Observing the Southern Ocean with the help of elephant seals
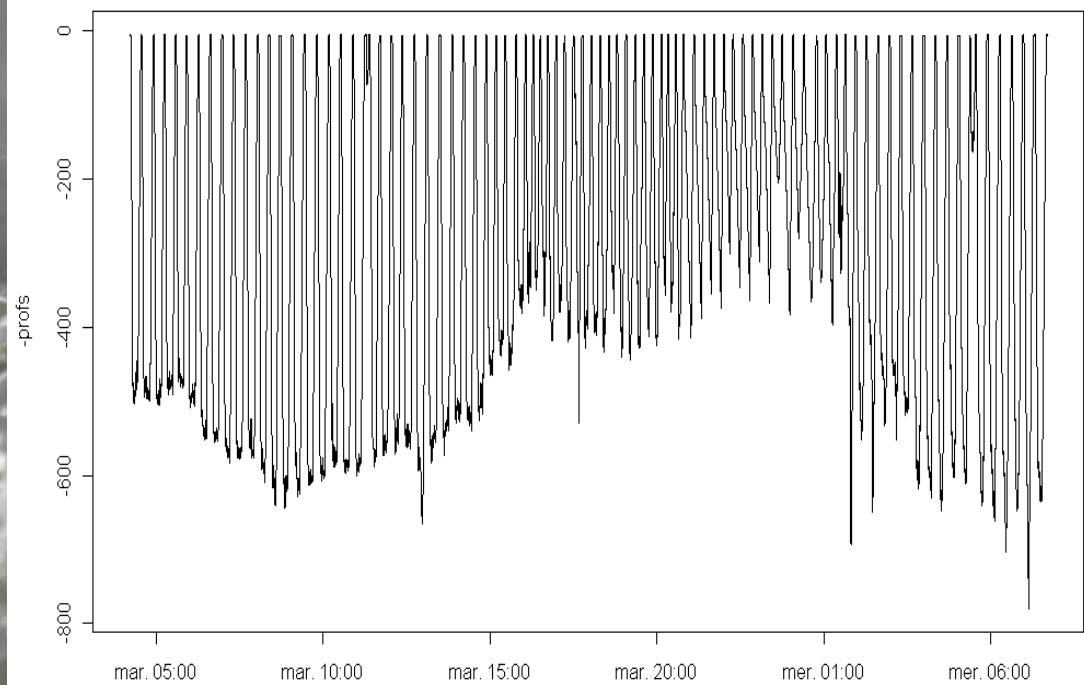
Fabien Roquet
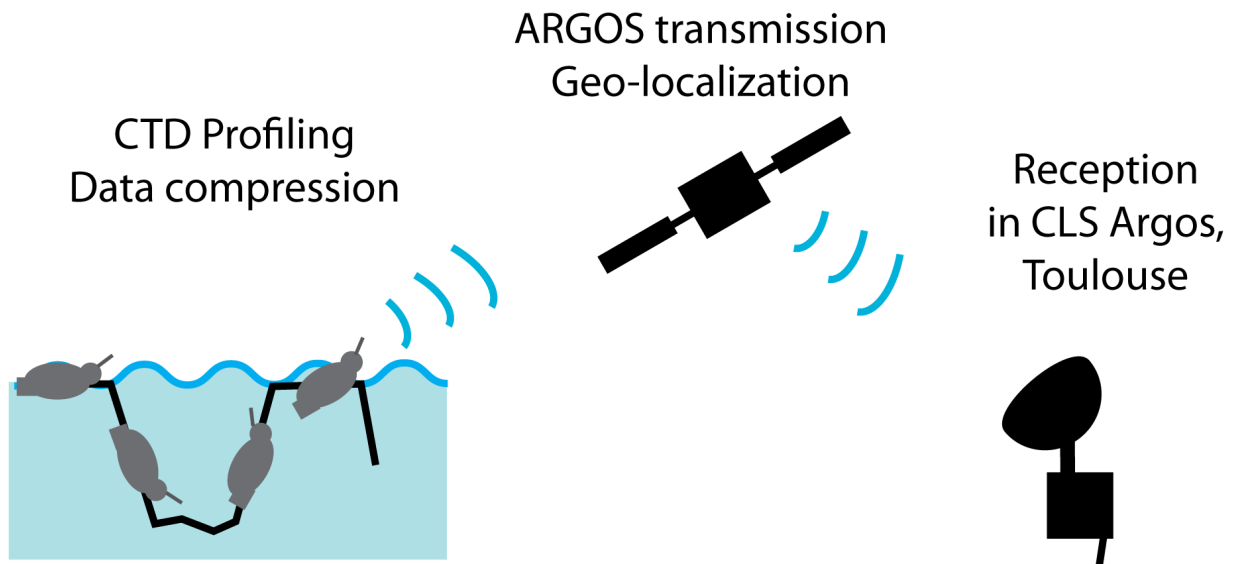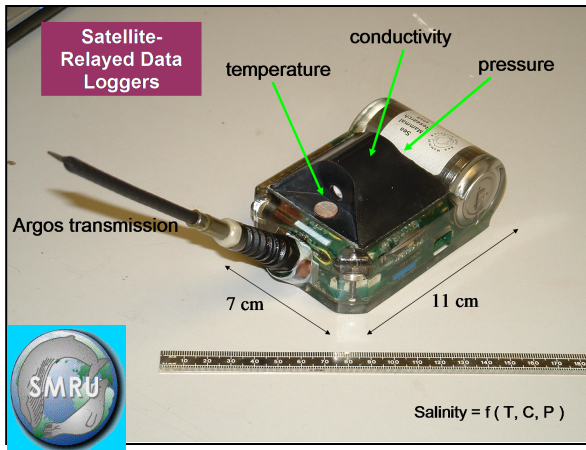Department of Meteorology of the Stockholm University

Mean Diving Depth: 450 m (max 2000 m)

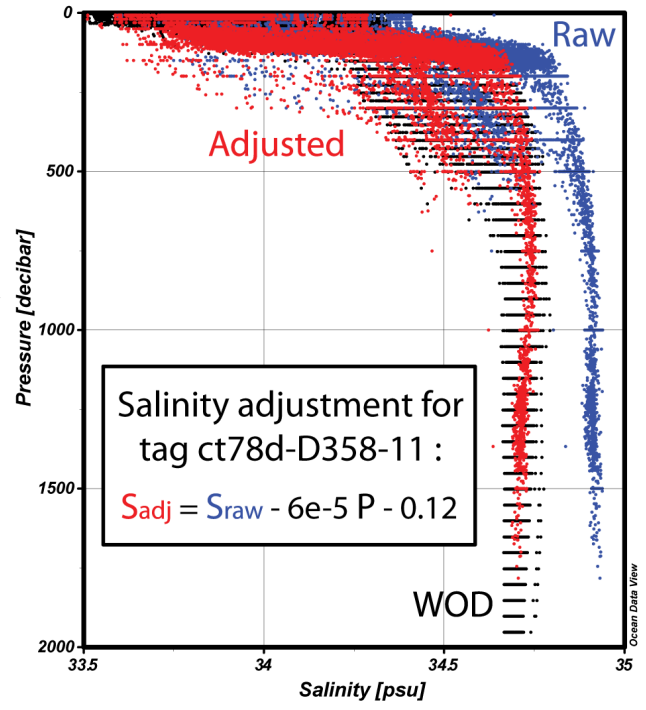**Mean Diving Duration: 21 mn (max 90 min)**

