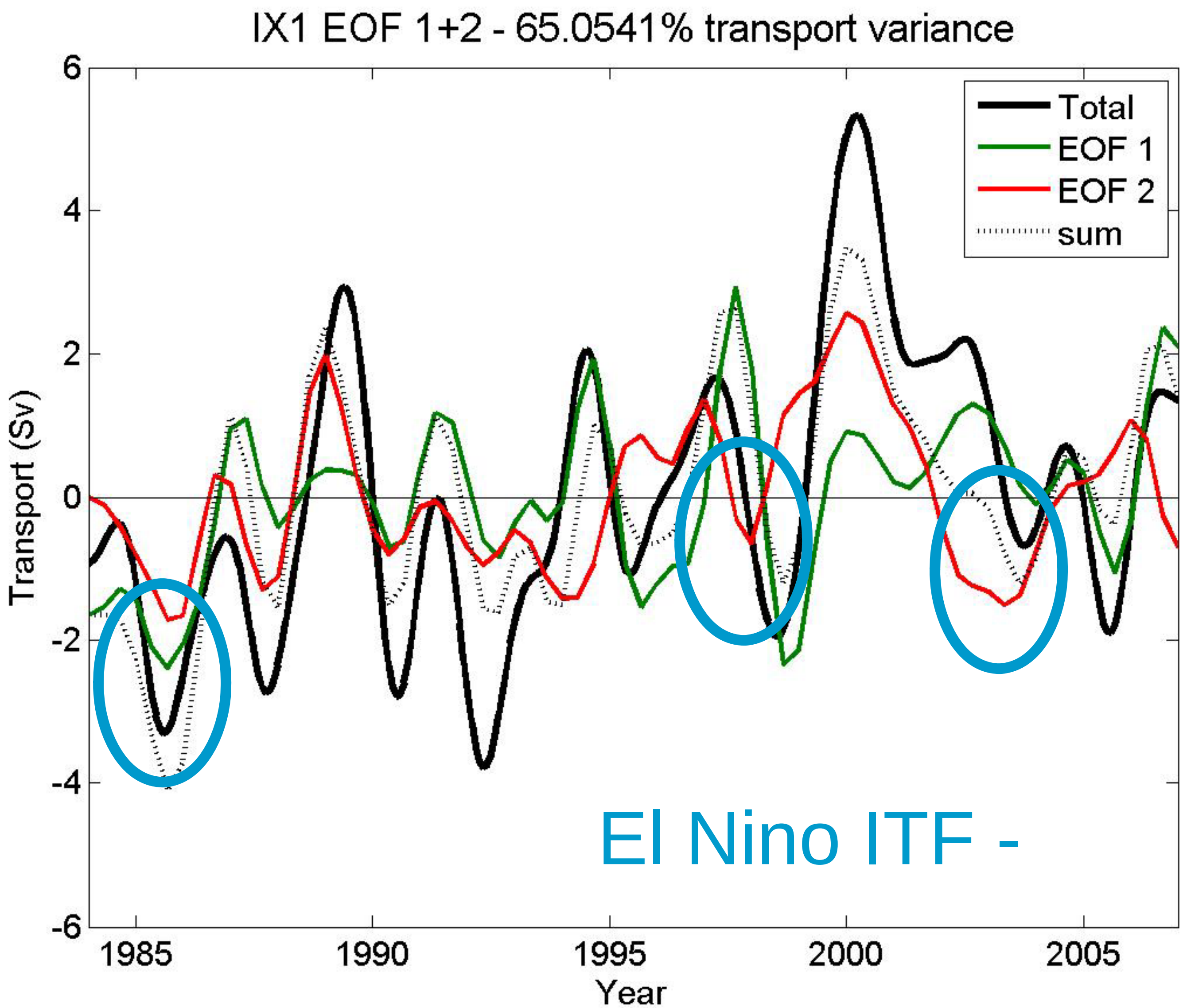
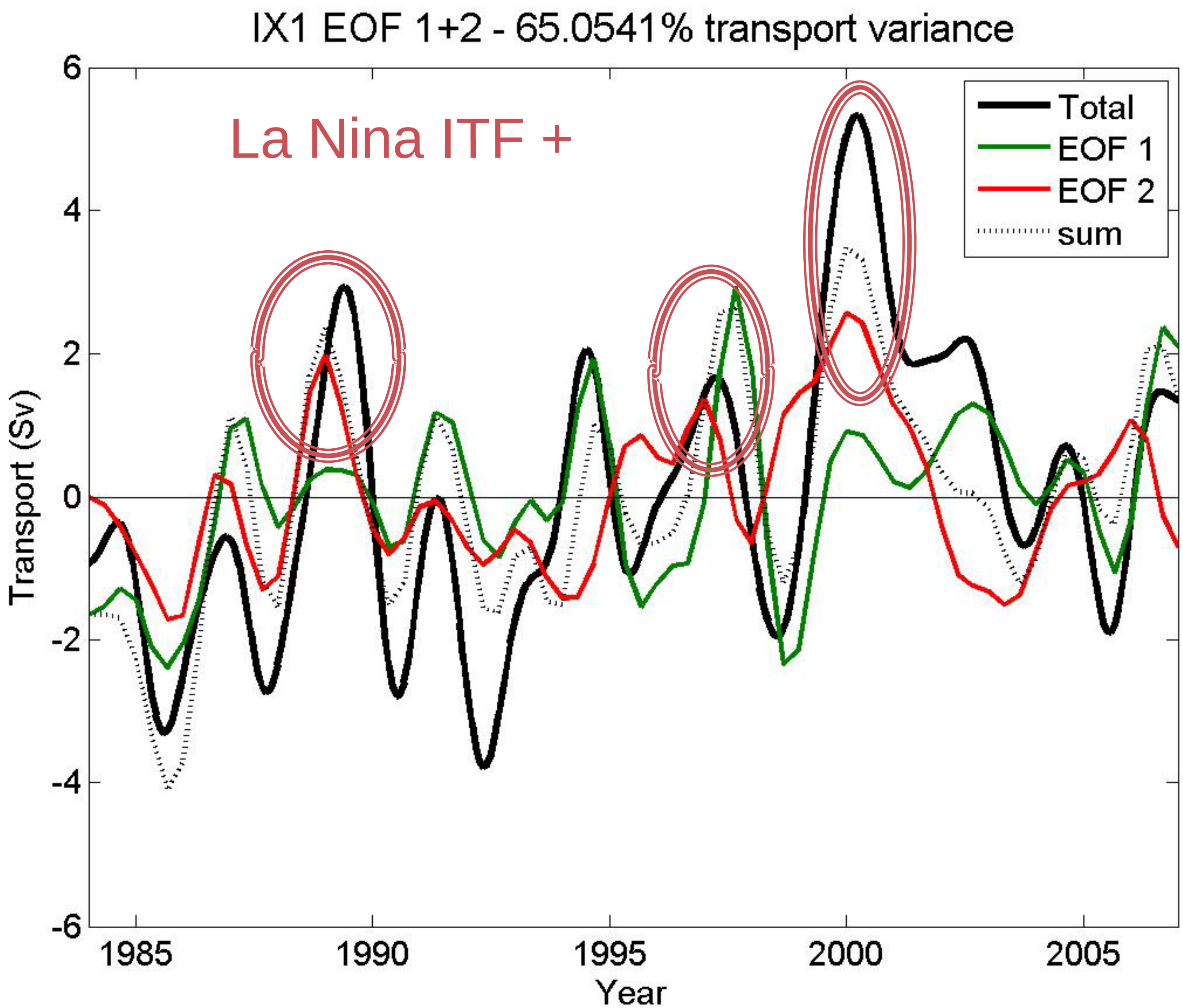
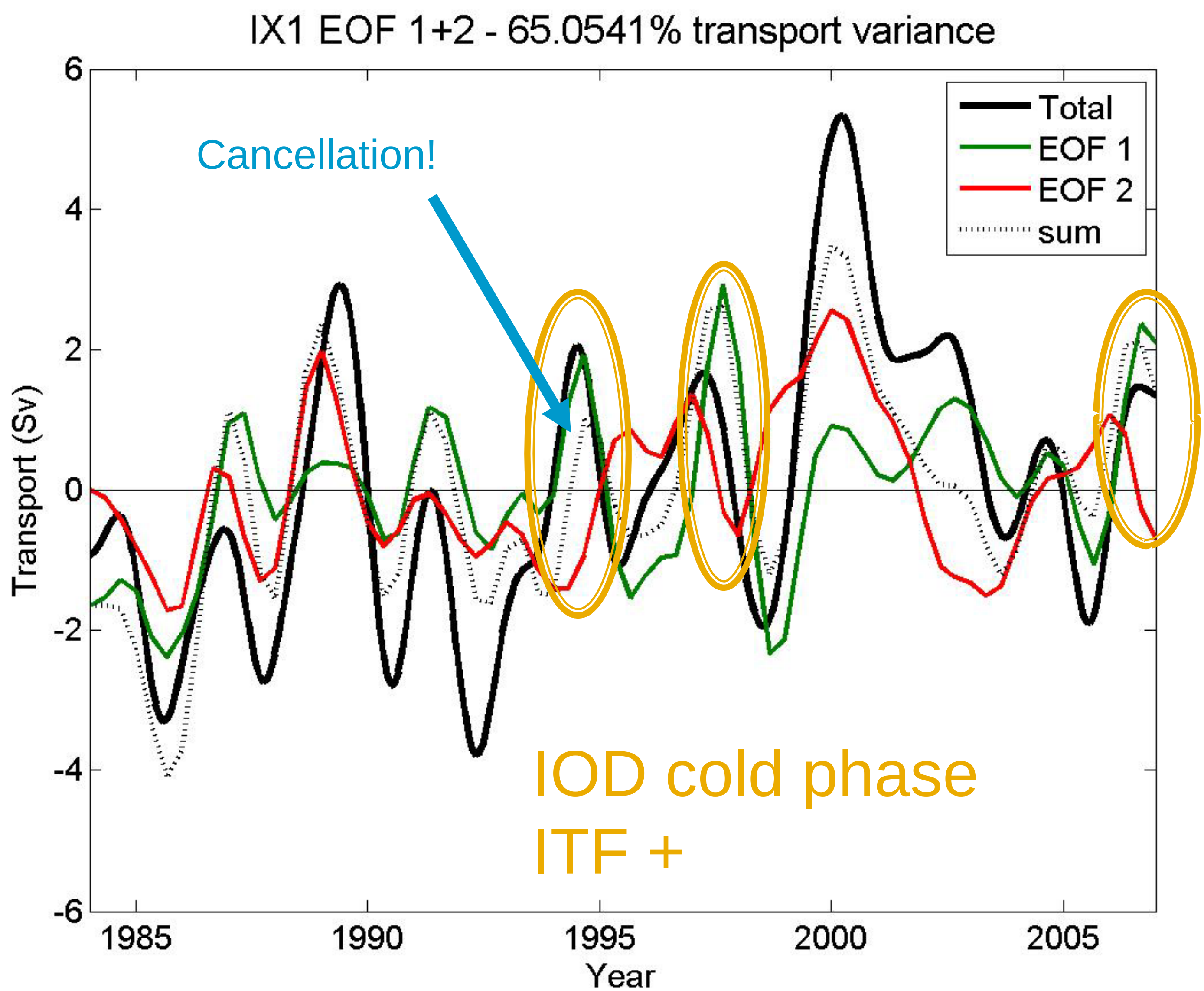
Total transport variability – El Nino



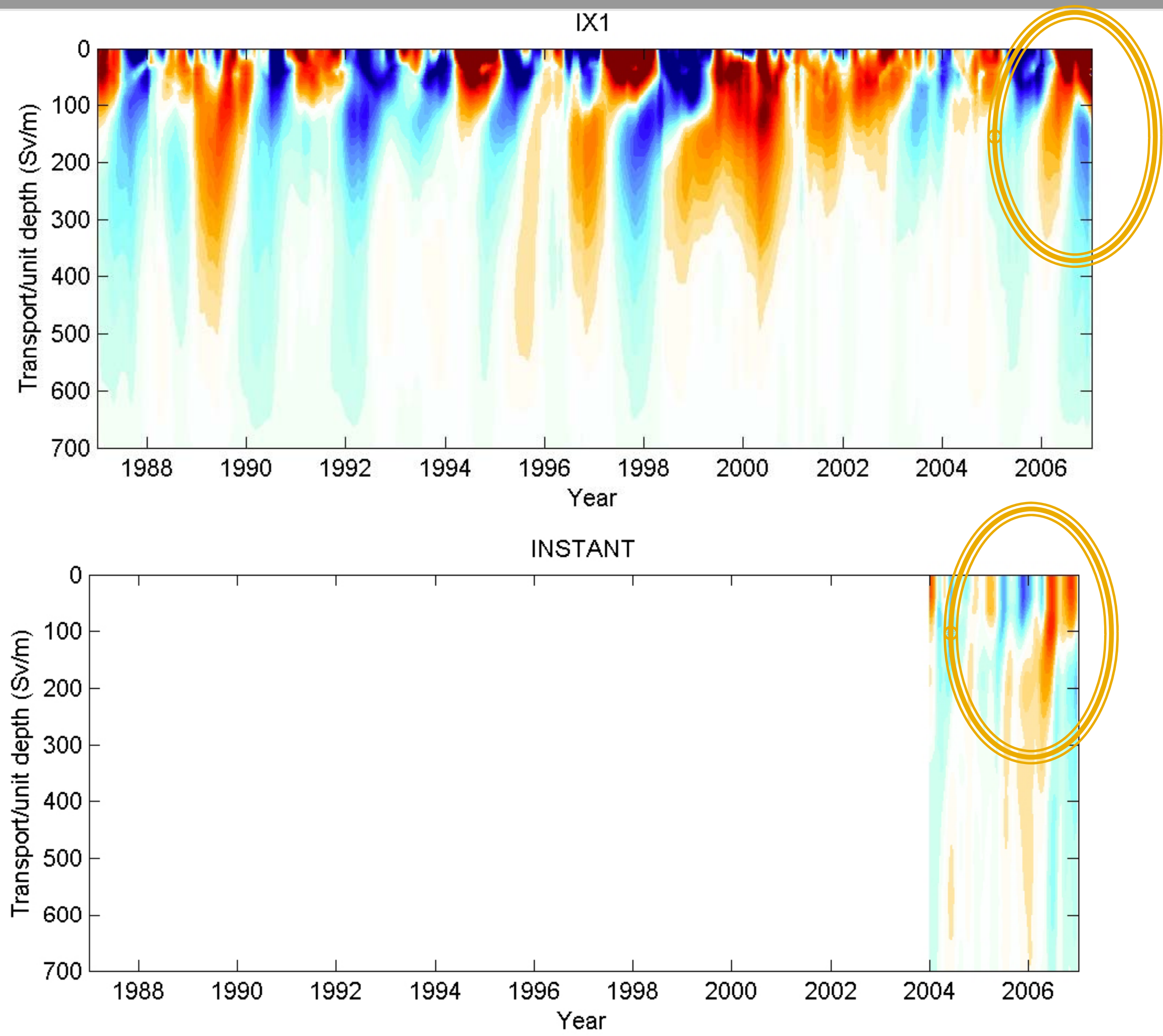
Total transport variability - La Nina



Total transport variability



Comparison with INSTANT



2006 cold IOD event

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Summary

• Estimated 20 years of geostrophic upper ocean transports from repeat XBT lines across the Indonesian Throughflow

• Interannual variability is ±4Sv, rough but not perfect agreement between two independent lines.

