

To the construction of ocean climatologies

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Issues:

- Definition of the Climatology
- Uses of digital climatologies
- Data basis and data quality control
- Systematic errors (biases) and their impact
- Construction of the WOCE-ARGO climatology (WAGHC)
- Comparison between WAGHC and NOAA WOA13 climatologies

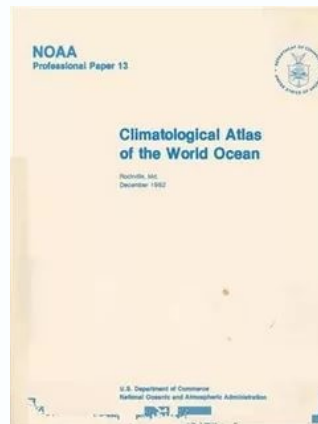
The Definition of the Standard WMO Climate Normal

- “Decadally updated 30-year average represents the standard WMO climate normal”
- “If we accept that climate conditions are indeed non-stationary, then for the purposes of providing more accurate depictions of current and future climate conditions, climate normals should be 1) updated as frequently as possible; and/or 2) computed in an alternative manner.”

From Smith et al, BAMS, June 2011

The first global ocean climatology: Climatological Atlas of the World Ocean

- The first digital atlas of the global ocean
- (Levitus, 1982)



- *"Sydney Levitus distributed this work without restriction, an act not common at the time. This seminal atlas moved the oceanographic diagnostic research from using hand-drawn maps to using objectively analyzed fields of ocean variables"*
- OCL Team, 2013)



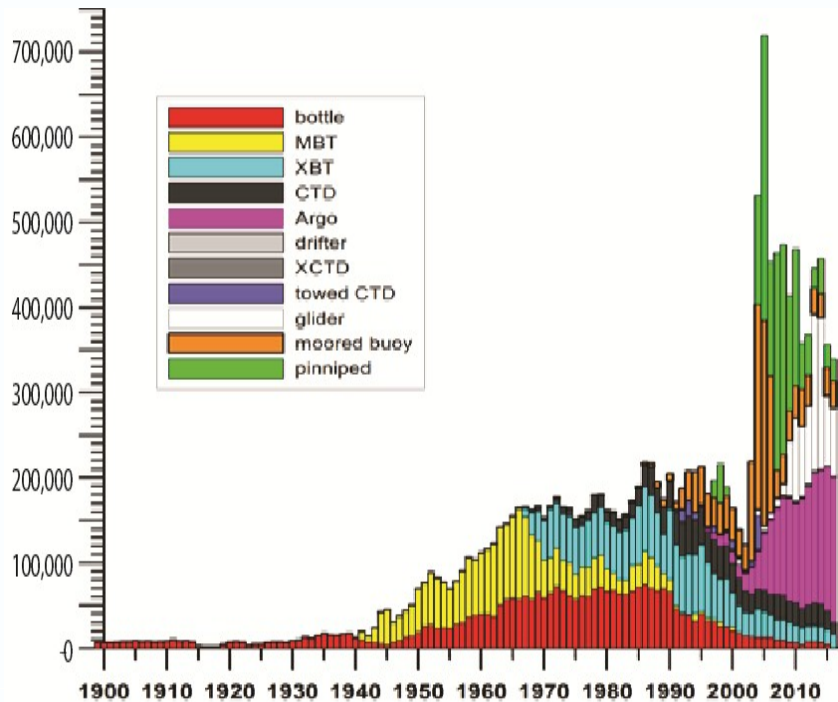
Uses of the WOA13 gridded Climatology (statistics over 63 articles published between 2014-2015)

WOA13 used for:	Number of references
Model boundary condition	0
Base line for climate change estimate	5
Comparison with other climatologies	3
Regional study	21
Biological study	4
Climate change study	5
Model validation	2
Chemical study	5
Other	4