Mean Surface Interval: 3 mn

Mean number of dives per day: 60

Satellite-Relayed Data Loggers

temperature
conductivity
pressure

Argos transmission

7 cm   11 cm

Salinity = f (T, C, P)

SMRU

CTD Profiling
Data compression

ARGOS transmission
Geo-localization

Reception
in CLS Argos,
Toulouse

Post-processing
of CTD data

Data extraction
Storage at SMRU
Distribution to GTS

Distribution
through
BODC portal

Example of salinity profile comparison

Raw

Adjusted

WOD

Salinity adjustment for
tag ct78d-D358-11 :
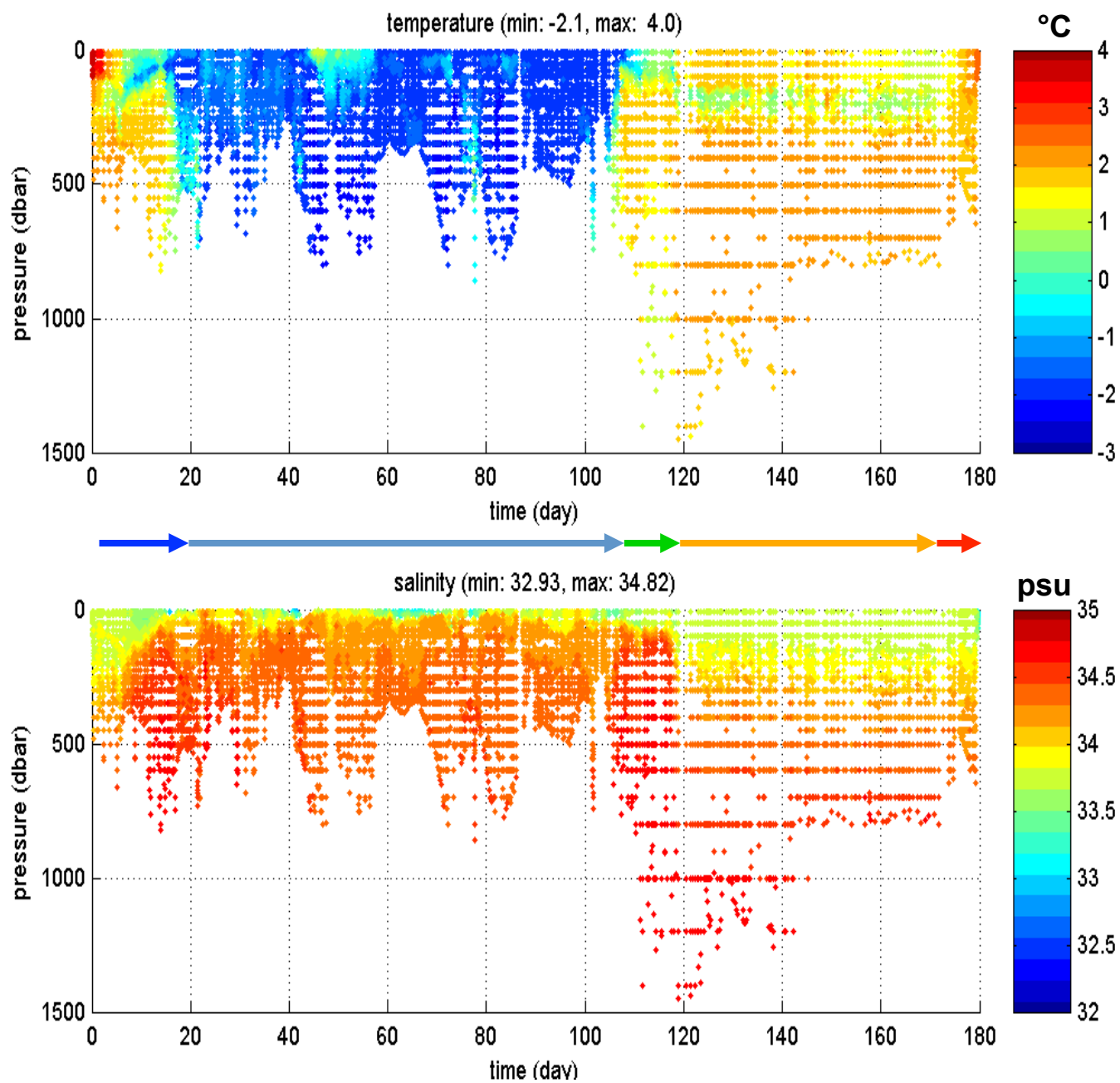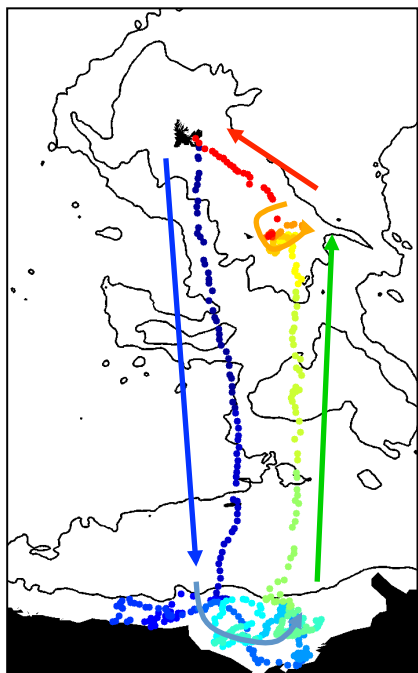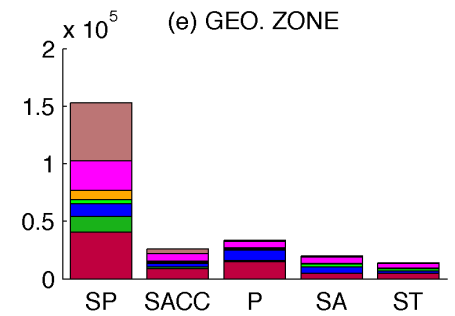
$S_{adj} = S_{raw} - 6e\text{-}5\ P - 0.12$

Pressure [decibar]
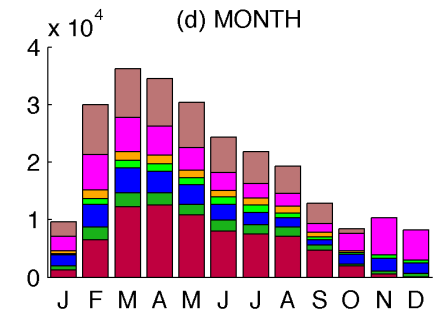
Salinity [psu]

Ocean Data View

Kerguelen Islands
552 profiles
6 months of data

2-3 profiles /day
20 datapoints /profiles

temperature (min: -2.1, max: 4.0)

°C

pressure (dbar)

time (day)

salinity (min: 32.93, max: 34.82)

psu

pressure (dbar)

time (day)