• Velocity variations associated with remote wind changes are consistent with Kelvin/RW propagation

• Velocity response to Indian and Pacific winds have *distinctly different structures*

• At IX1 Indian Ocean IOD winds dominate transport variability, though Pacific ENSO wind-changes are also important

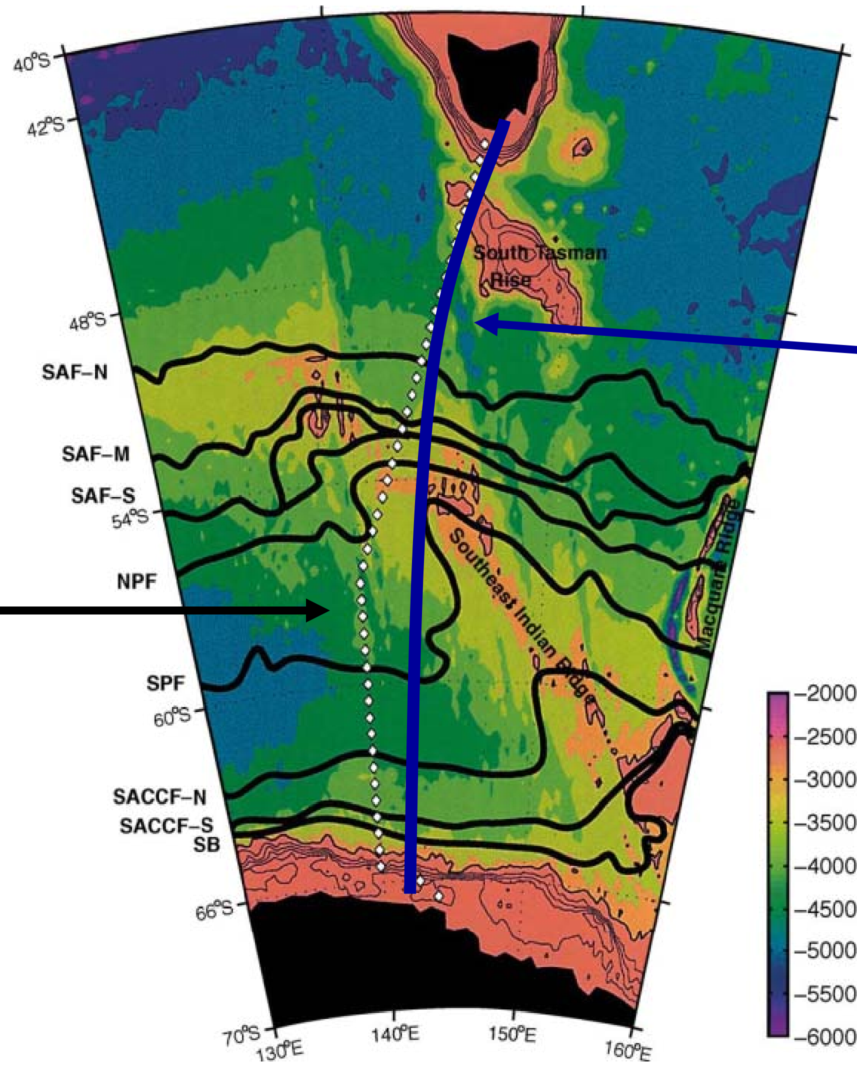
• transport cancellation via the modulation of the Walker circulation is also observed as described by Lee et al. 2007

The SURVOSTRAL high density XBT line south of Australia

S. Rintoul, R. Morrow, A. Chaigneau, JB Sallée, S. Sokolov

CSIRO Marine and Atmospheric Research
Centre for Australian Weather and Climate Research
Wealth from Oceans National Research Flagship
Antarctic Climate and Ecosystems Cooperative Research Centre
Hobart, Tasmania , Australia

Repeat measurements south of Tasmania



SR3

8 sections since 1991.

Full depth, ADCP, tracers, biology, biogeochemistry.

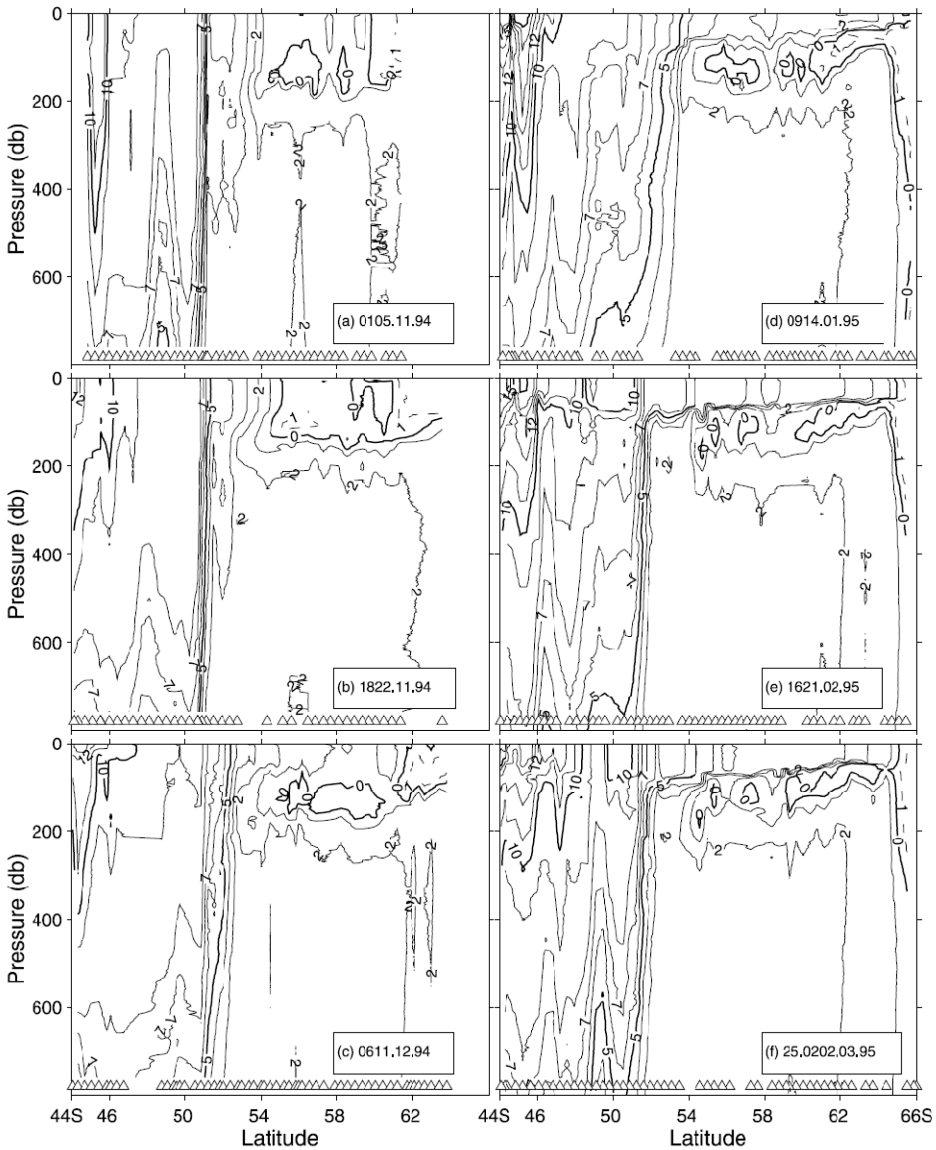
SURVOSTRAL

Since 1993.

6 sections/year, from Oct – March.

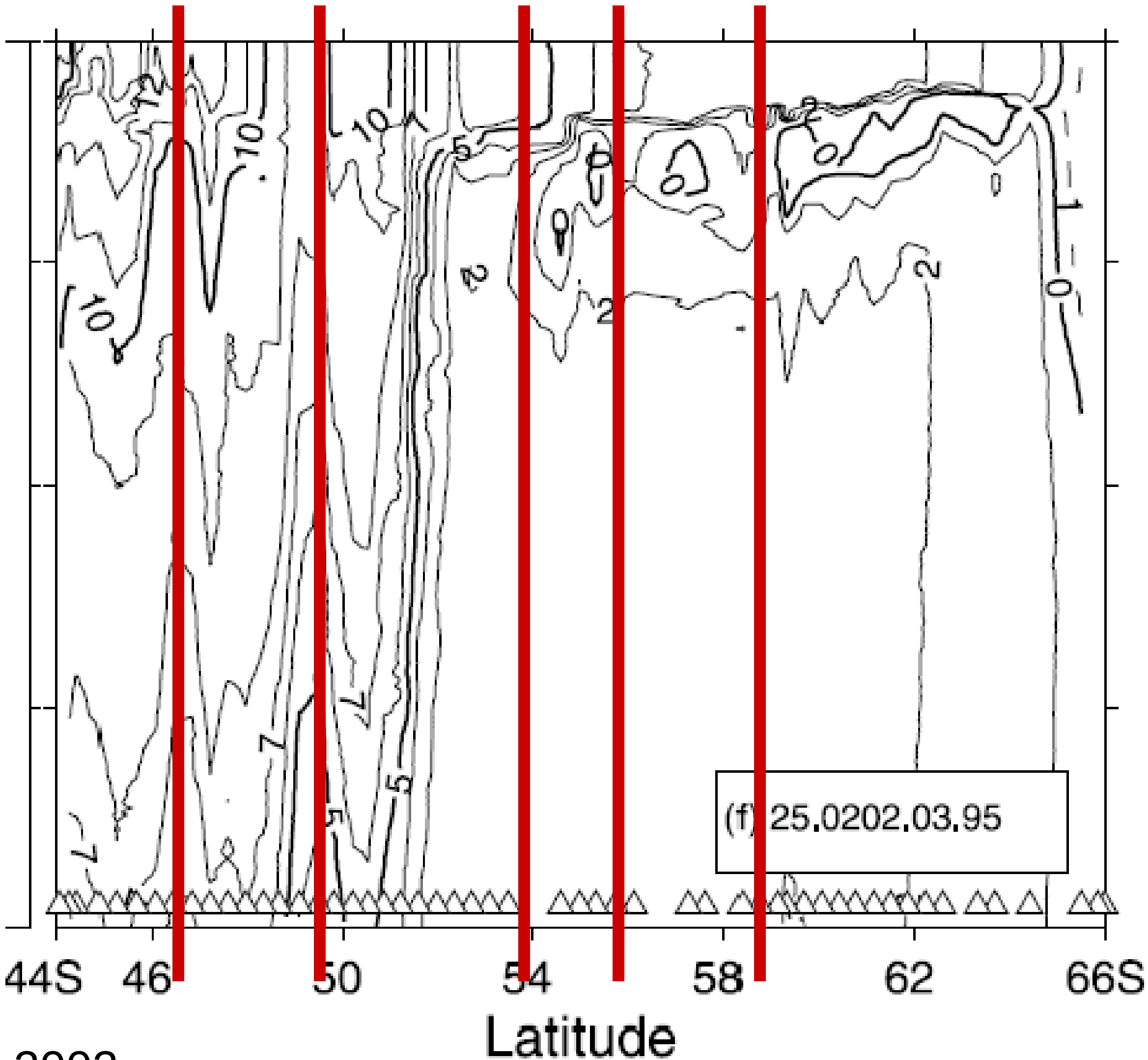
TSG, IMET, biology, biogeochemistry.