Courtesy of A. Grodsky, NOAA, NCEI

A heterogeneous archive of the global profile data

Yearly number of profiles

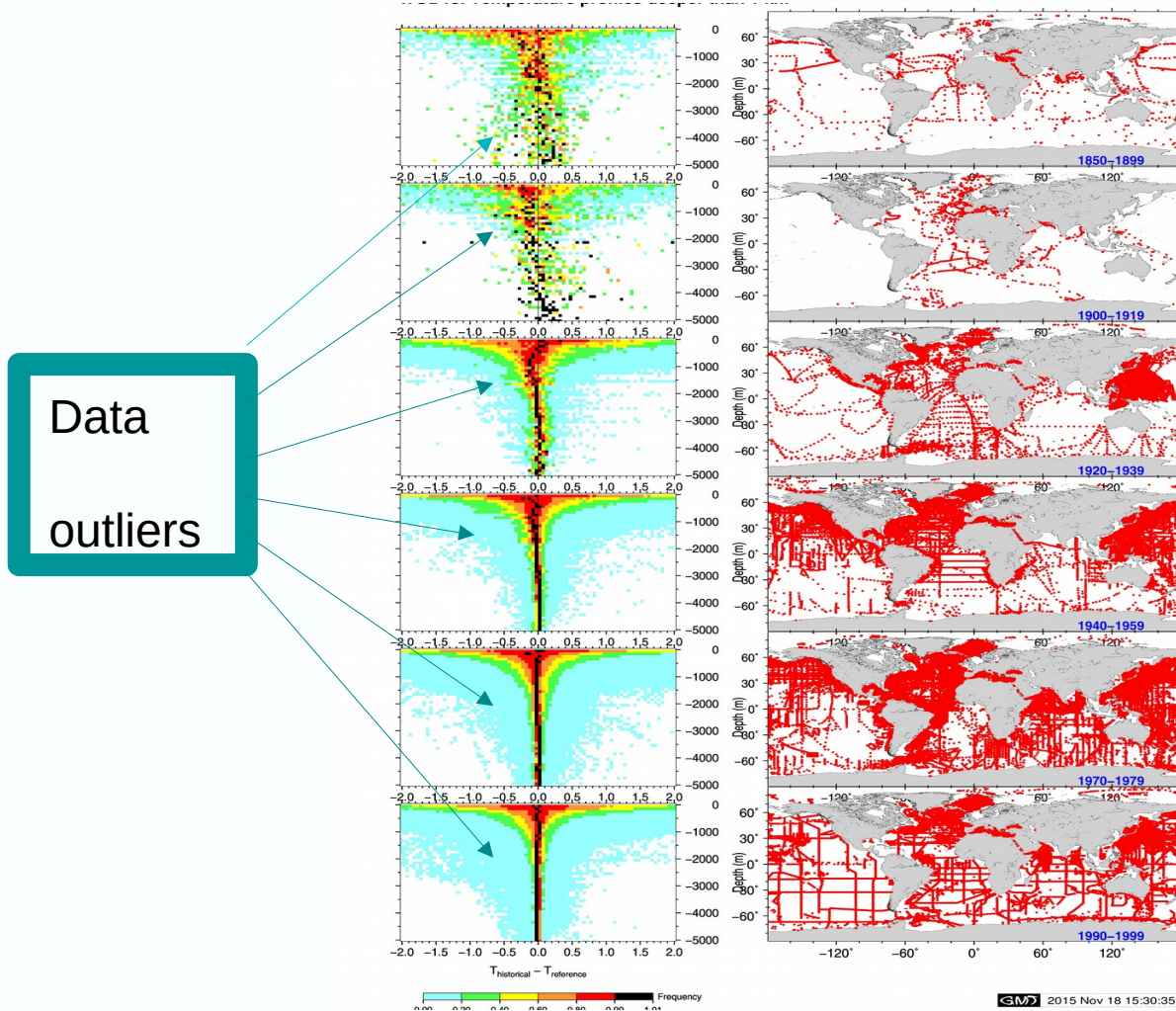


The newest release (WOD18) includes more than 15,7 million temperature profiles

- 11 instrumentation types in the World Ocean Database
- Each data type has a different data quality and data precision
- Caution: MBT and XBT instruments were not designed to serve scientific research
- Caution: Only (smaller) part of hydrographic profiles was obtained on scientific cruises

Evolution of Measurement Accuracy

Temperature anomaly histograms for selected decades



1870s



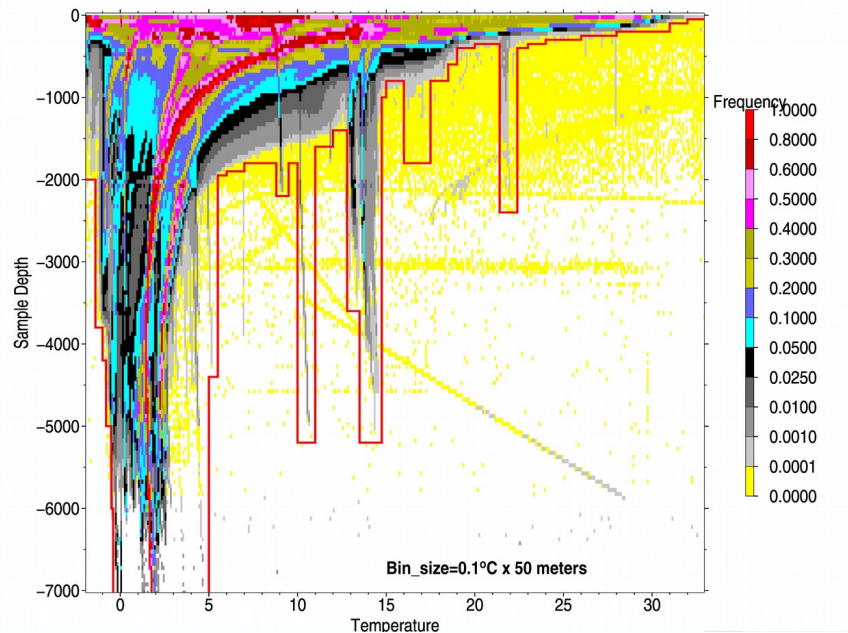
2000

Automatic Quality Control Procedure

- Due to the big data volume only automatic QC is feasible
- Quality checking is required for two purposes:
 - ✓ to allow use of the data within an acceptable time frame
 - and
 - ✓ to filter out profiles that are almost certain to contain only good quality data in order to reduce the quantity of profiles that need to be inspected by manual quality control
- **A set of quality control tests is applied**