(a) MEOP-CTD dataset: 245863 profiles, 547 tags

(b) DIVE DEPTH

(c) YEAR

(d) MONTH

(e) GEO. ZONE

AUS
BRA
FR
GER-SAf
NOR
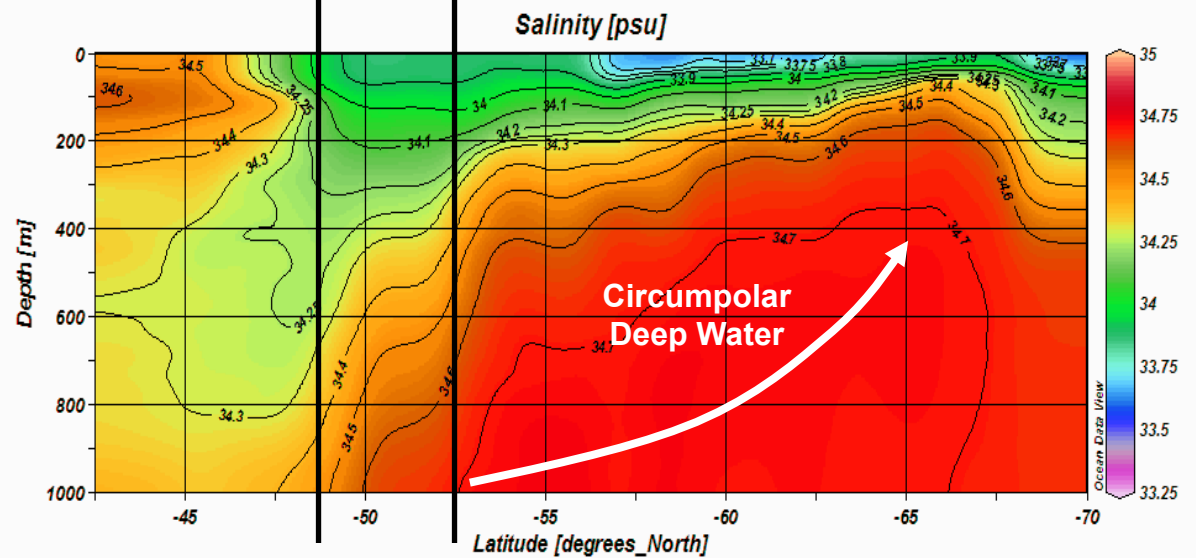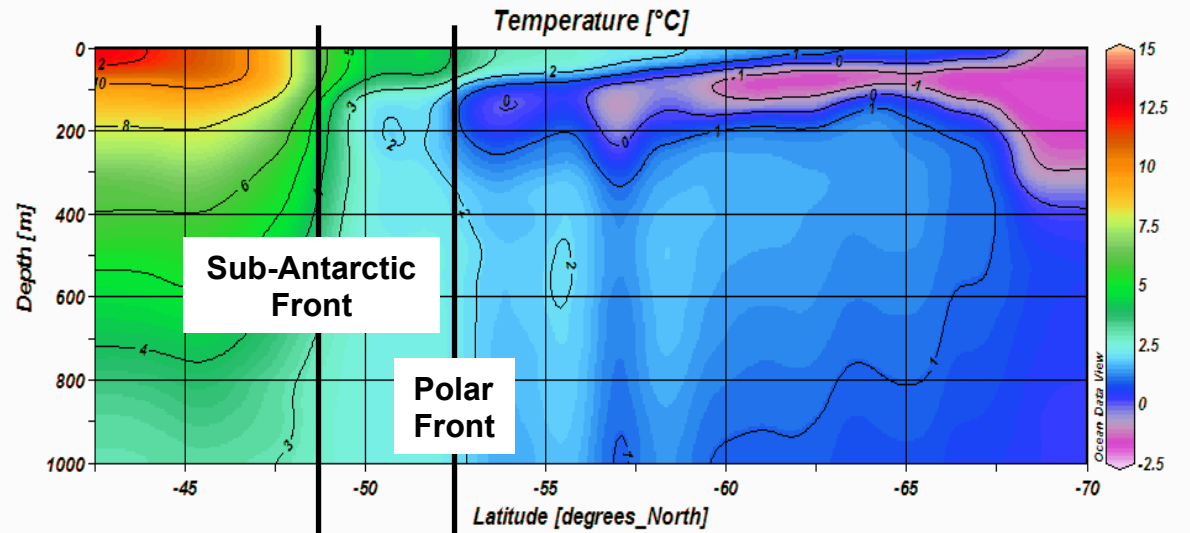UK
USA

Roquet et al., GRL, 2013
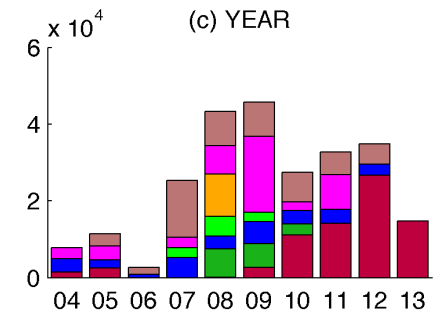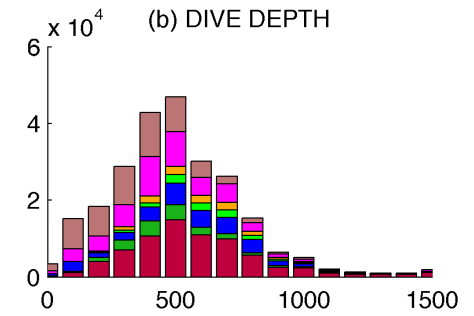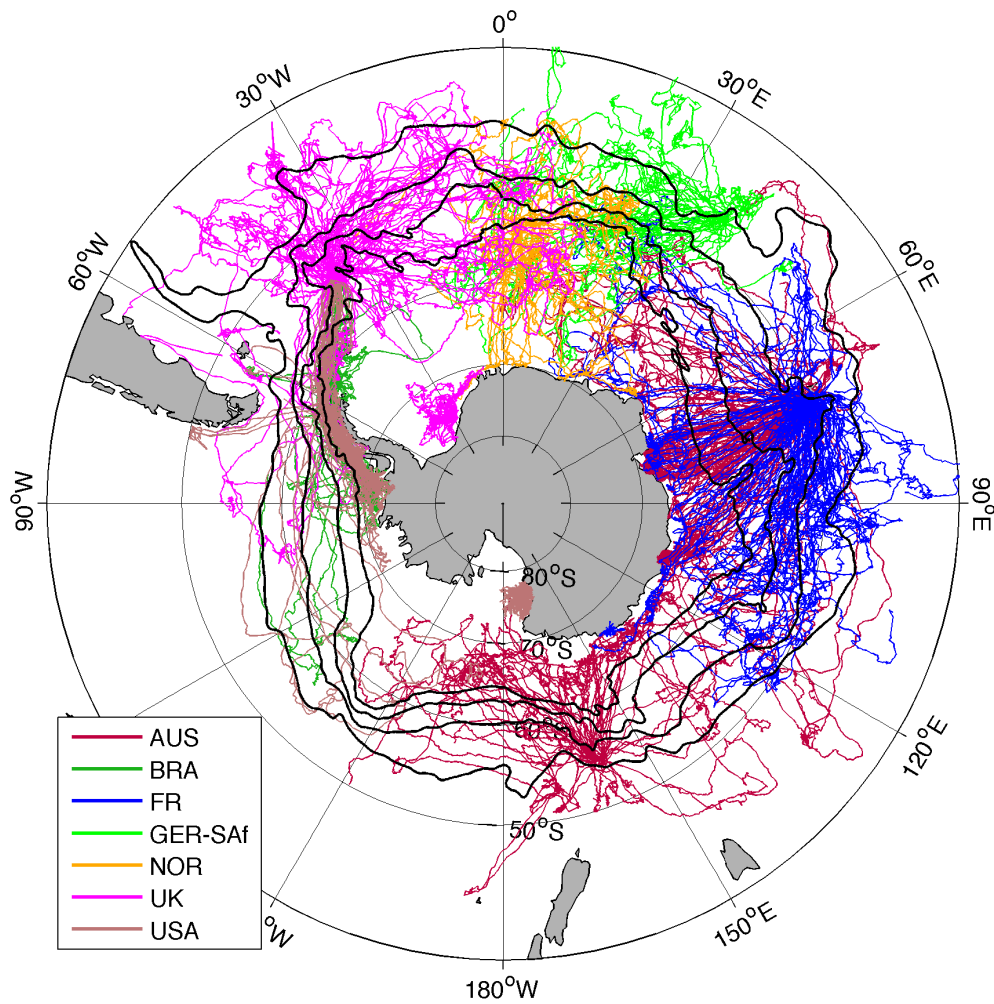
Calibration/Validation work