Seasonal cycle of upper ocean temperature



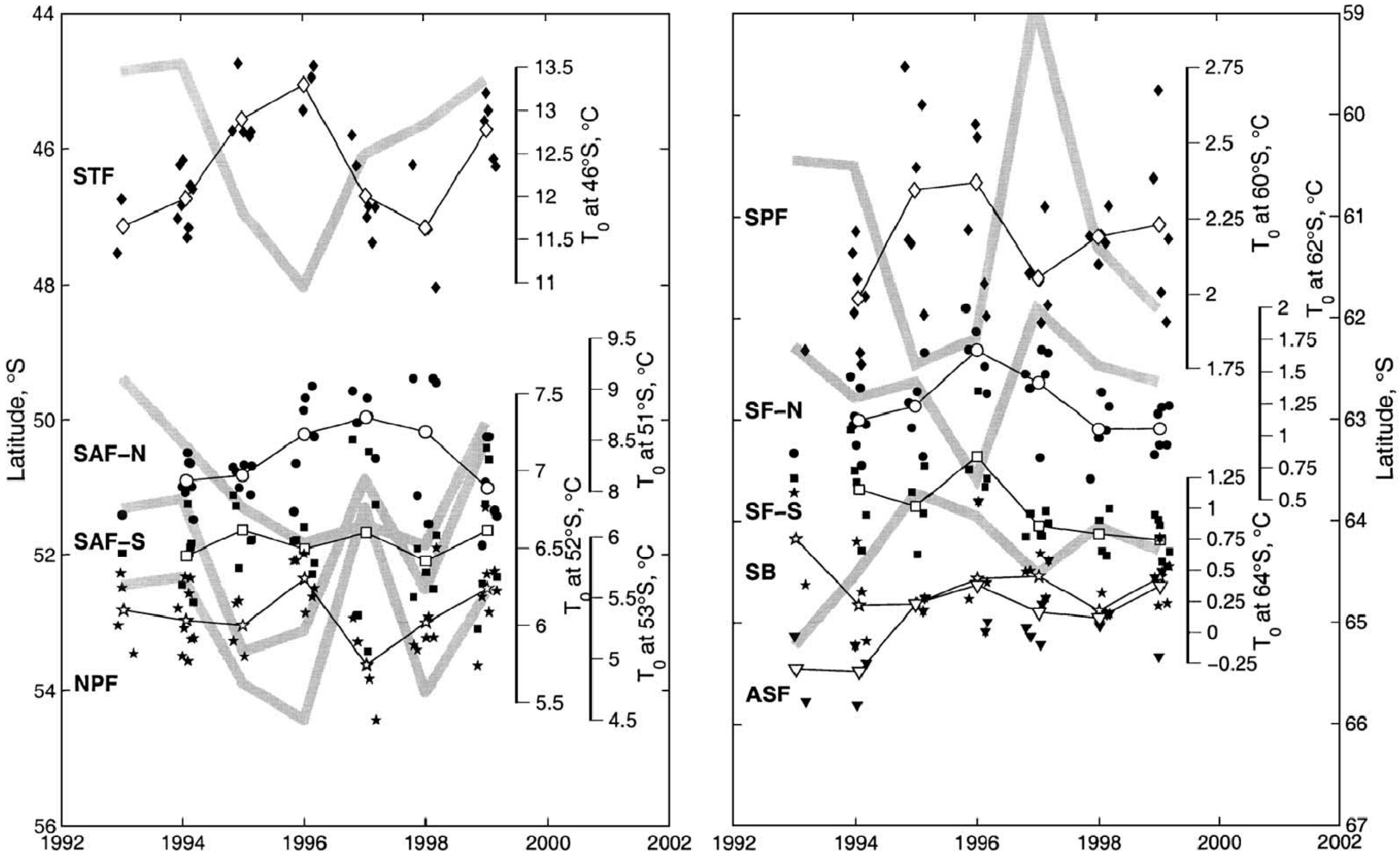
Rintoul et al., 2002

Seasonal cycle of upper ocean temperature



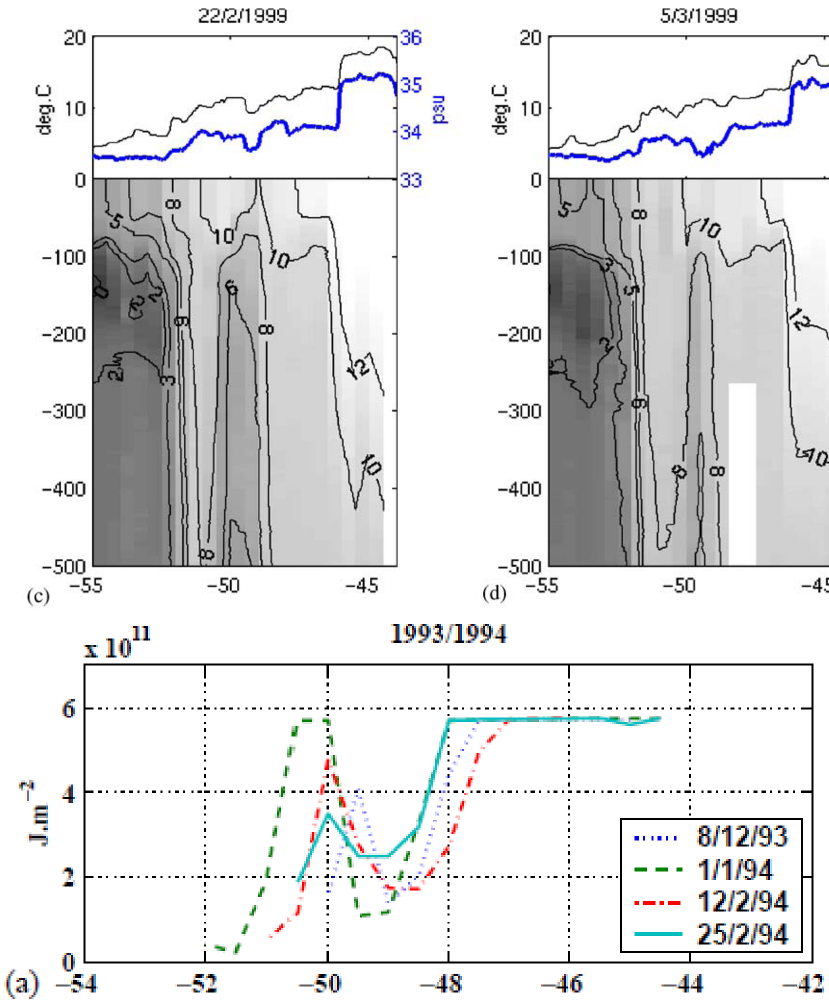
Rintoul et al., 2002

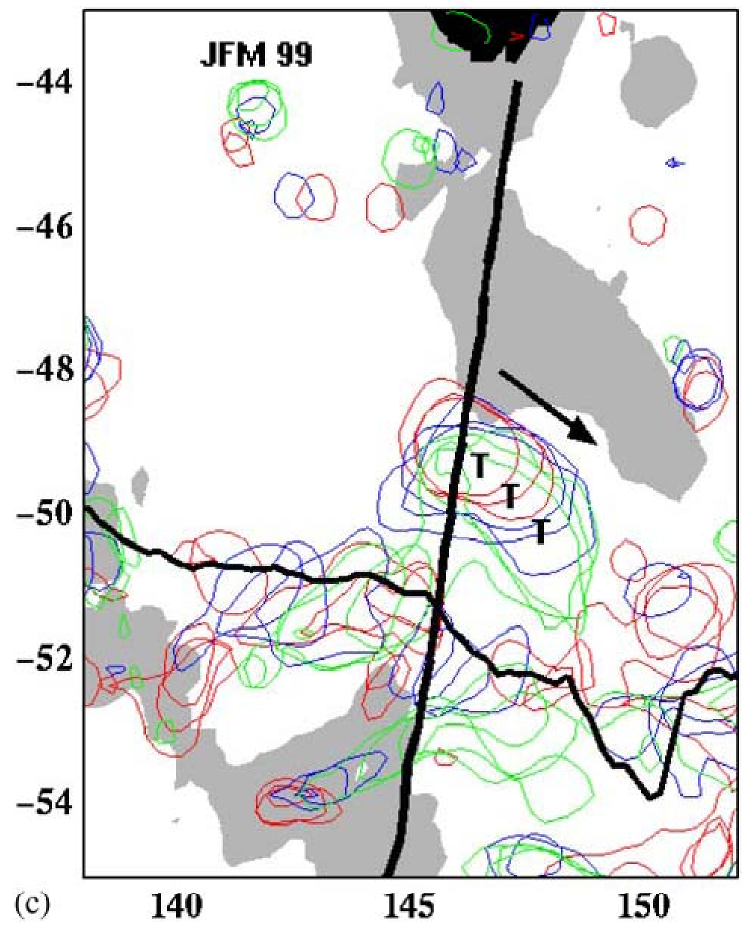
Tracking ACC frontal movements



Sokolov and Rintoul, 2002

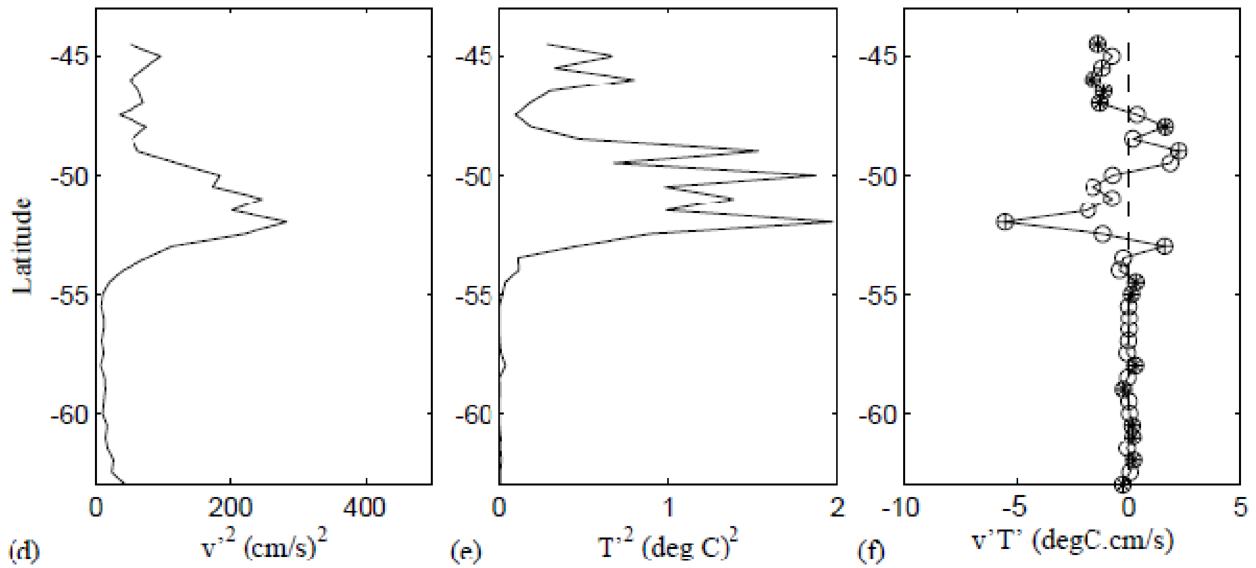
Contribution of cold-core rings to heat budget