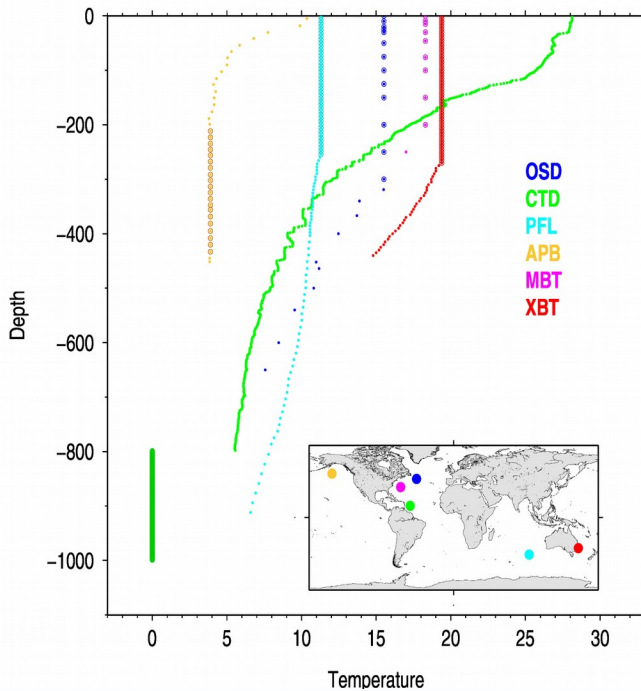
Crude range check : screen for observations being grossly in error

- a) The overall T-range : $[-2.5; 33.0 \text{ }^{\circ}\text{C}]$ and
- b) Global Temperature vs Depth mask:

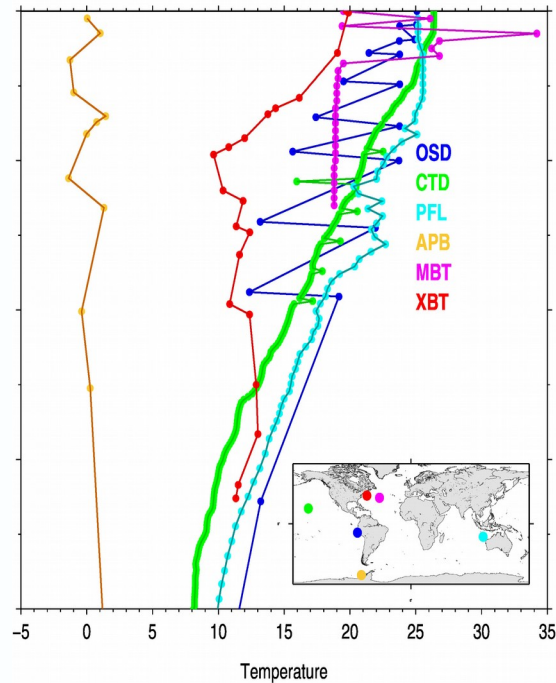


Profile shape and vertical gradient check

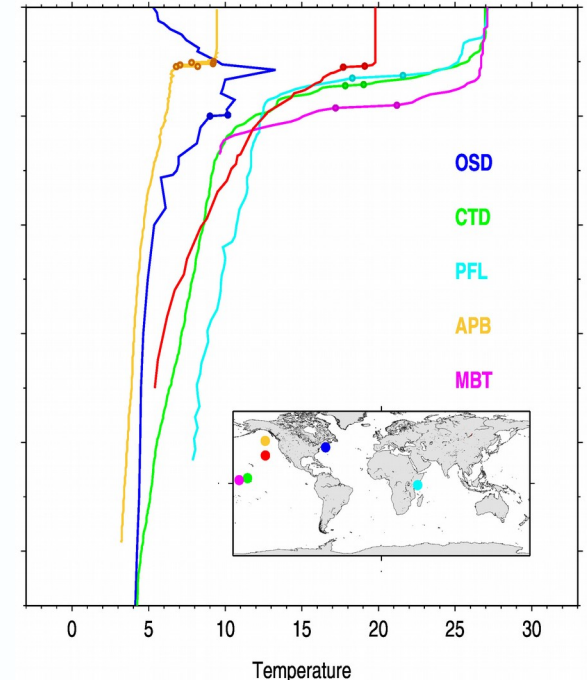
Stuck Value Check



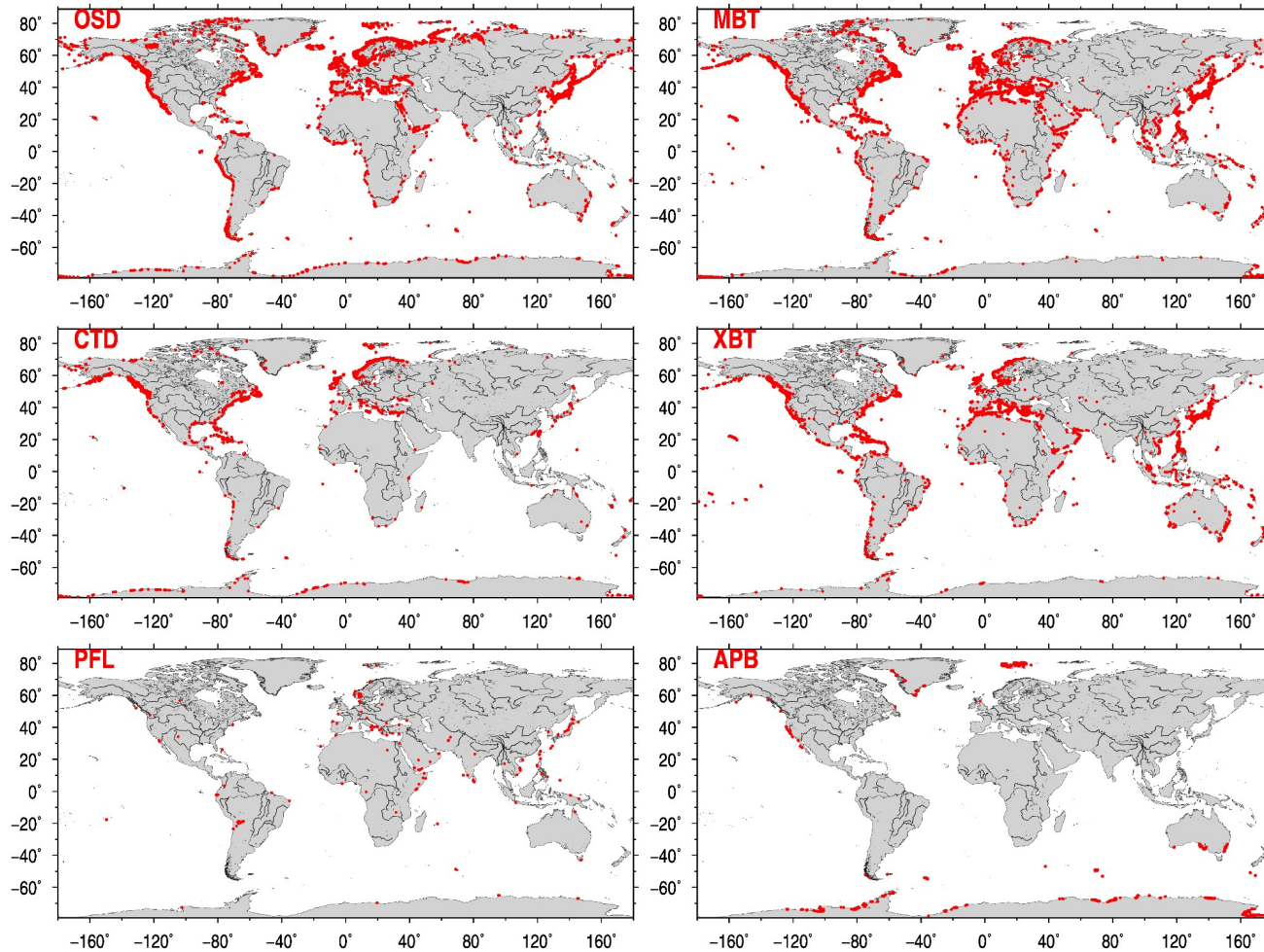
Multiple Extrema Check



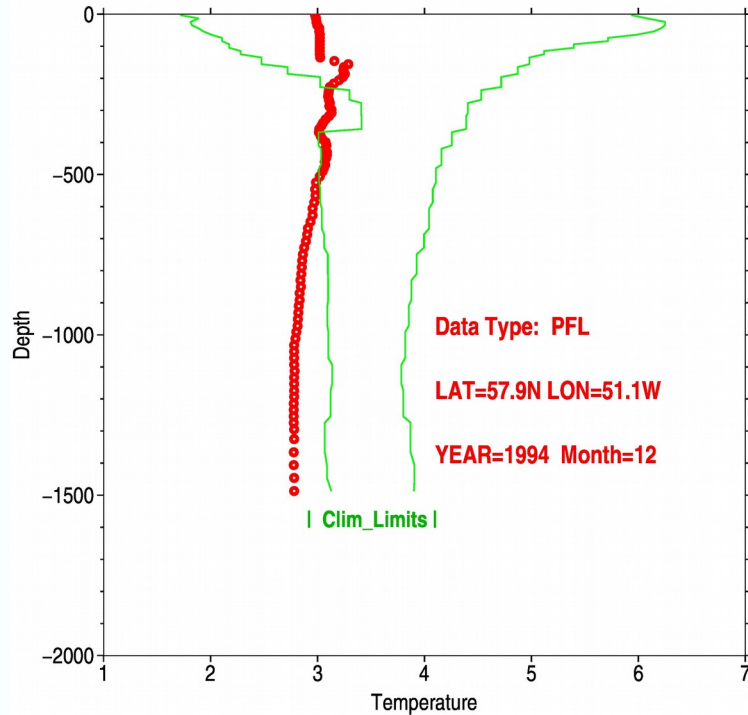
Vertical Gradient Check



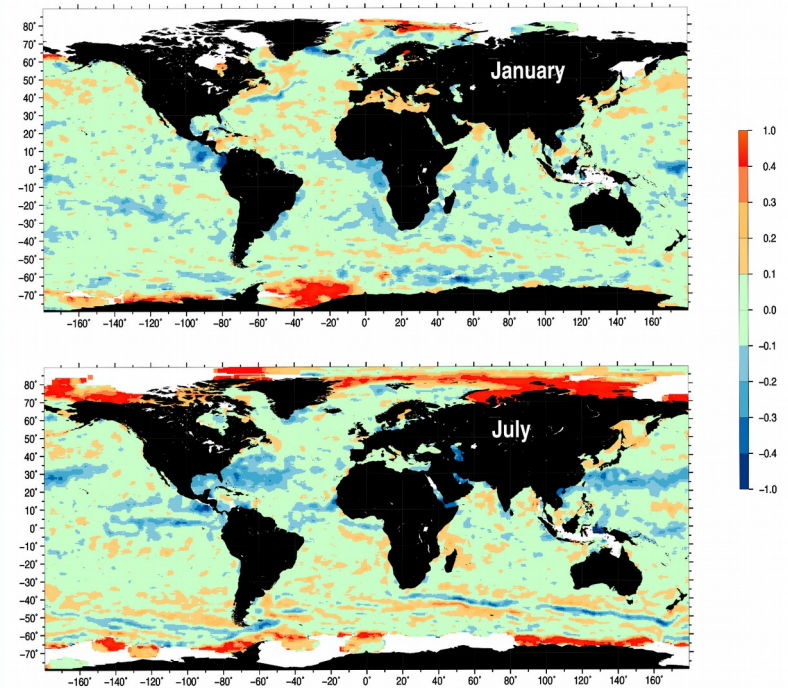
Position on land and local bathymetry test