- Objectives:
  - Produce a validated dataset for scientific analyses
  - Integrate this dataset in oceanographic databases (i.e. WODB)
  - Distribute to the largest possible community

- Calibration/Validation procedure (see Roquet et al. 2011 JAOT) :
  - Edit and filter out false T/S profiles
  - Calibrate pressure effects using ship-based CTD comparisons (when available)
  - Calibrate the salinity offset using delayed-mode techniques

- Precision (repeatability) around 0.01°C, 0.01 psu
- Accuracy after calibration: better than 0.03ºC and 0.05 psu.

Delayed-mode techniques for salinity

- WJO method (standard Argo procedure)
  - Objective method to estimate a reference S profile based on a database of profiles
 - Assume high quality of T data
  - Depends on the availability of a dense database of profiles

- LCDW maximum salinity (Roquet et al. 2011)
  - Use the maximum salinity as a reference
  - Works only in the southern part of the Southern Ocean, where the salinity maximum is close enough from the surface.

- Cross-comparisons of profiles (Durand and Reverdin 2005, Roquet et al. 2011)
  - Least-square minimization of differences between salinity measurements obtained between different instruments.
  - Especially useful in regions where few historical data exist.

Historical section at 30°E

CIRCUMPOLAR DEEP WATER METHOD

Mirounga 2007: tag #03

BEFORE

Historical profiles

SRDL profiles
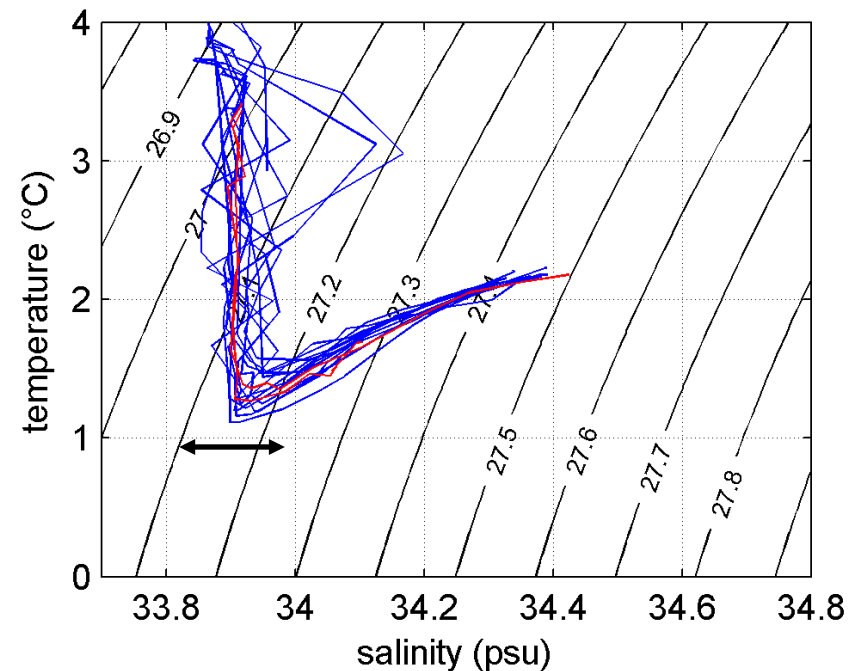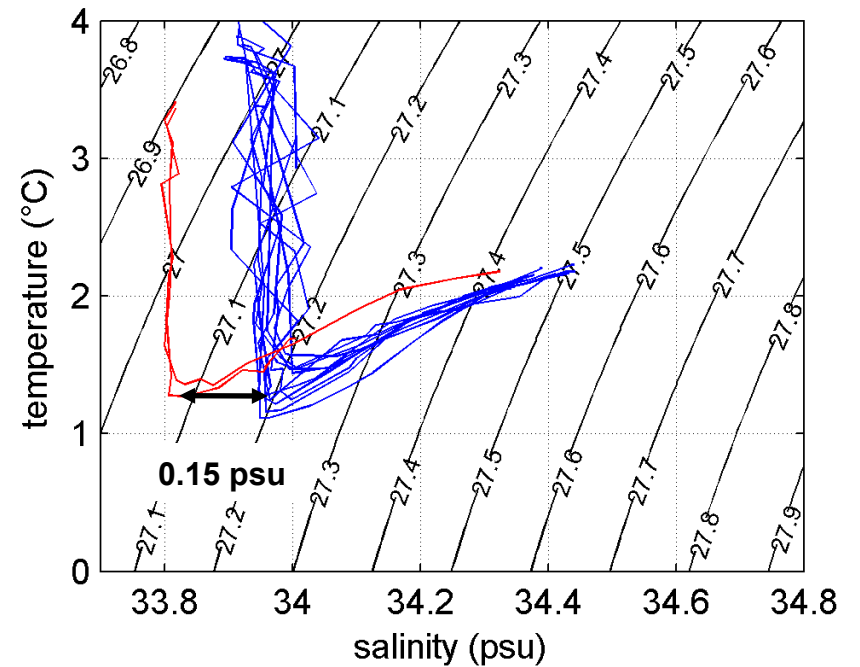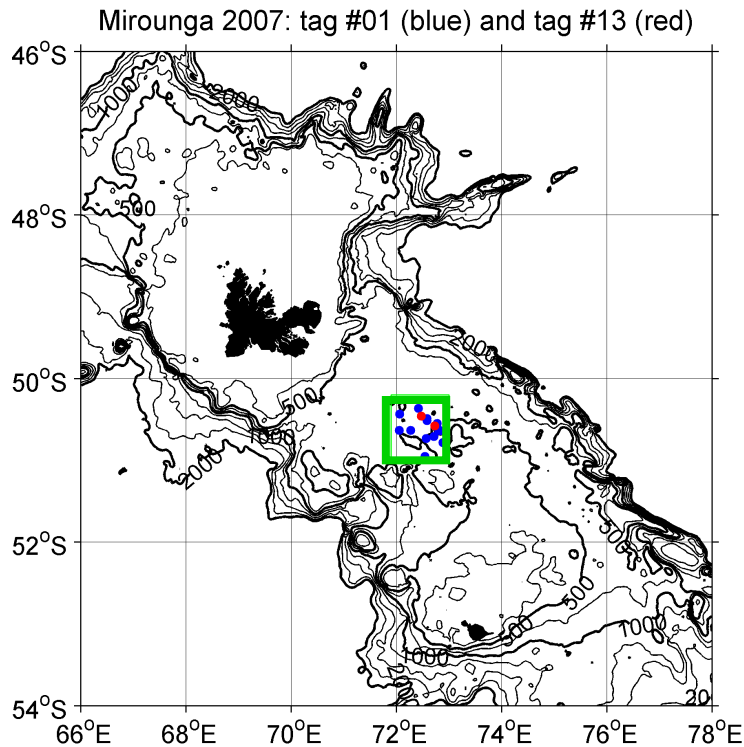
AFTER
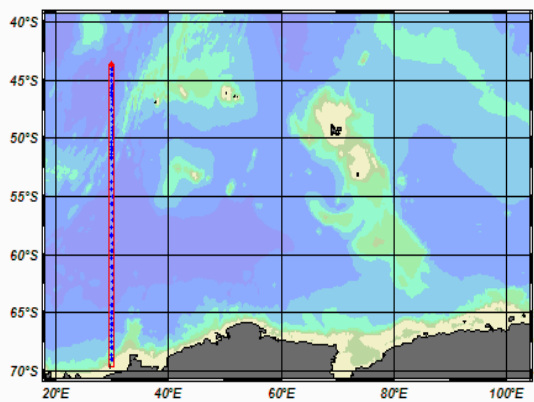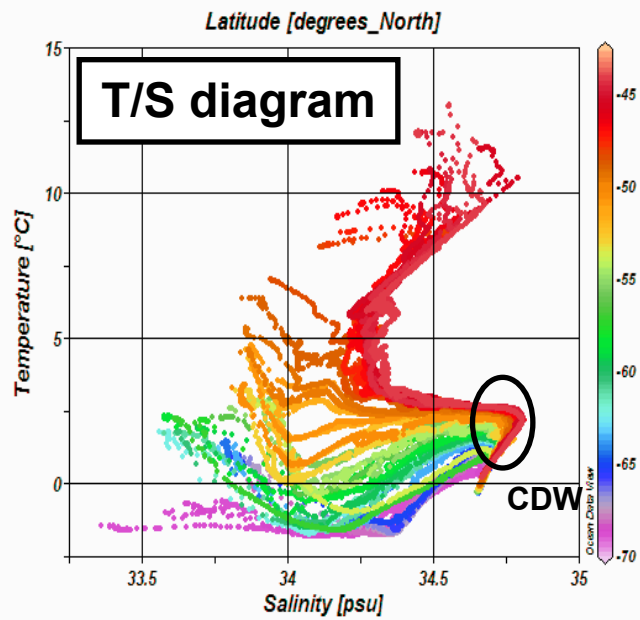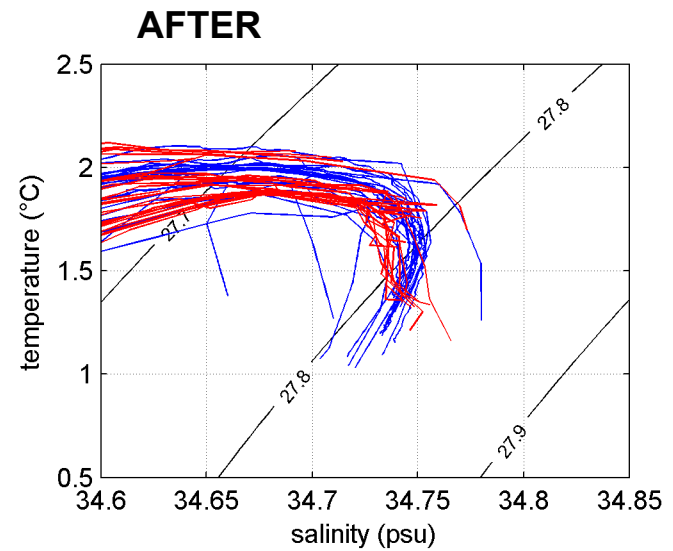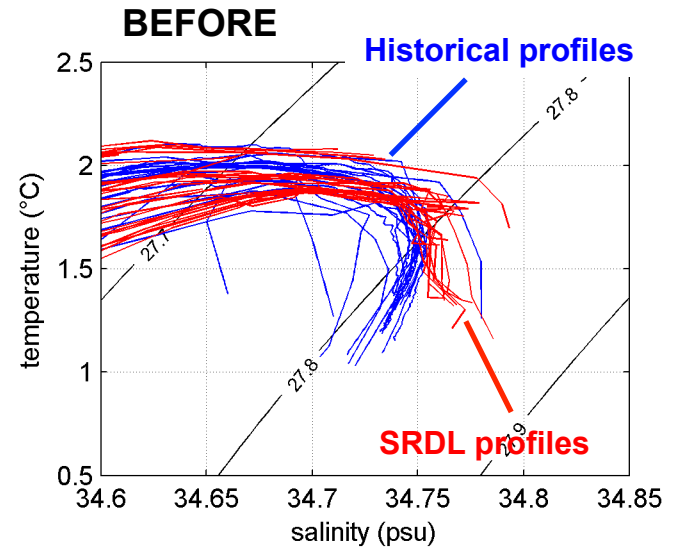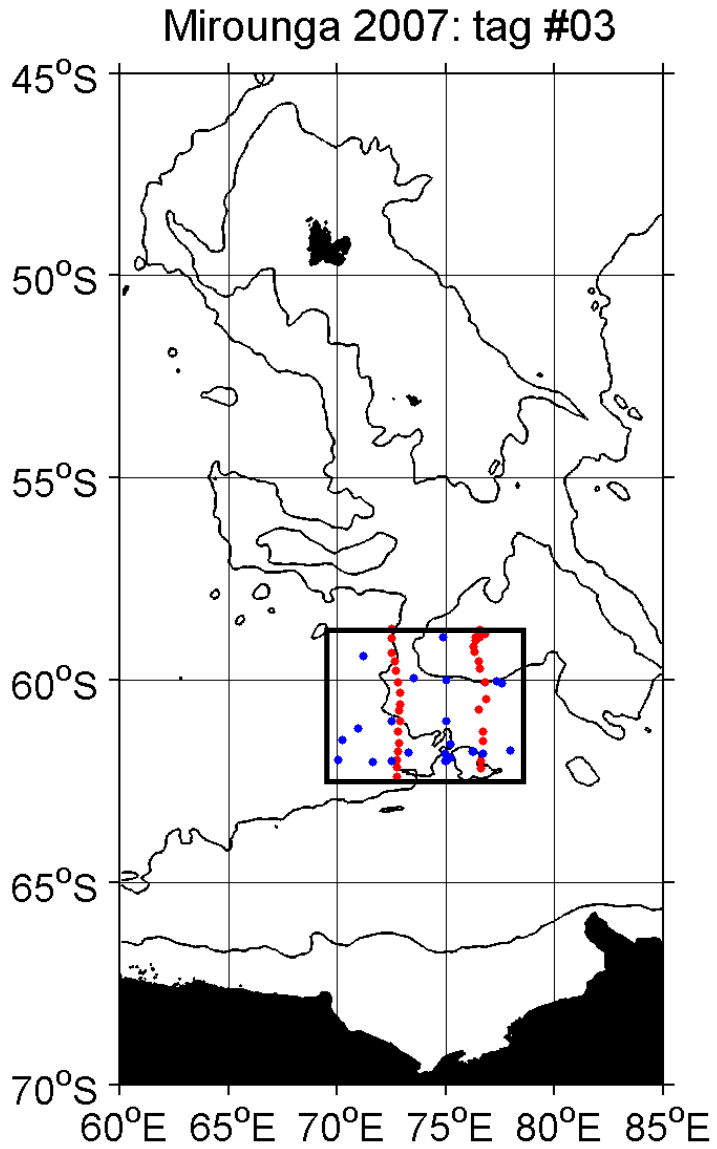
Estimated offset: - 0.02 psu

Cross-comparison among tags
over the Northern Kerguelen Plateau:
A case study

Mirounga 2007: tag #01 (blue) and tag #13 (red)

Need for an absolute reference :
Use historical profiles or other validated seal data

In this case, tag #1 corrected using the Circumpolar
Deep Water method provided the reference.