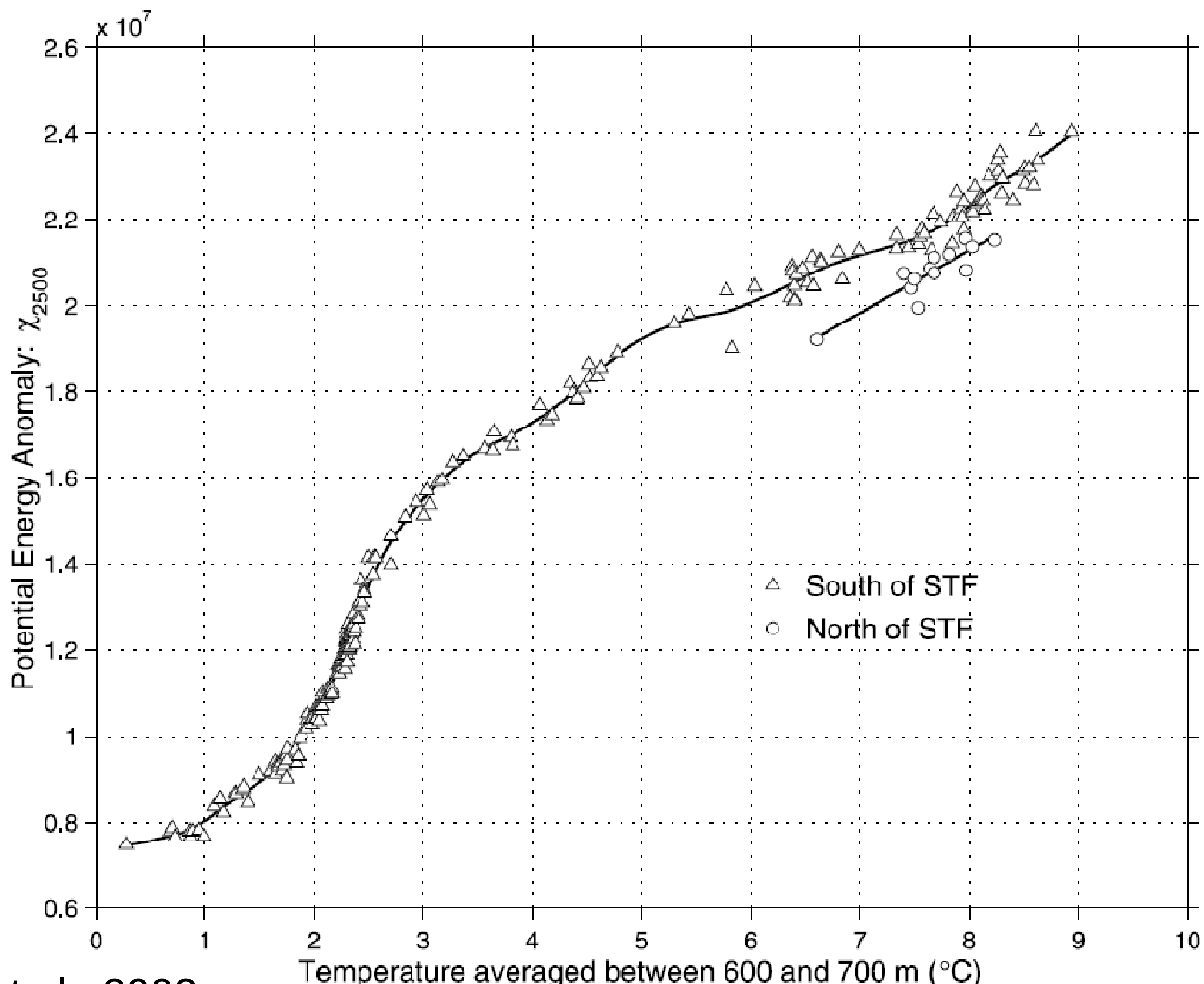
Morrow et al., 2004

Eddy heat flux from altimetry and XBT



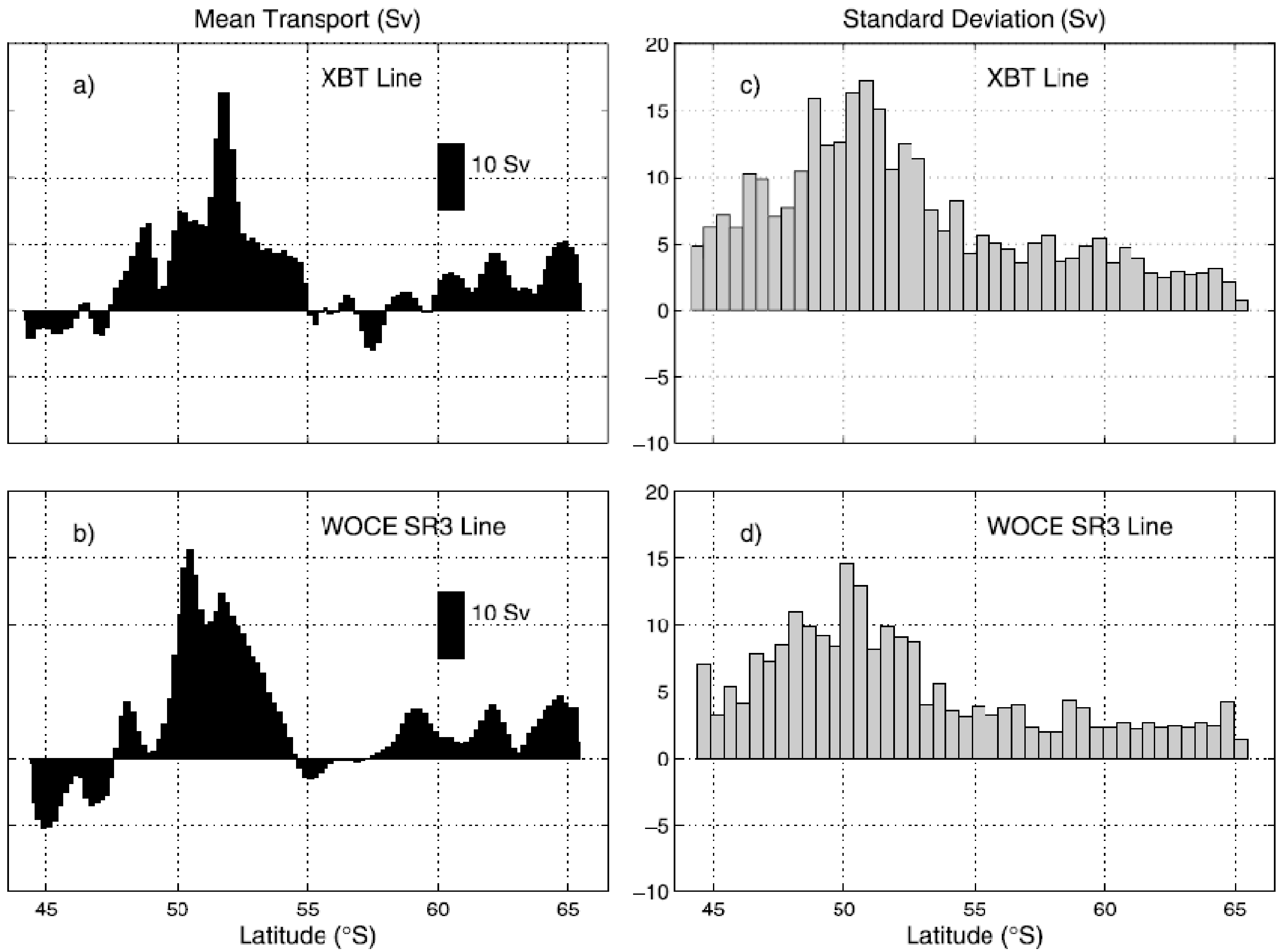
Morrow et al., 2003

Temperature – baroclinic transport relationship

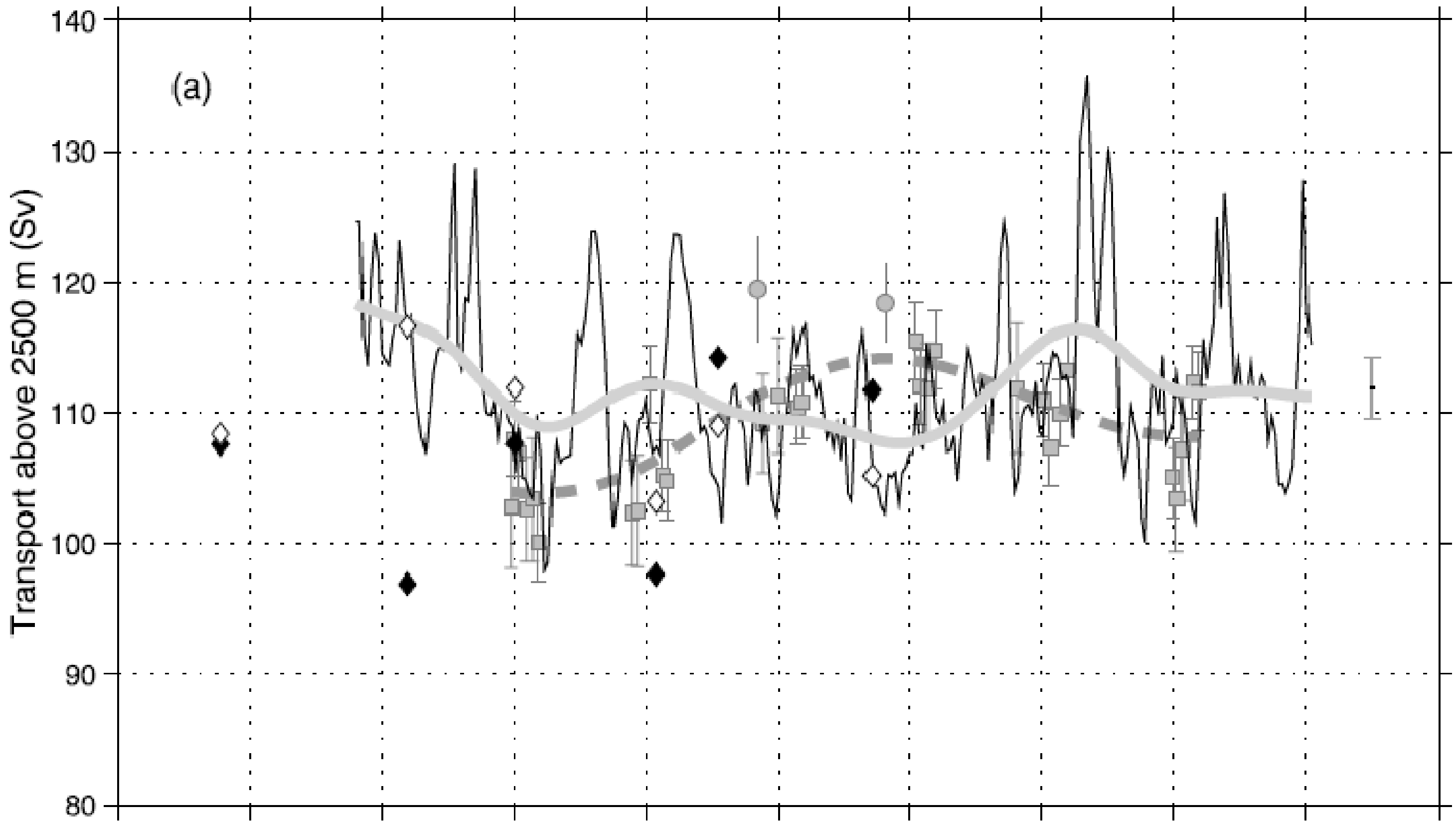


Rintoul et al., 2002

Transport variability



Transport time series from XBT and altimetry

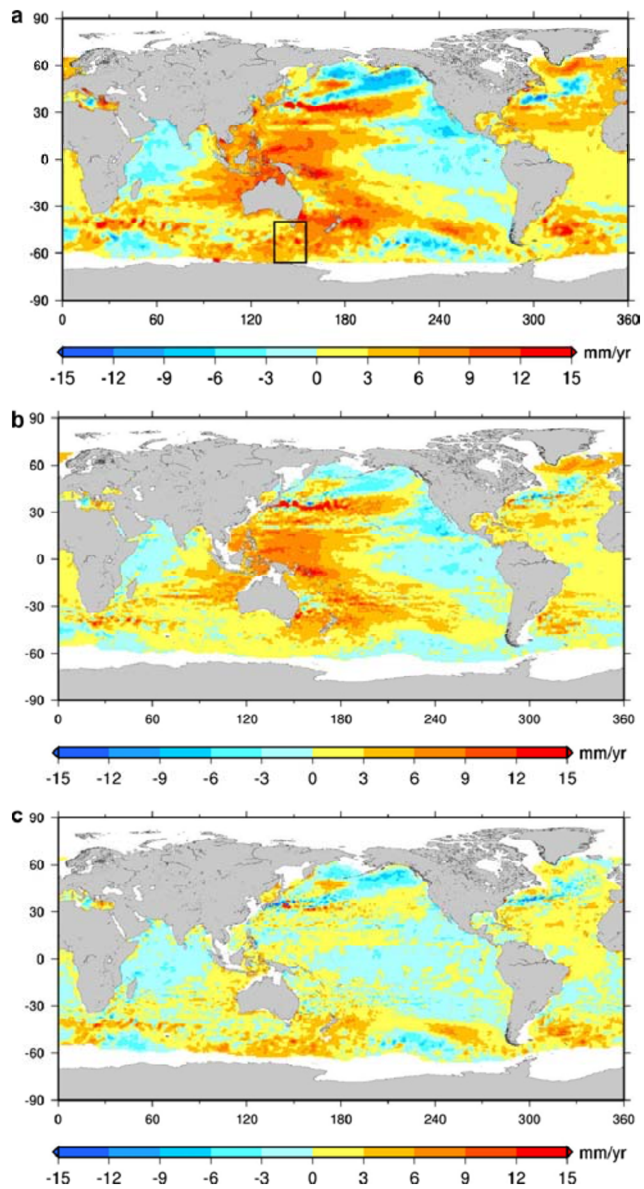


Causes of Southern Ocean sea level rise

TOPEX

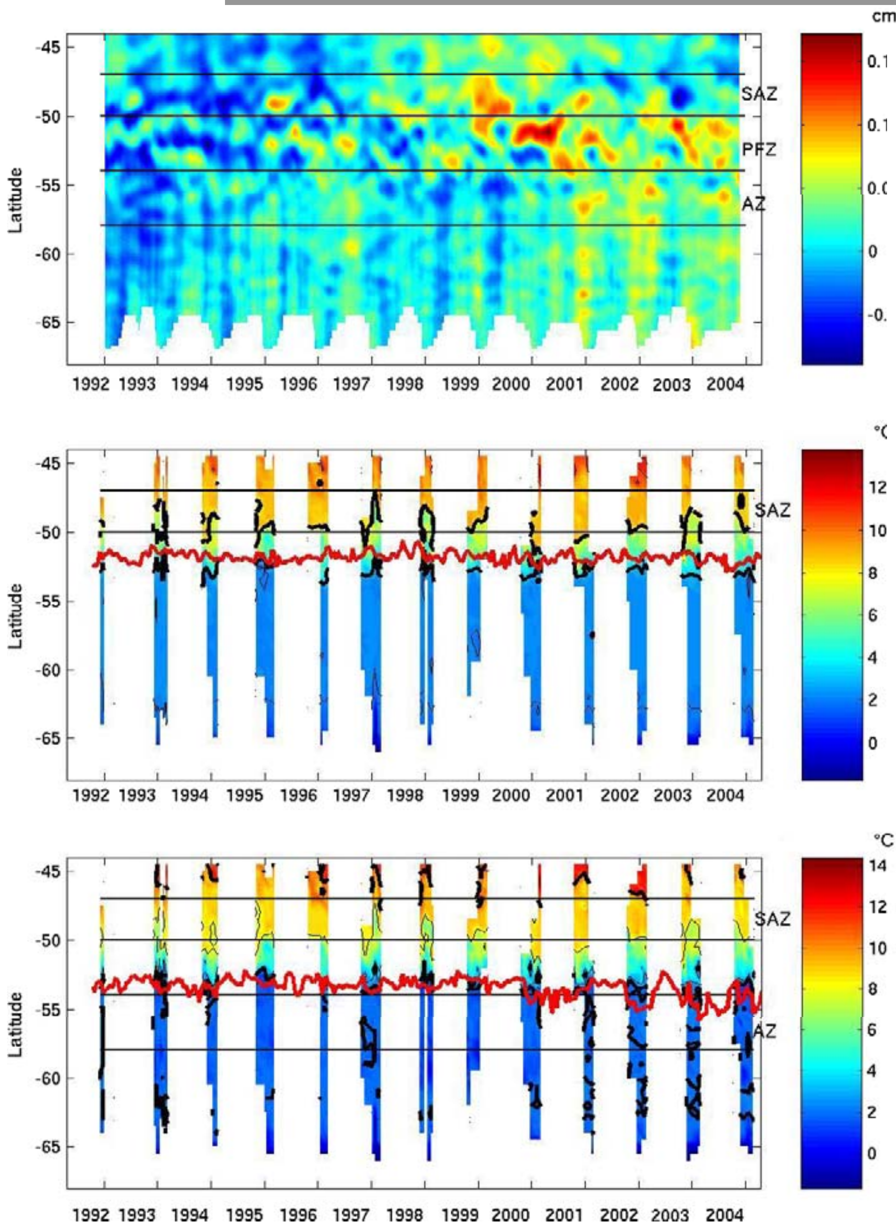
0-700 m

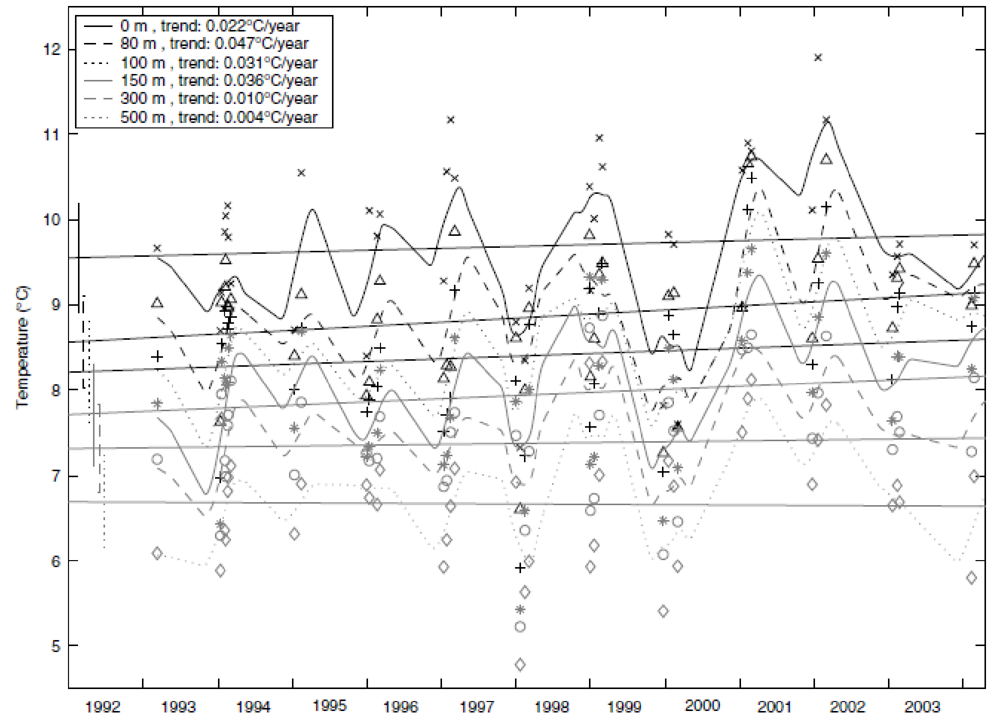
difference



Morrow et al., 2008

XBTs reveal steric changes in upper ocean explain only 1/3 of observed sea level rise





Morrow et al., 2008

Measured parameters:

- -SST, salinity
- -meteorology
- -Chlorophyll -*a*
- -Macronutrients (silicate, phosphate nitrate)
- -DIC and TA
- -*f*CO_2 (atmospheric and oceanic)
- -pigments

Institut Pierre Simon Laplace – Sciences de l'environnement

IPEV – Institut Polaire Français Paul Emile Victor

ace CRC – Antarctic Climate & Ecosystems Cooperative Research Centre

CSIRO Marine Research

NOAA

lbcm

Australian Government – Department of the Environment and Heritage – Australian Antarctic Division

Bureau of Meteorology

Institut National des Sciences de l'Univers – INSU

Aims

- Improve estimates of seasonal to interannual variability in air-sea CO_2 exchange and links to atmospheric CO_2 composition changes

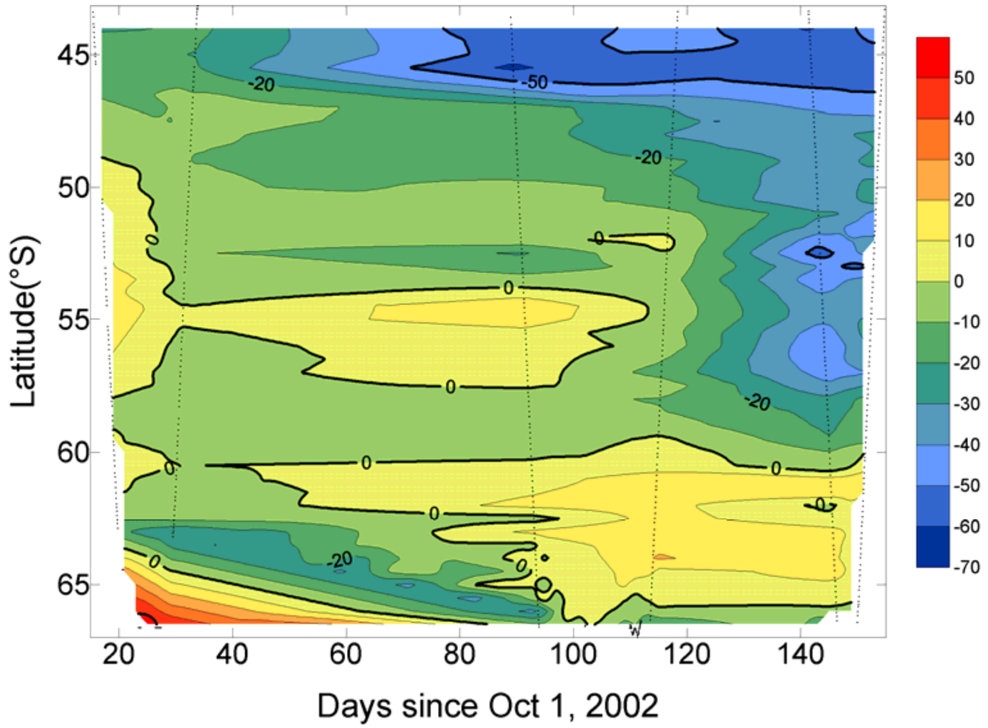
- Determine biological and physical drivers of the variability

- Determine the variability in phytoplankton biomass and species composition in the major water masses

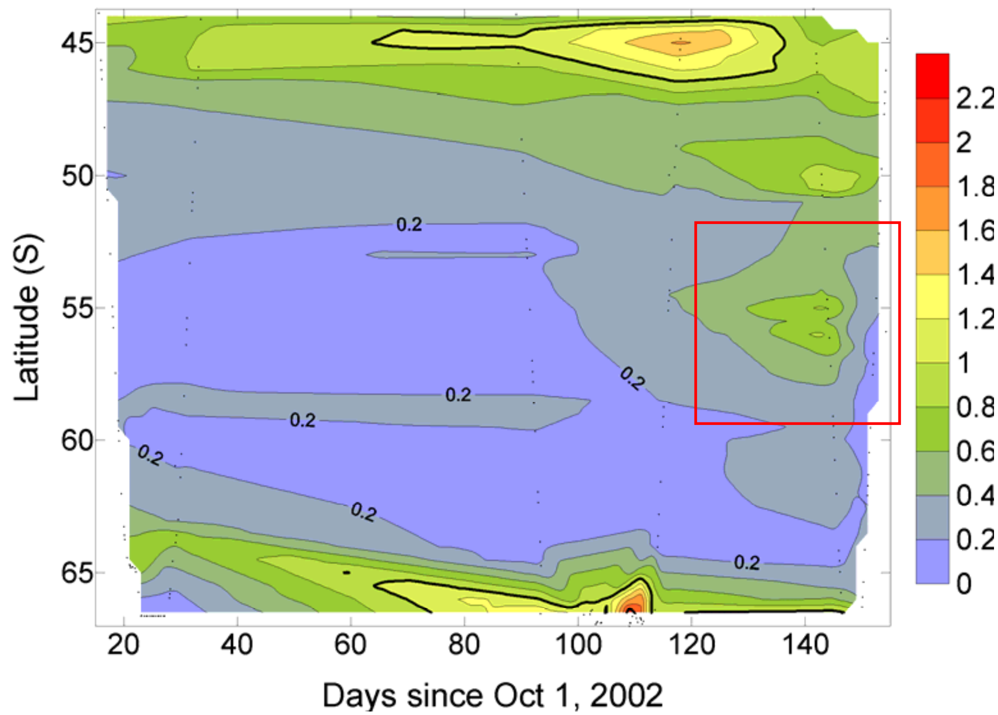
- Baseline data for assessing climate impacts (eg. stratification, acidification, sea-ice retreat) on carbon cycling and ecosystems