Check against local climatology



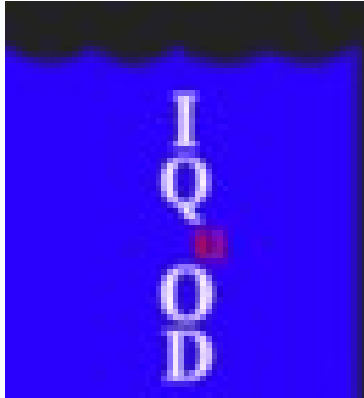
Medcouple – a robust measure of skewness



More accurate identification of outliers: adjusted box-plot method

$$[Q1 - 1.5e^{a_{MC}} IQR; Q3 + 1.5e^{b_{MC}} IQR]$$

IQuOD-International Quality controlled Ocean Database



- To construct a climate-quality ocean temperature database using a consistent and unified Quality Control Standard
- to produce and freely distribute the highest quality and **complete single ocean profile repository** along with (intelligent) metadata and assigned uncertainties
- for data assimilation, anthropogenic warming estimates, ocean heat content and sea level change estimates.

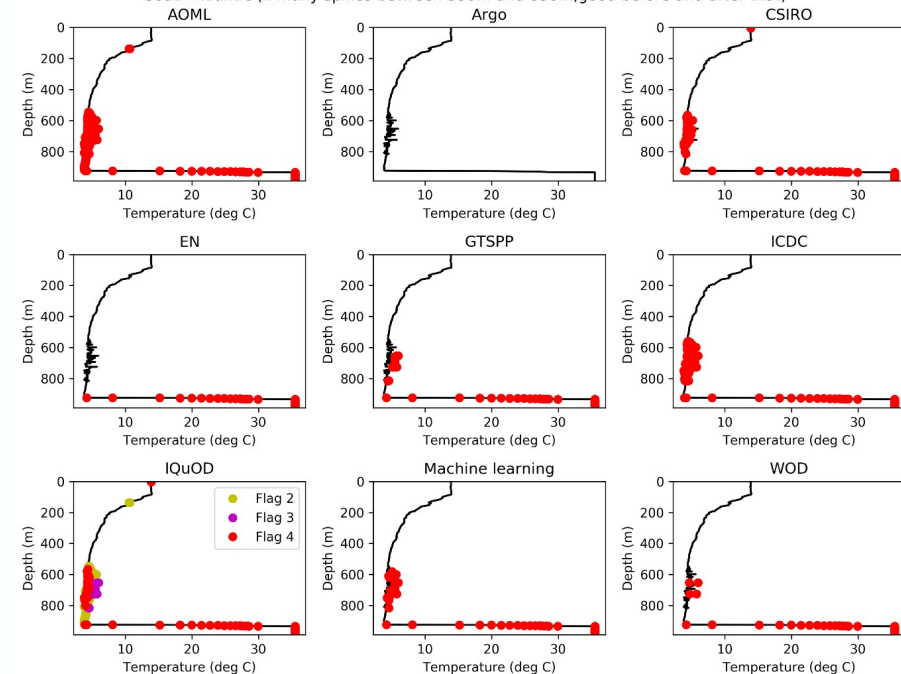
<http://www.iquod.org>

Performance of different AQC Schemes: Benchmarking Tests

AOIML100 Dataset

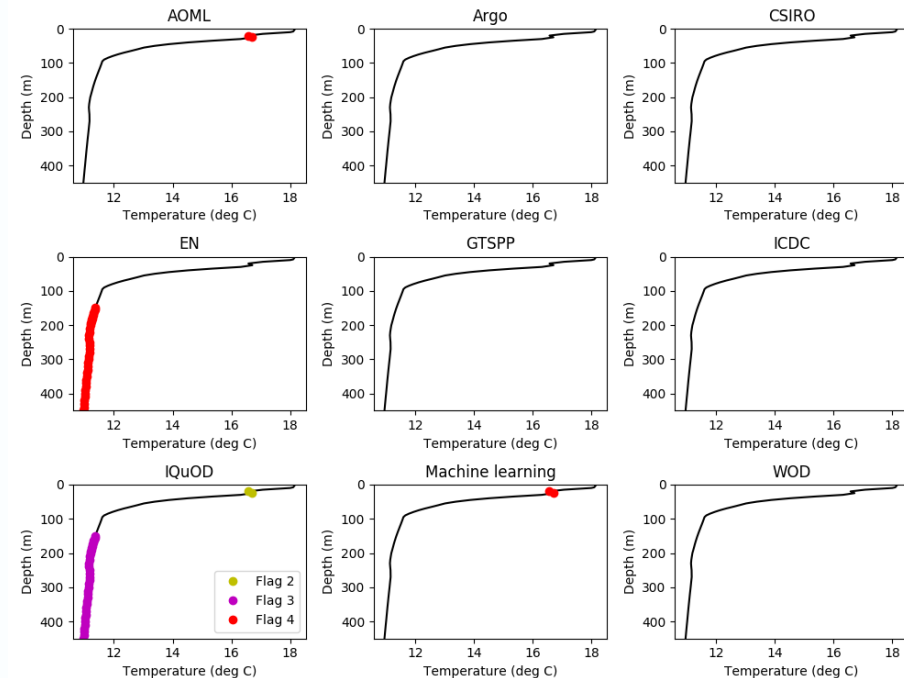
Profile 067

South Atlantic (x many spikes between 550m and 850m, good before and after that)