Defining an Optimal Reference Profile

- New method for the Southern Ocean, that tries to optimally combine hydrography and satellite information.

- Local refinement of the CARS climatology:

$$S_i^{ORP} = S_i^{CARS} + \delta S_i$$

- Objective analysis

$$\delta S_i = \Sigma_j w_{ij} \delta S_j$$

  - δS_j obtained using a database of historical profiles (WOD09)
  - w_{ij} function of distance in longitude, SSH (instead of latitude) and time
  - distance in sea surface height determined using KerMDT+MSLA (based on equivalent barotropic assumption, Meijers et al. 2011)
  - covariance parameters chosen empirically: 5º in longitude, 10cm in ssh, 30days in time, noise to signal variance ratio: 5%.
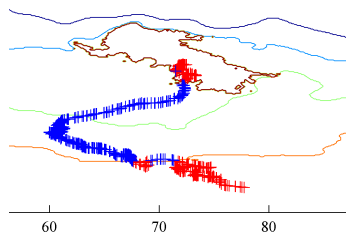
ct78DS03
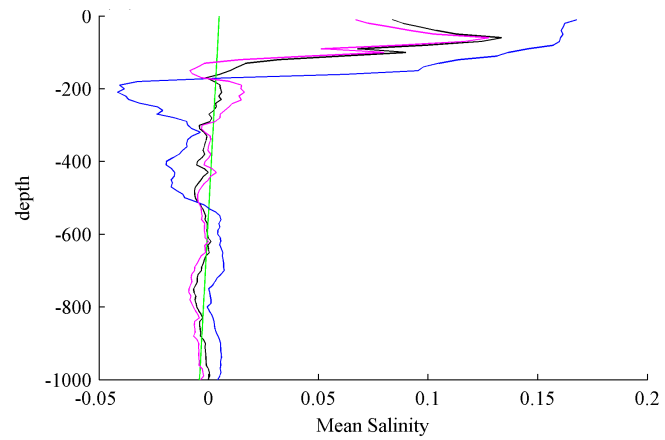
$$x = (-8.9887\text{e-}06 \pm 3.9558\text{e-}06)*|z| + (0.004761 \pm 0.0030723)$$
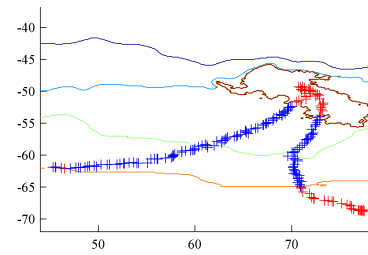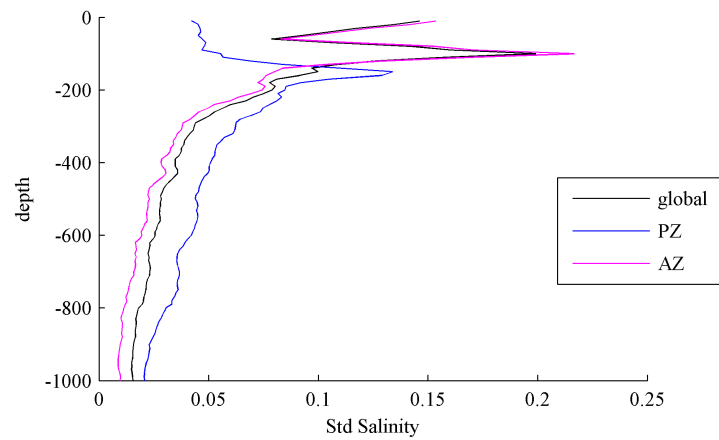
ct78DS08
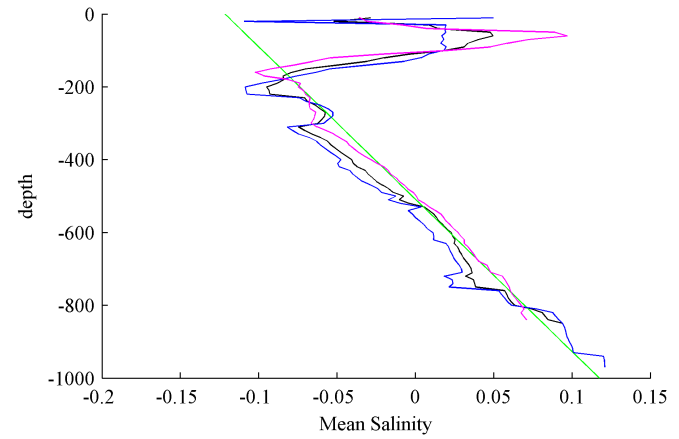
$$x = (0.00023896 \pm 8.1659\text{e-}06)*|z| + (-0.12156 \pm 0.0059546)$$
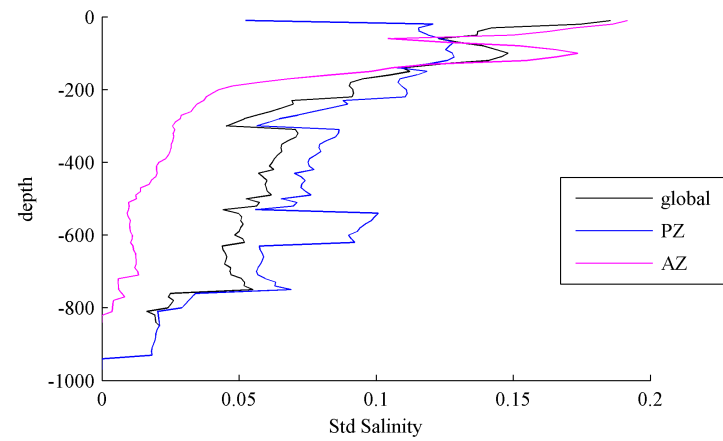
Correction for the ct78 dataset