Astrolabe 2002/03

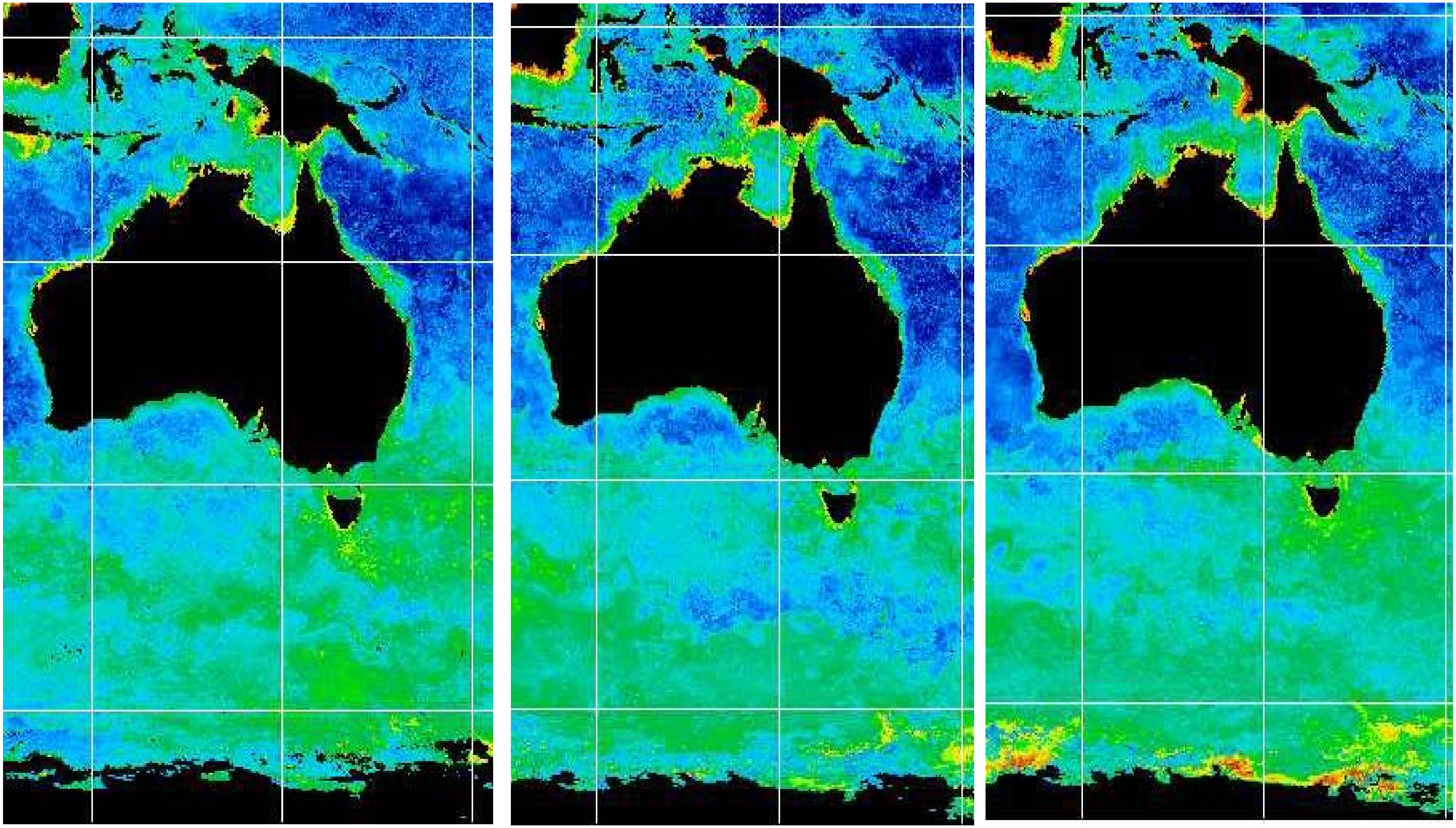
CO2 drawdown



Chlorophyll *a*

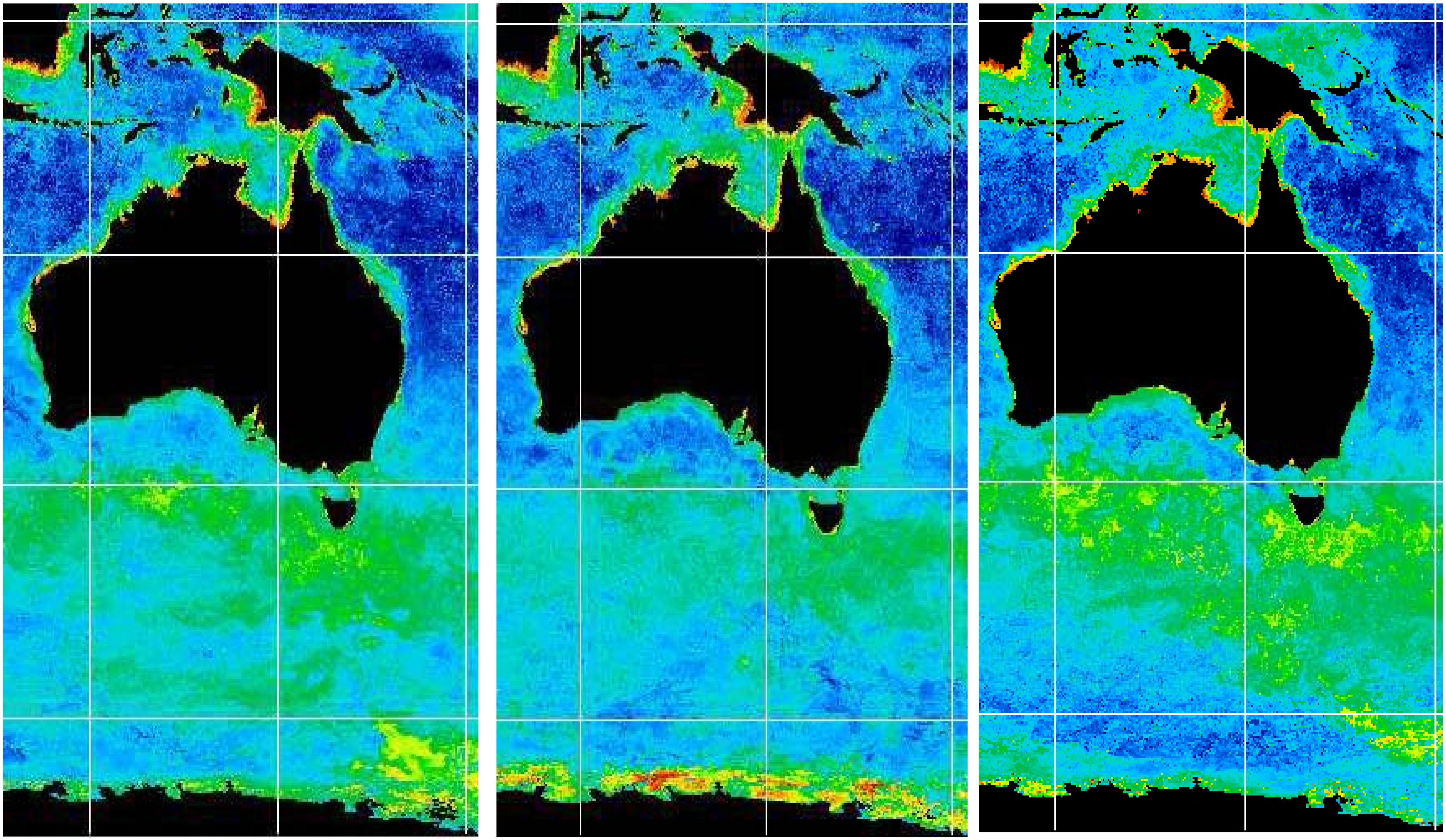


1997-98 1998-99 1999-00



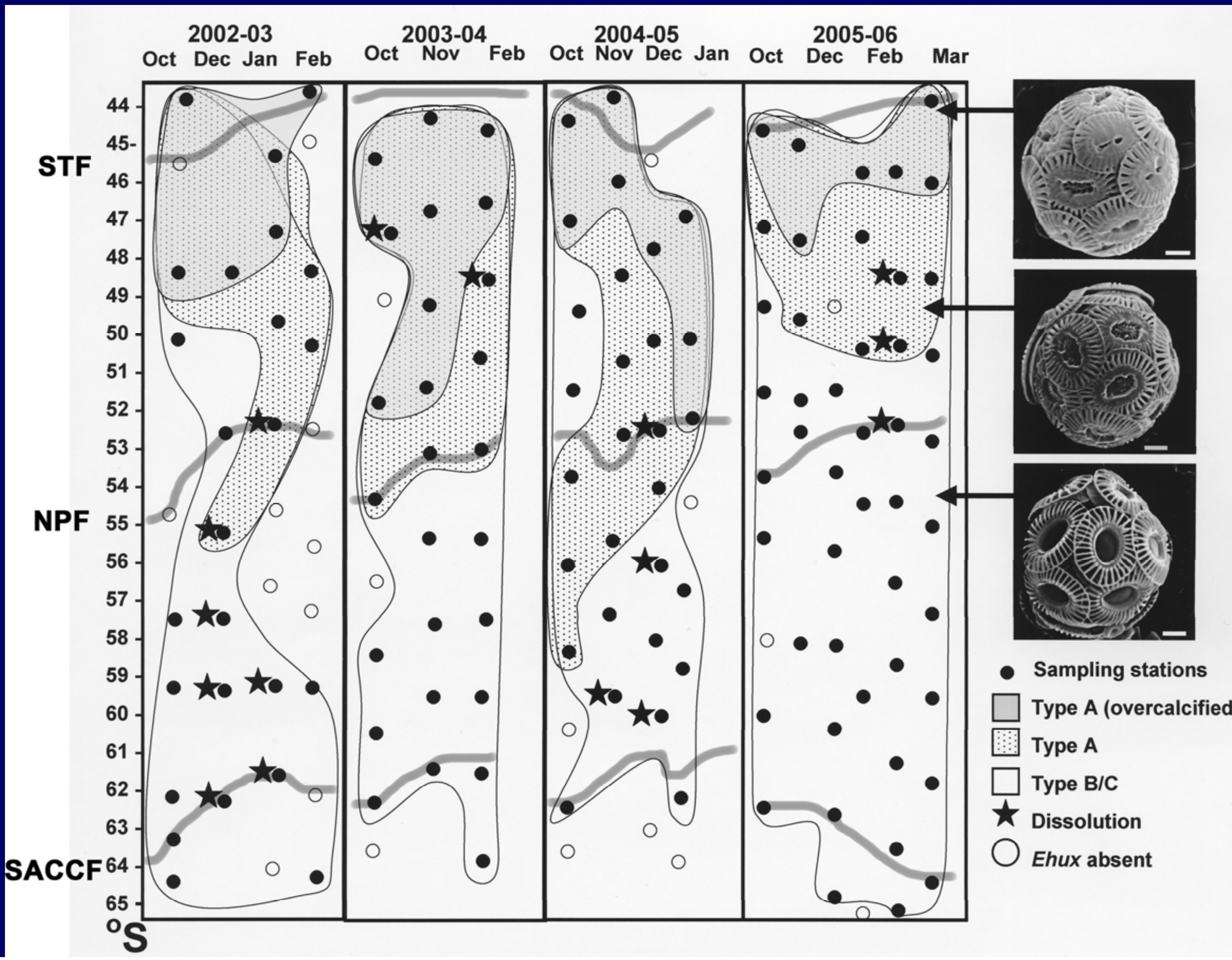
11 Dec 1997 3 Dec 1998 1 Jan 2000

2000-01 | 2001-02 | 2002-03

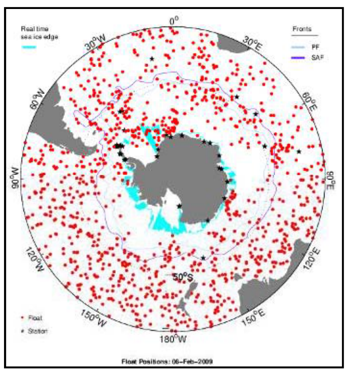


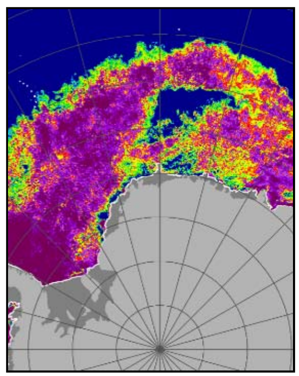
25 Jan 2001 | 25 Jan 2002 | 10 Feb 2003

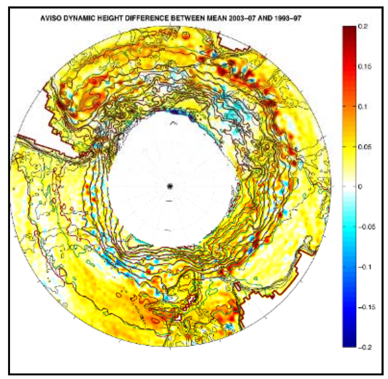
Coccolithophorid calcification and distribution