North Sea Dataset

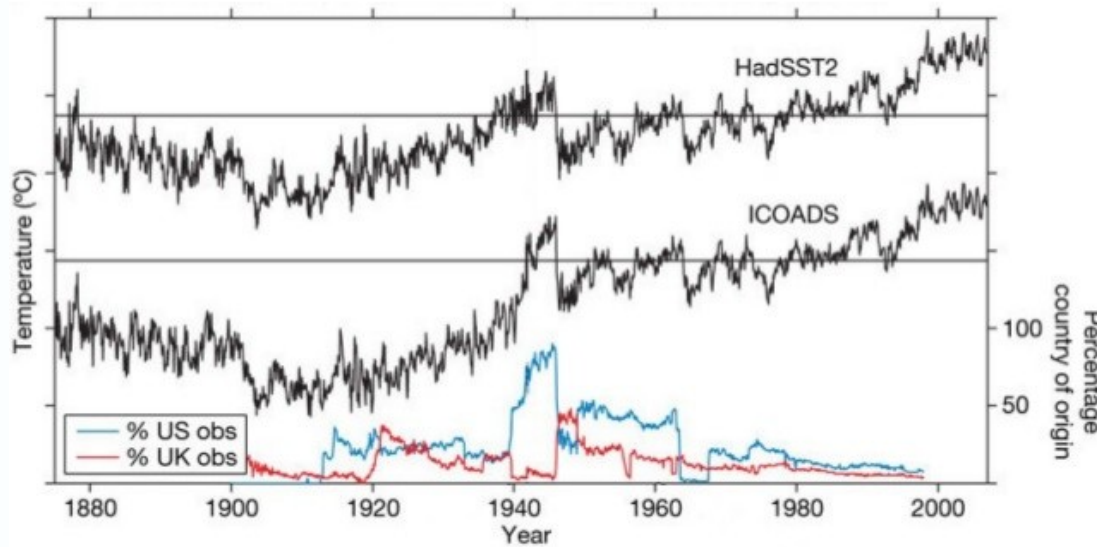
Profile 188121



Courtesy of S. Good, manuscript in preparation

Data heterogeneity artifacts in the global sea surface temperature time series

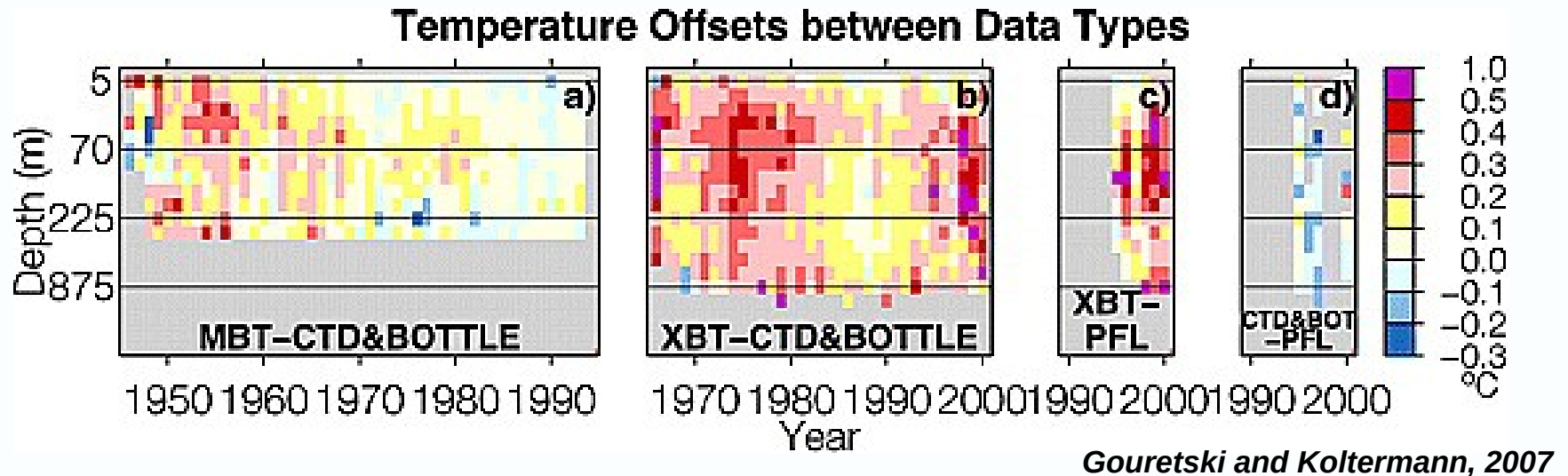
Sea Surface Temperature Anomaly



Thomson et al., 2008

- Large (0.3°C) drop in 1945 is the result of the instrumentation change and the use of uncorrected **biased** data
- Why should the hydrographic profile data be bias-free?