raw data
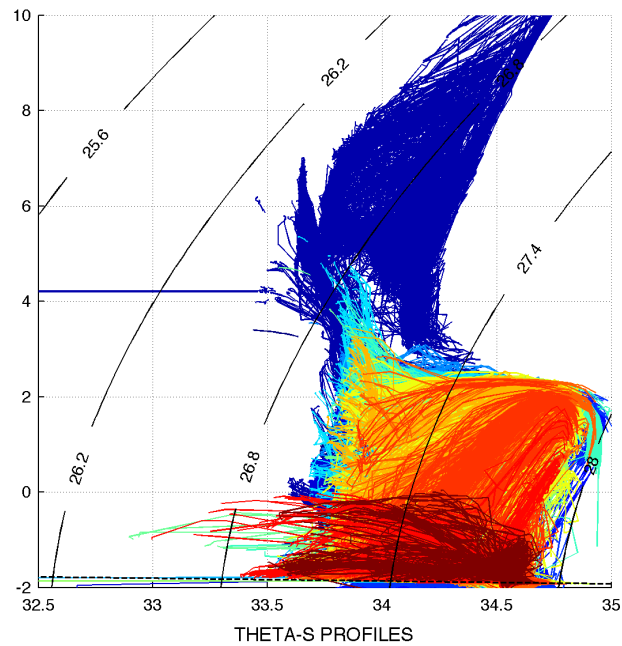
Corrected data

Validation

(a) DH500 - Raw seal data

(b) DH500 - Adjusted seal data

(c) DH500 - WOD data

(d) Comparisons of seal-derived and WOD-based DH500 values
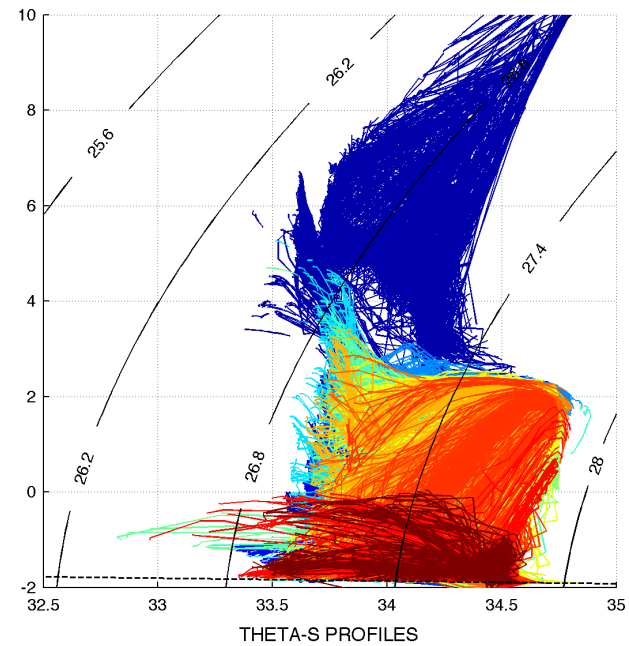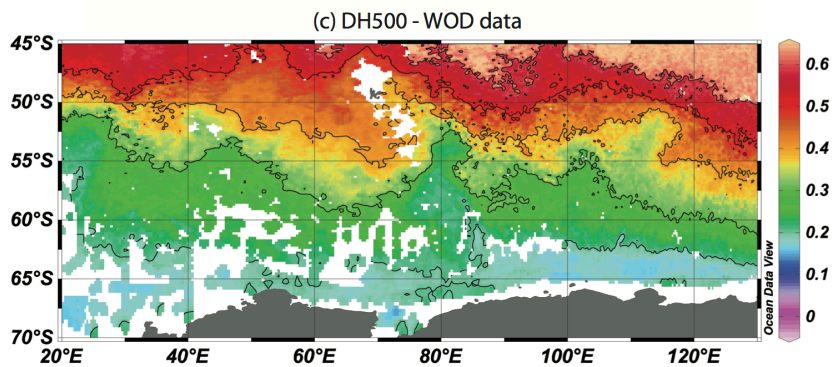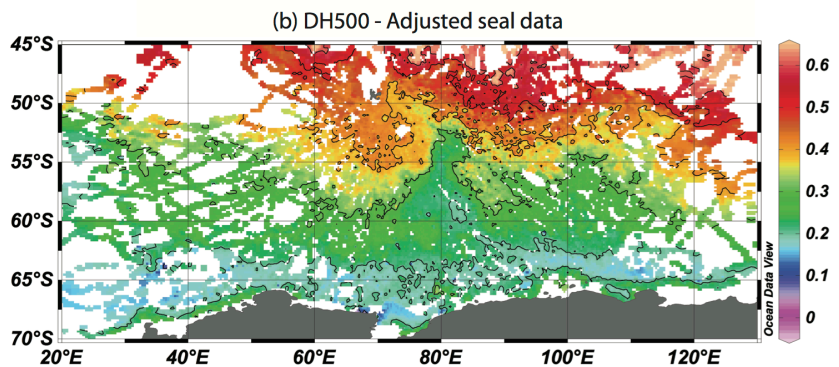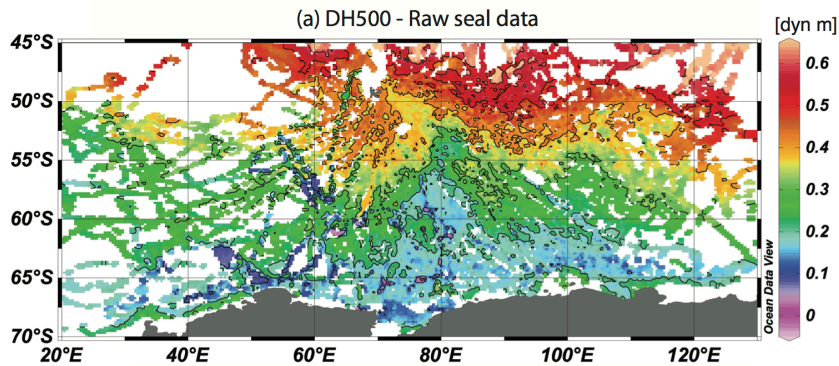
- Dynamic Height at 20 dbar relative to 500 dbar

- Mapping using Ocean Data View

- Adjustments are clearly improving the data quality.

- Seal data reveal details of the circulation not seen by other means.
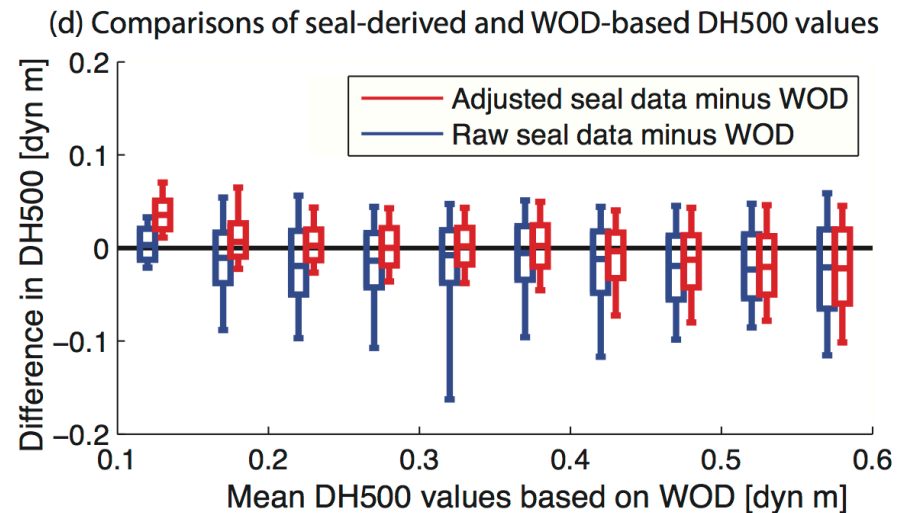
Conclusion

- **Elephant seal data represent now a major contribution to the Southern Ocean observing system.**
- **Post-processing of seal data is very important, especially for salinity.**
- **New methods to adjust salinity are under development. Information provided by altimetry should improve these methods.**
- **Other approaches are used, such as cross-comparisons between seal datasets.**

Bibliography:

Roquet et al. Delayed-Mode Calibration of Hydrographic Data Obtained from Animal-Borne Satellite Relay Data Loggers. J. Atmos. Oceanic Technol., 28, 787-801 (2011).

Roquet et al. Estimates of the Southern Ocean General Circulation Improved by Animal-Borne Instruments. Geophysical Research Letters, 2013GL058304 (2013).