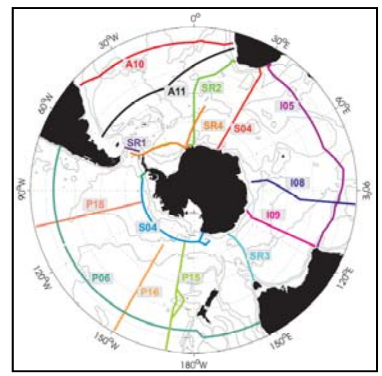


A Southern Ocean Observing System:
A Legacy of the International Polar Year

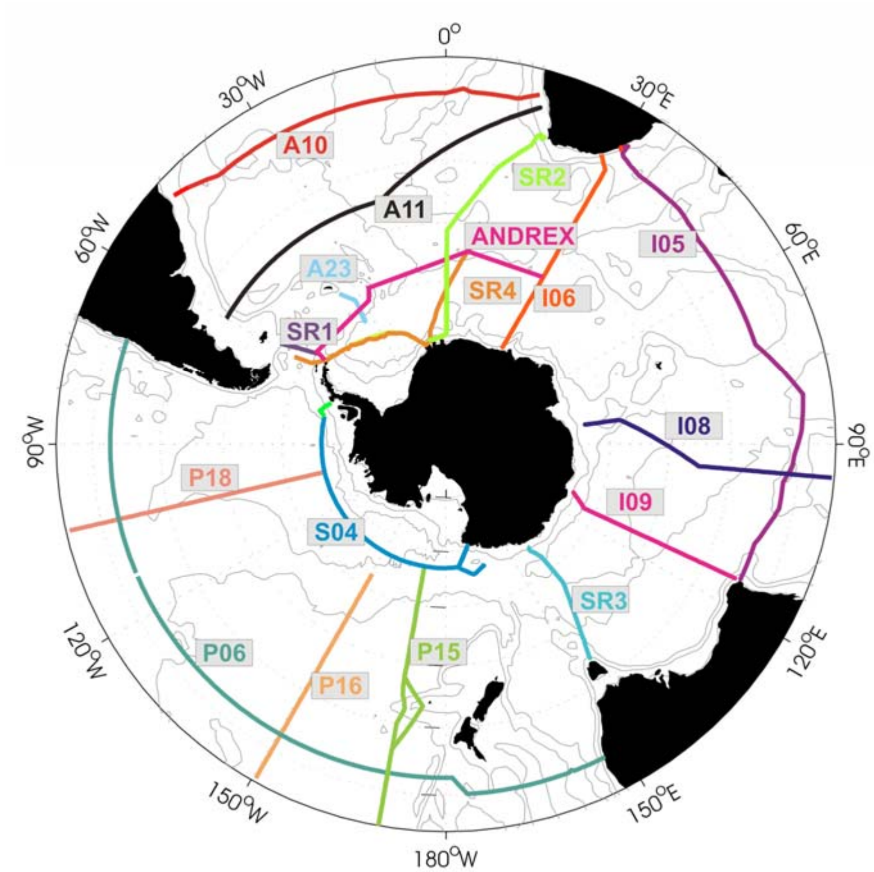


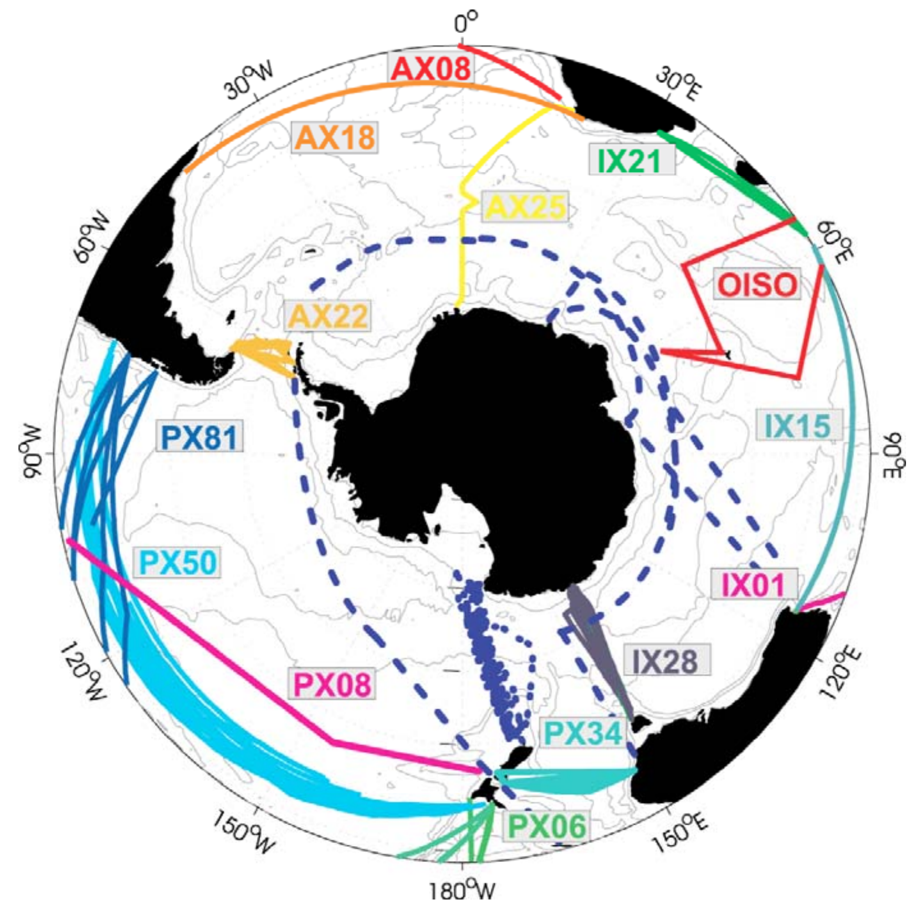






SOOS: Repeat hydrography/tracers and SOOP





SURVOSTRAL achievements

Determined seasonal/interannual variability in upper ocean thermal structure (heat content, mixed layer depth), resolving narrow fronts and eddies.

Resolved variability of fronts and transport.

Estimated of eddy heat flux.

Contribution of deep ocean to SSH trends.

Integrated observations of ocean physics, biology and biogeochemistry and air-sea interaction.

Exploited synergy between CTD, XBT, altimetry, Argo.

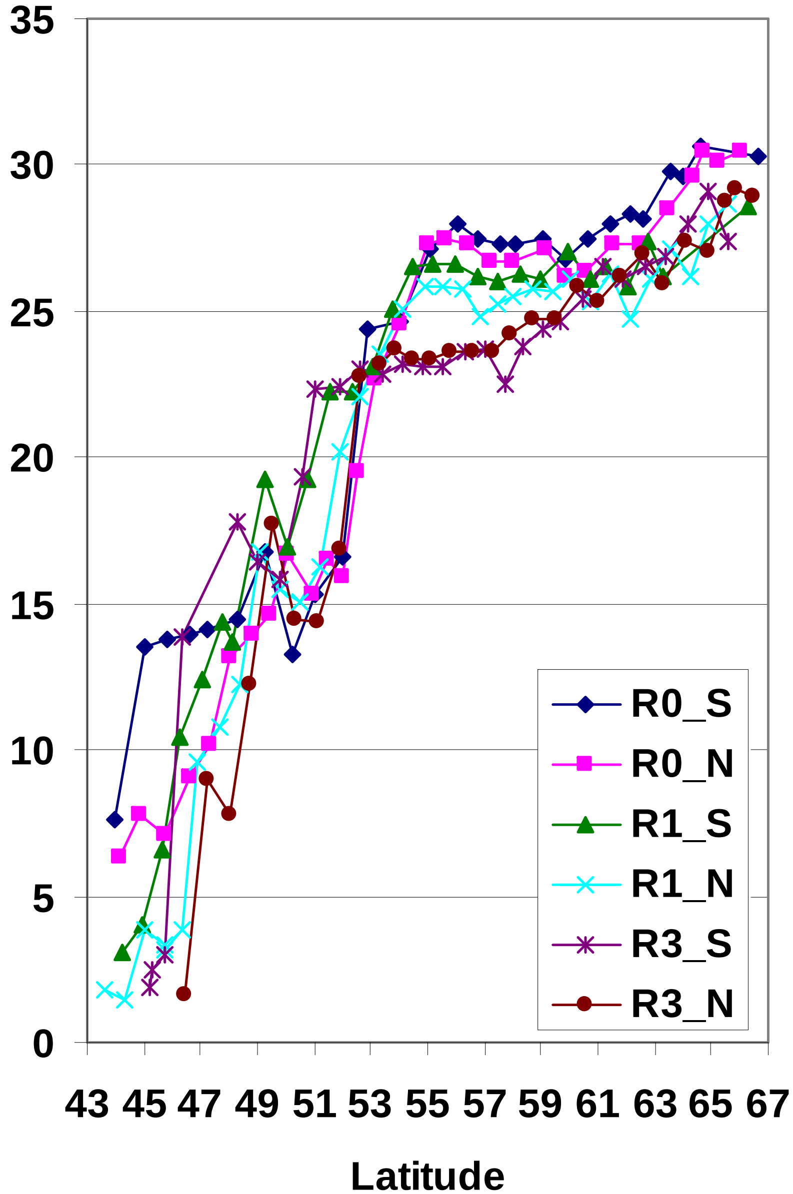
CTD vs Argo vs XBT

	CTD	Argo	XBT
Spatial resolution	good along-track	coarse, broad-scale	excellent along-track
Temporal resolution	hopeless	excellent	good
Depth coverage	Full-depth	0-2000 m	0-700 m
Variables measured	everything	T, S (O2)	T
Cost per profile	$10-50k	$100	$500

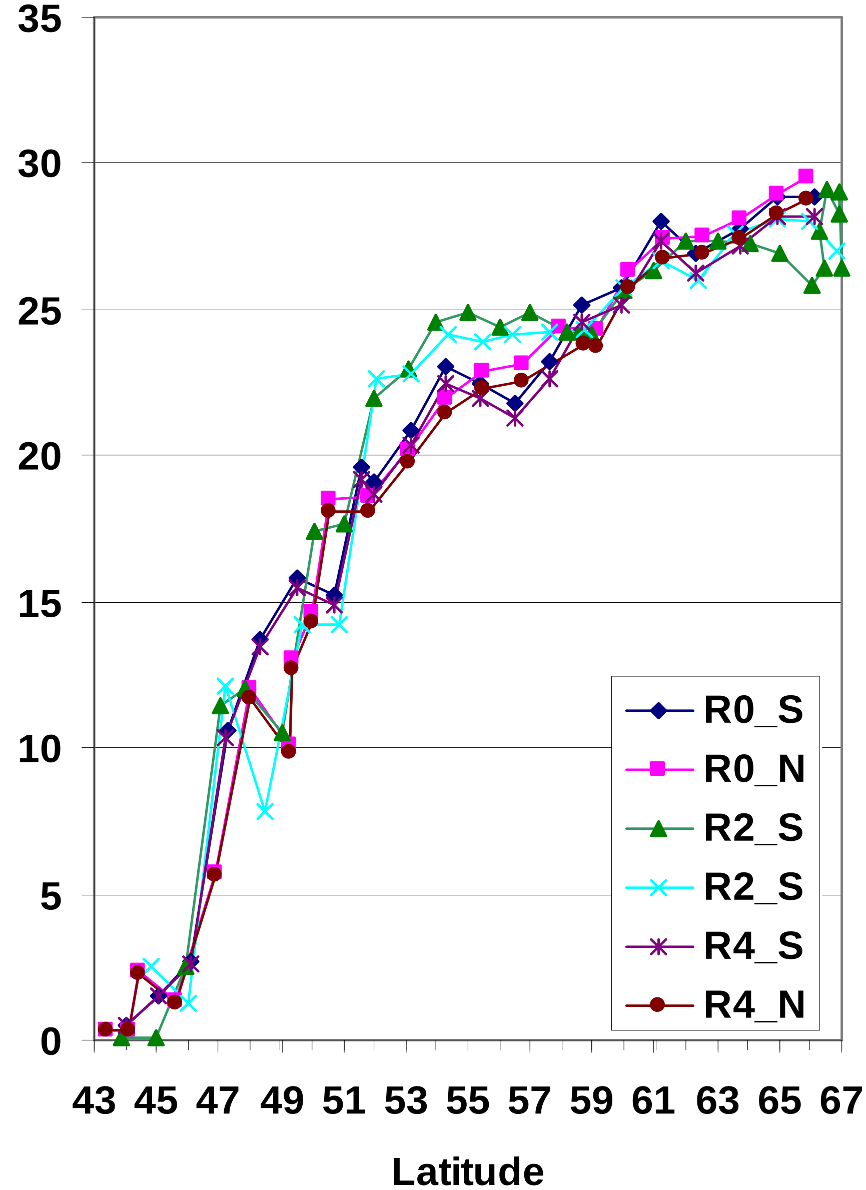
$\Rightarrow$ *Complementary components of an ocean observing system*

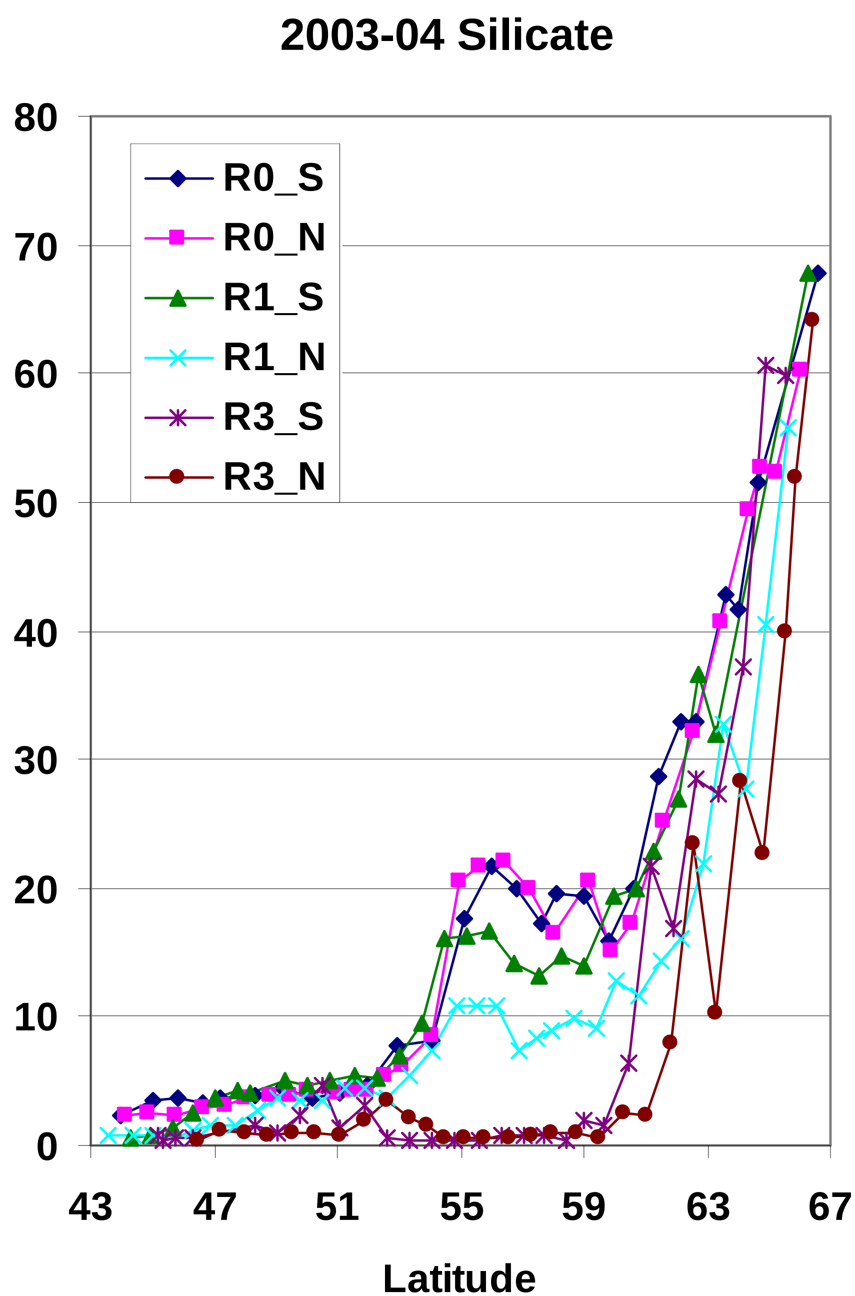
[redacted]