Biases in the MBT and XBT data revealed by the comparison with reference profiles

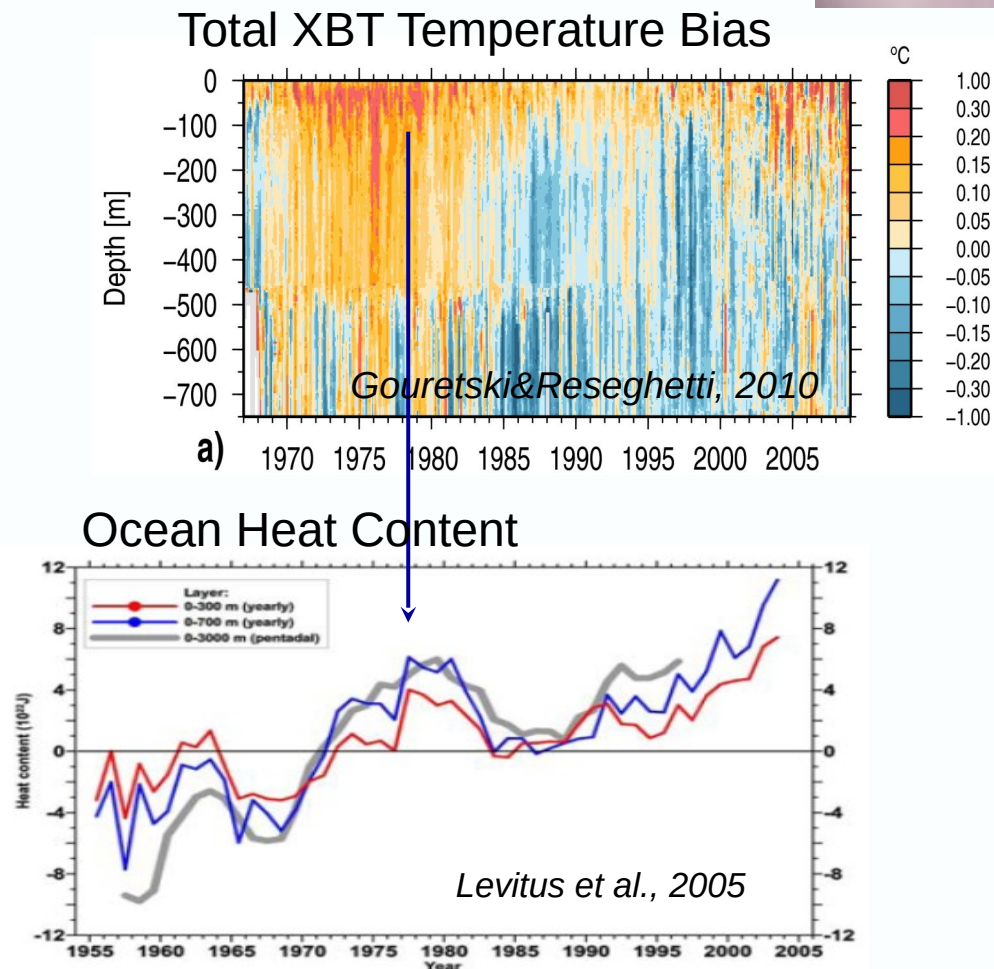


- Both instruments were designed to provide data for operational analysis, small T-bias was unimportant
- Leads to artifacts in climate applications!