Roquet et al. A Southern Indian Ocean database of hydrographic profiles obtained with instrumented elephant seals. Under review at Nature Scientific Data.

Dataset:

Roquet F.; Guinet C.; Hindell M. (2014). A Southern Indian Ocean hydrographic database obtained with instrumented elephant seals. British Oceanographic Data Centre - Natural Environment Research Council, UK. doi:10/srk.

IQuOD objectives

Objective
- The 2nd IQuOD meeting will bring together existing and new members of the IQuOD project to review progress since the last meeting, further refine the project goals if necessary and move forward into the next stage of the project.

The topics of the meeting include:
- Evaluation of auto QC benchmarking tests/results. (potential scientific/technical papers resulting from this activity)
- Development of goals for the subgroup on manual QC (potential scientific/technical papers resulting from this activity)
- Attaching uncertainties to observations - forming a sub-group on data formats, flagging and uncertainty estimates.
- Discuss and refine the importance of the project to data assimilation/climate forecasting efforts.
- Review funding opportunities.

Meeting Outcomes
- Review the first workshop goals and revise as required
- Review the structure of the project. Steering team, working groups, expert groups etc
- Review action items from the last meeting
- Review the scientific implementation plan
- Set goals and action items for the next year
- Workshop report
- Technical papers as decided on at the workshop

Concentration en glace de mer

(a) REF estimate
(b) SEAL estimate
(c) SSMI climatology

(d) Comparison of annual-mean sea-ice covered area

Total area (million km²)
10.2
8.1
7.3
0.8
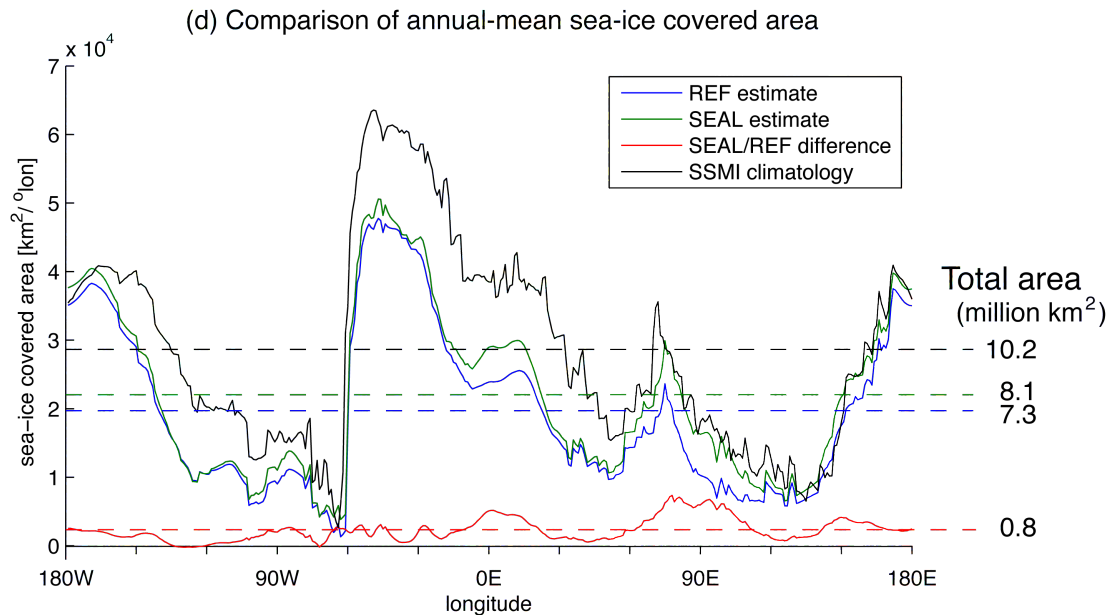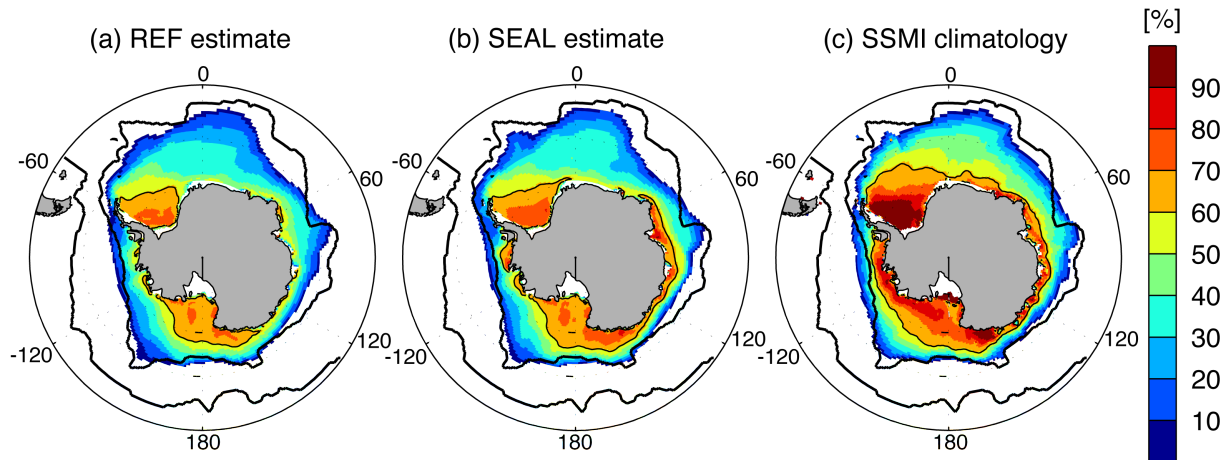
- Augmentation de la surface englacée (+10%)
- Augmentation de la couverture de glace en été
- Surtout vrai dans les régions où il y a des données d'éléphants de mer
- Augmentation encore insuffisante comparée aux observations (28% plus proche des observations satellite).

Roquet et al., GRL, 2013

Comparison with climatologies

- Climatologies are computed by interpolation and averaging of available TS profiles
- Comparison with climatology = indirect comparison with existing TS profiles
- Three climatologies are considered
  - CARS
  - MIMOC
  - satGEM (use TS+MSLA)

	Climatology name			
	WOA09	CARS09	AMA	MIMOC
Mapping surfaces	isobaric	isobaric	isobaric	isopycnal & mixed layer
Vertical level count (to 1950 dbar[1])	40 (24)	79 (65)	58 (57)	81 (81)[2]
Horizontal resolution	1°x1°	0.5°x0.5°	0.5°x0.5°	0.5°x0.5°
Max. depth (with seasonal cycle)	5500 m (1500 m)	5500 dbar (1800 dbar[3])	1975 dbar (1975 dbar)	1950 dbar (1950 dbar)
Mapping method	multi-pass Gaussian smoothing	LOESS	objective analysis	objective analysis
Covariance shape, bathymetry influence on mapping	circular, regional boundaries between basins	CSIRO-BAR filter (ellipse along bathymetry)	distance penalty for profiles over varying topography	path finding algorithm using median filtered ETOPO-1
Mixed layer	none, separate climatology available	none, separate climatology available	none	included, separate climatology available
Variables mapped	$T, S,$ & biogeochemical	$T, S,$ & limited biogeochemical	T & S	θ & S, Θ & S_A

Method of comparison

- For each profile, extract TS profile at same position and time-of-the-year in climatology, then compare.

- Database of reference (Histo+Argo) :