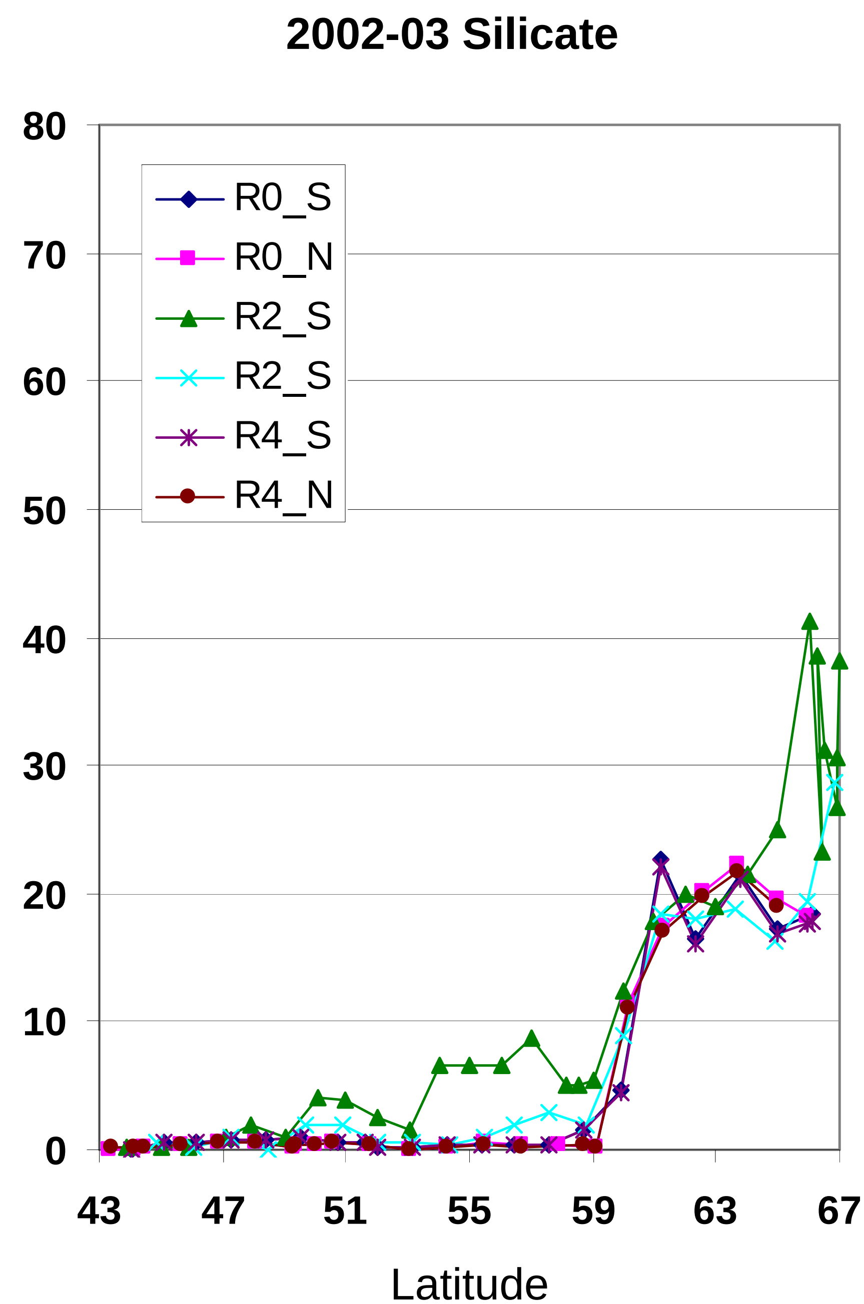
2003-04 Nitrate

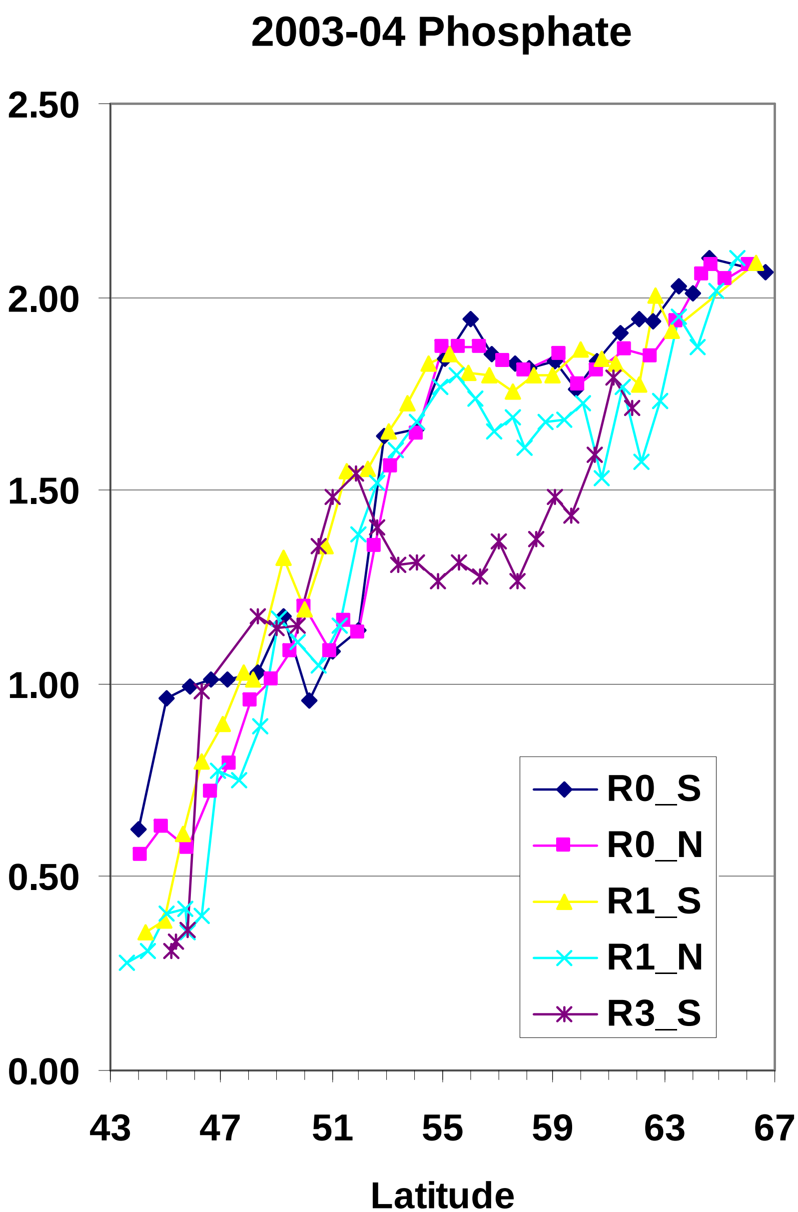


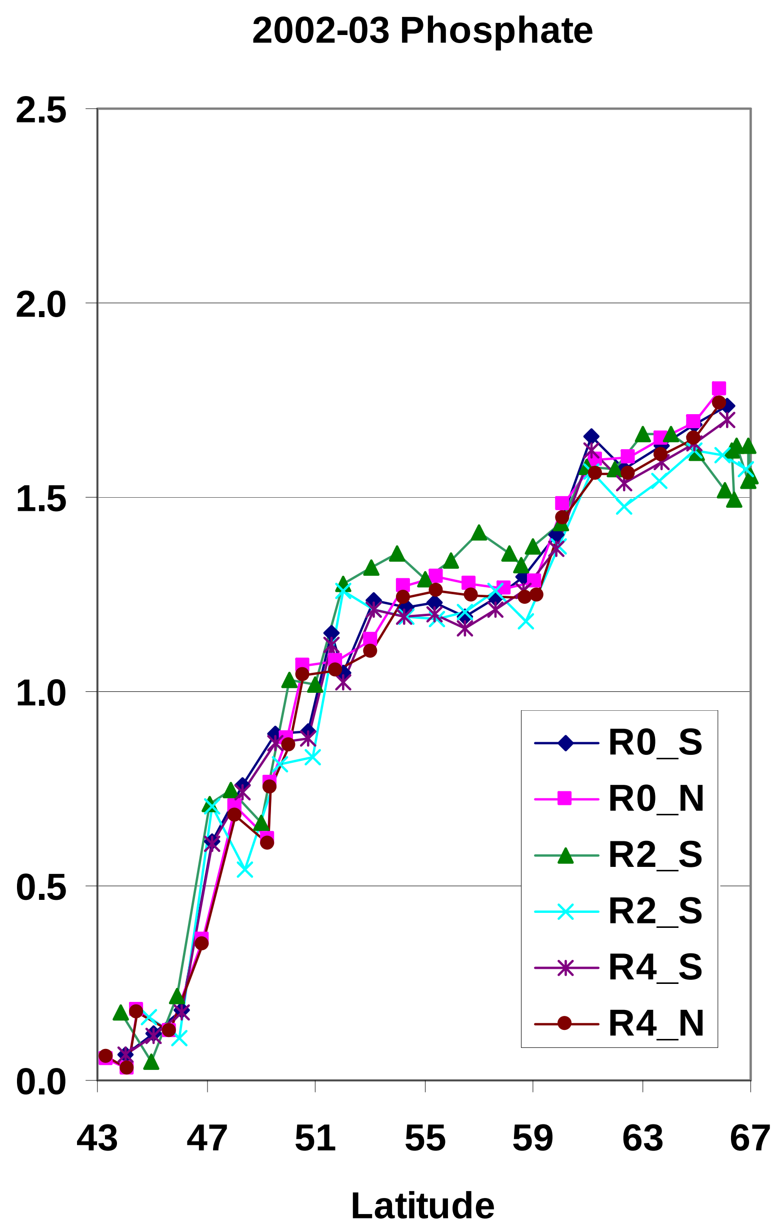
2002-03 Nitrate

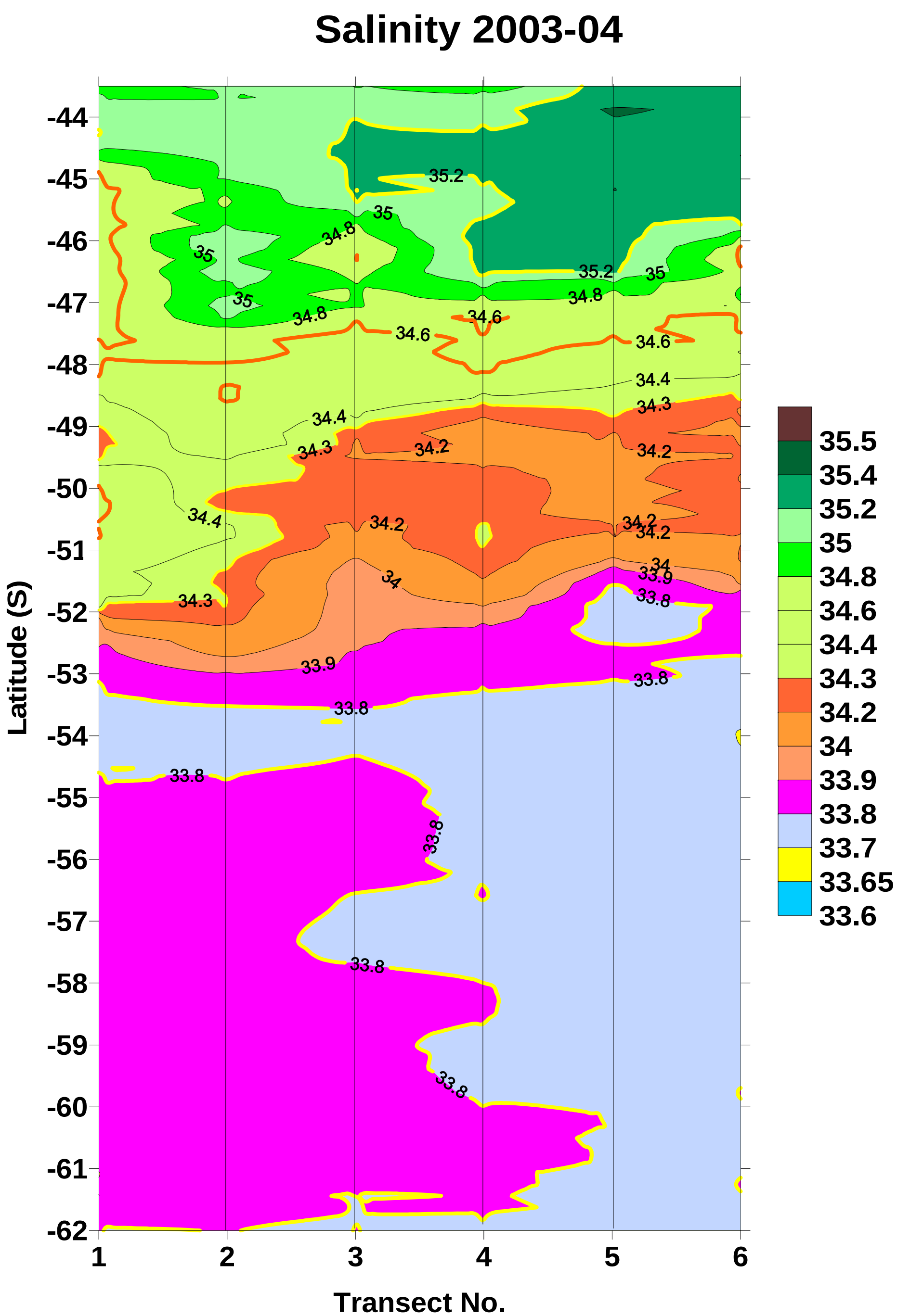


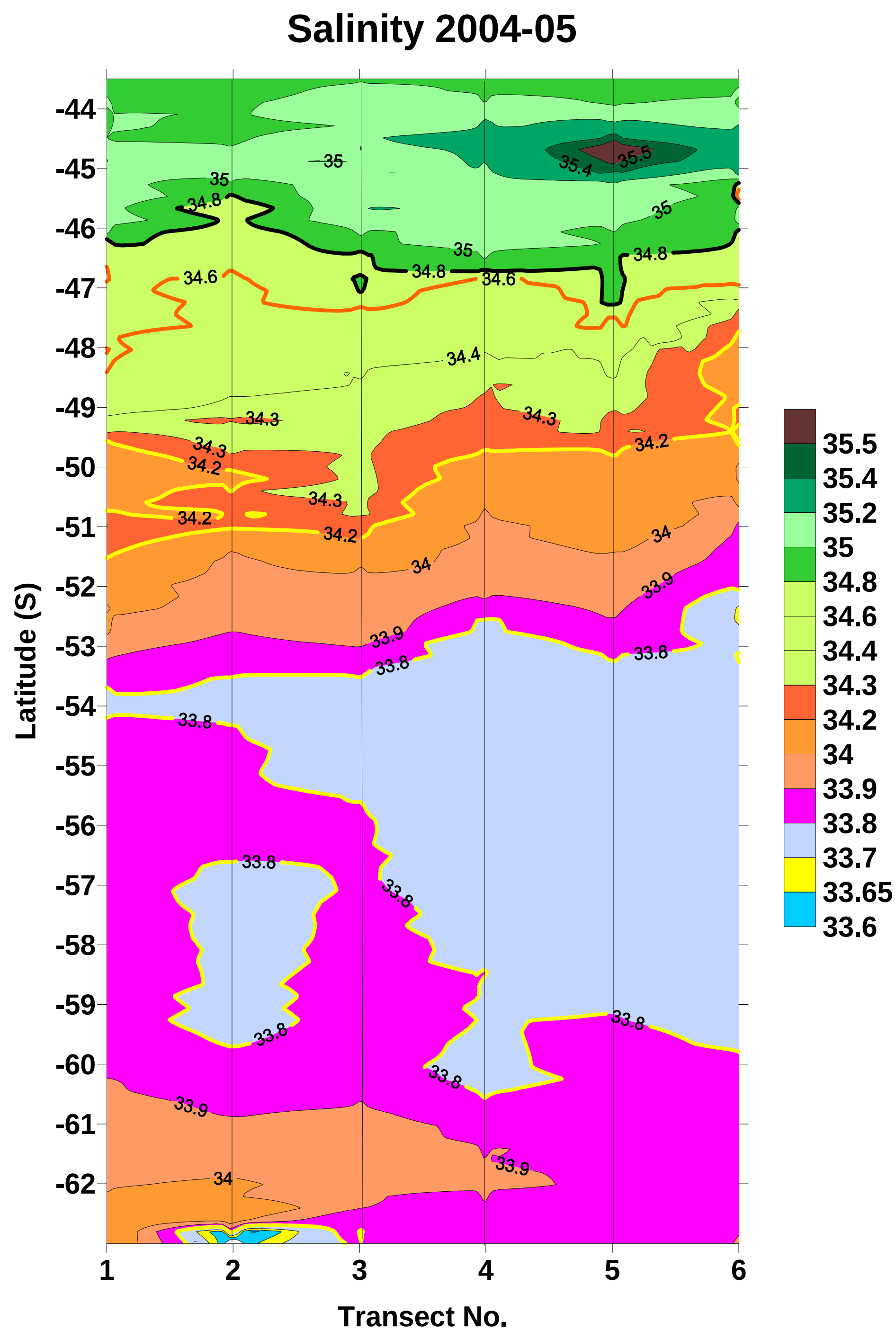

2003-04 Silicate
R0_S
R0_N
R1_S
R1_N
R3_S
R3_N
80
70
60
50
40
30
20
10
0
43
47
51
55
59
63
67
Latitude


2002-03 Silicate
R0_S
R0_N
R2_S
R2_S
R4_S
R4_N
80
70
60
50
40
30
20
10
0
43
47
51
55
59
63
67
Latitude


2003-04 Phosphate
2.50
2.00
1.50
1.00
0.50
0.00
43
47
51
55
59
63
67
Latitude
R0_S
R0_N
R1_S
R1_N
R3_S


2002-03 Phosphate
2.5
2.0
1.5
1.0
0.5
0.0
43
47
51
55
59
63
67
Latitude
R0_S
R0_N
R2_S
R2_S
R4_S
R4_N


Salinity 2003-04
Latitude (S)
Transect No.
35.5
35.4
35.2
35
34.8
34.6
34.4
34.3
34.2
34
33.9
33.8
33.7
33.65
33.6


Salinity 2004-05
Latitude (S)
Transect No.
35.5
35.4
35.2
35
34.8
34.6
34.4
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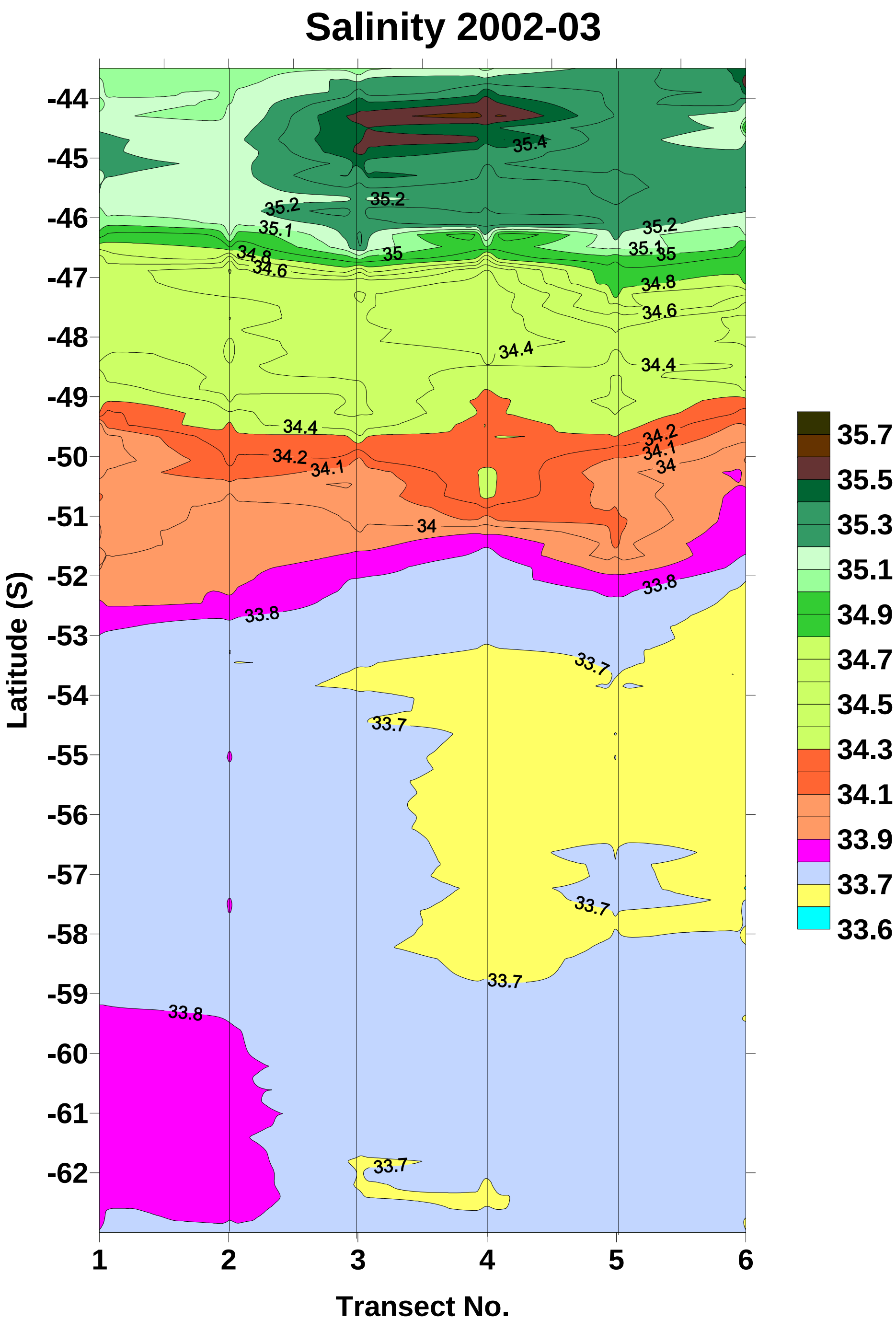
34.2
34
33.9
33.8
33.7
33.65
33.6



Salinity 2002-03
Latitude (S)
Transect No.
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35.3
35.1
34.9
34.7
34.5
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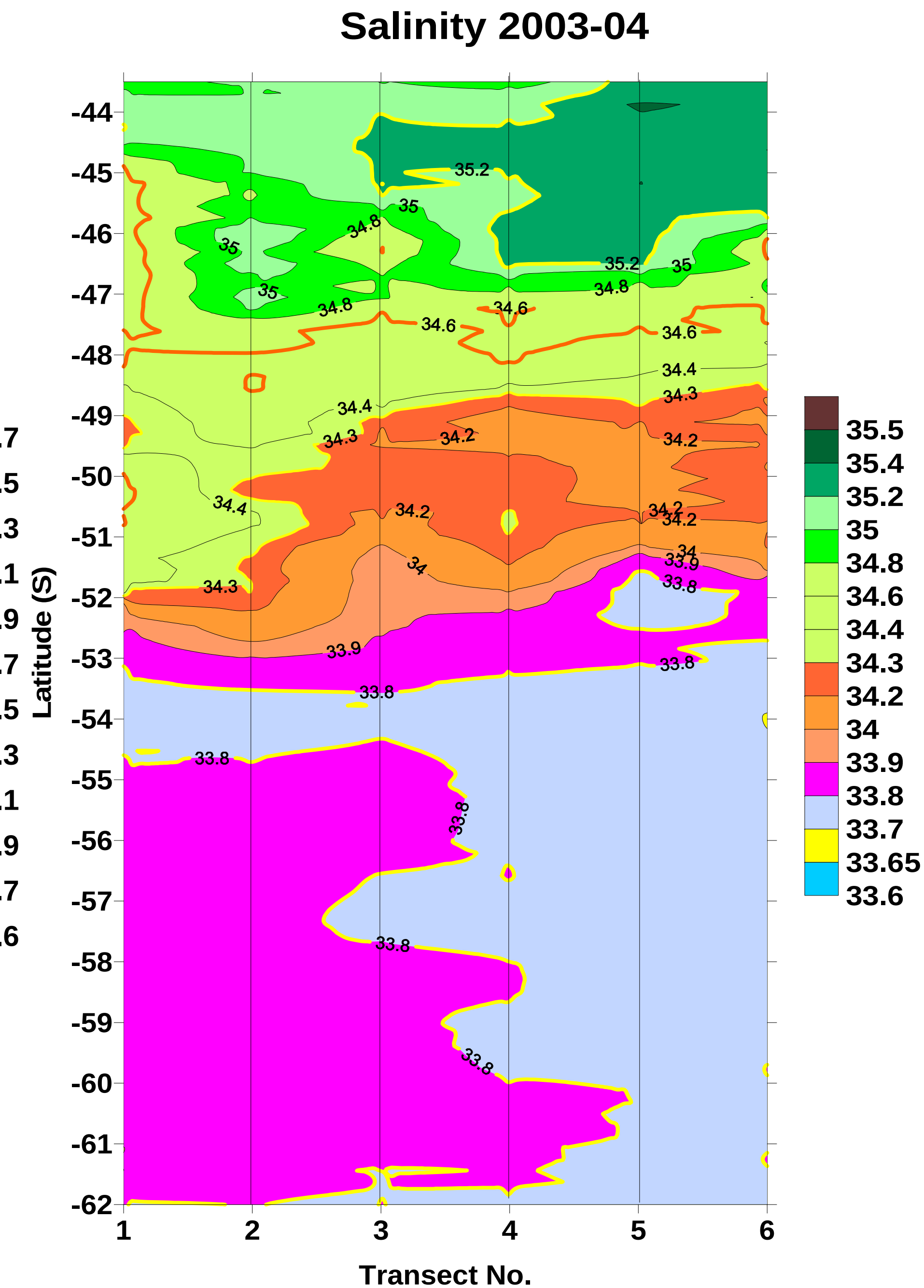
34.1
33.9
33.7
33.6



Salinity 2003-04
Latitude (S)
Transect No.
35.5
35.4
35.2
35
34.8
34.6
34.4
34.3
34.2
34
33.9
33.8
33.7
33.65
33.6

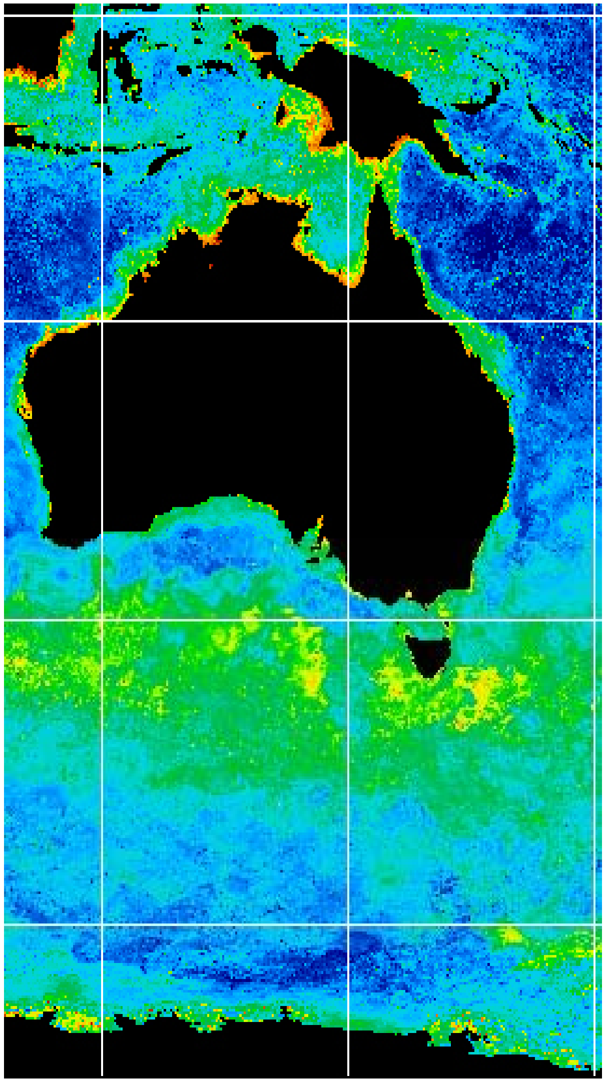
Bloom dynamics at mid latitude (53- 60ºS)

The late bloom in 2002-2003 was associated with relatively warm, very low salinity water

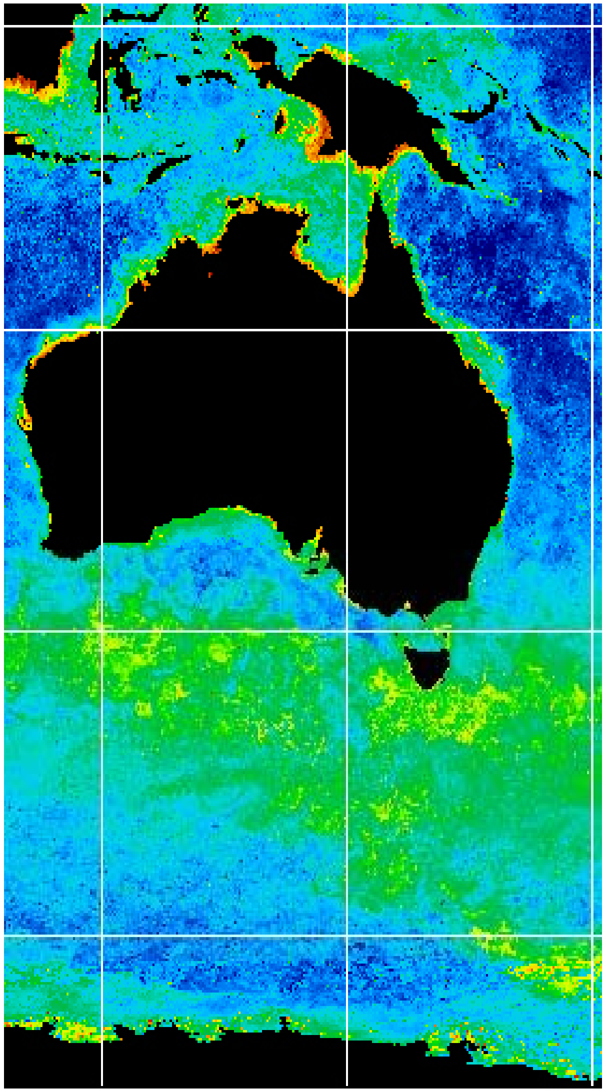
This water had low nutrient concentrations.

Waters to the south did not show the normal summer bloom pattern.

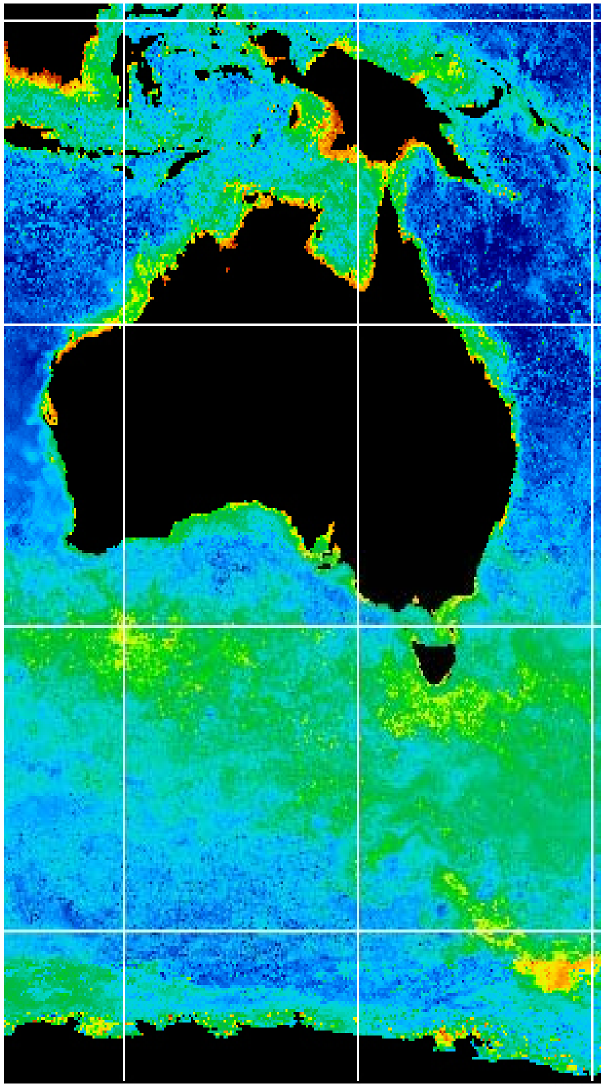
A bloom developed only after nutrient concentrations increased.



25 Jan 2003



10 Feb 2003



26 Feb 2003