XBT-bias related artifacts in decadal-scale climate variability

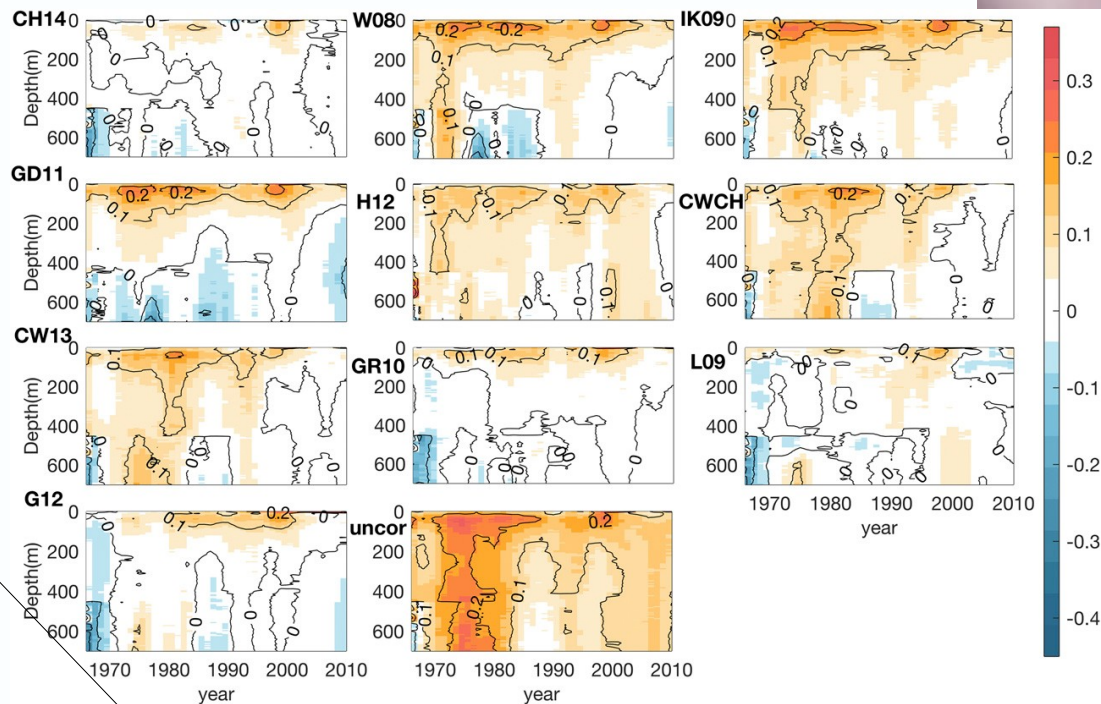
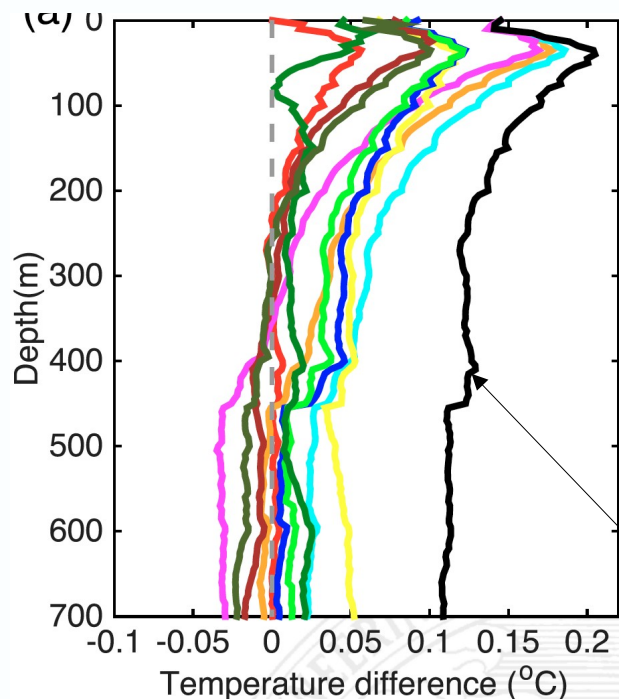


- Biased XBT data created an artificial decadal-scale variability in earlier global heat-content calculations
- The total systematic error in temperature is both due to the depth and thermal bias
- Several factors cause this bias
- Metadata is crucial for understanding the biases for 2.3 mill. profiles



XBT bias correction schemes reduce the biases

Residual XBT T-bias for different correction schemes



**Comparison between quasi-
collocated XBT and CTD&Bottle
profiles**

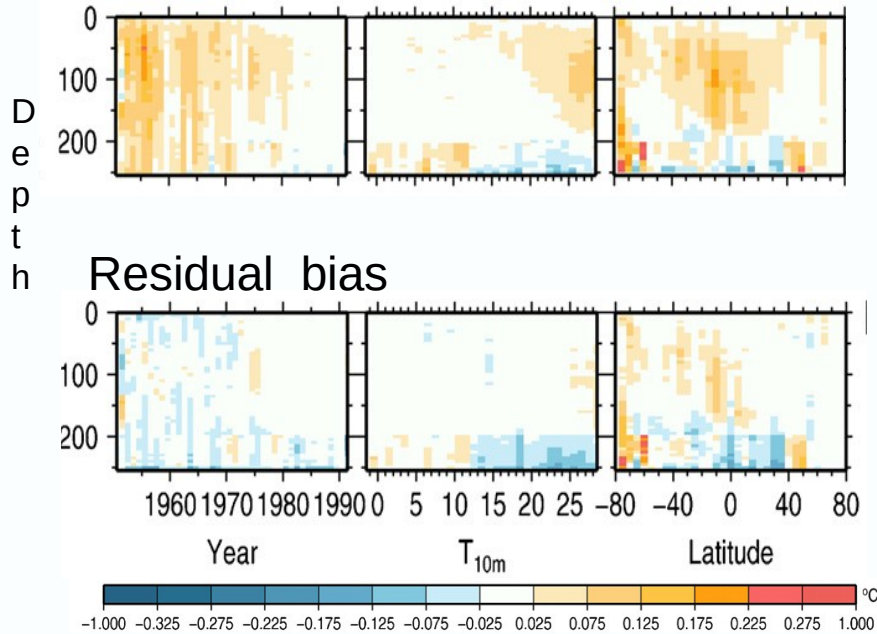
Biased original
profiles

Cheng et al., 2018

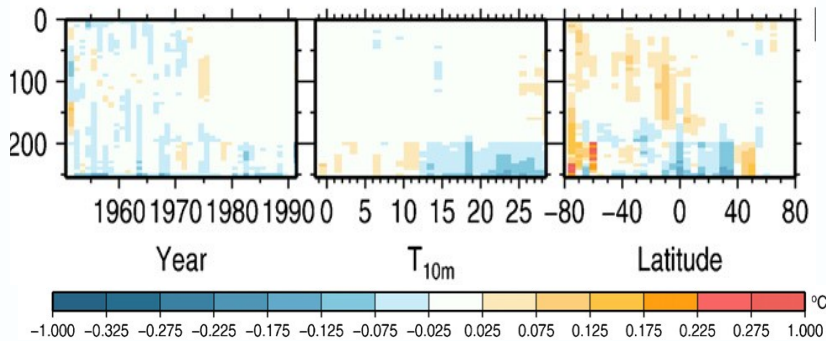
Biases in MBT temperature profiles



Original bias

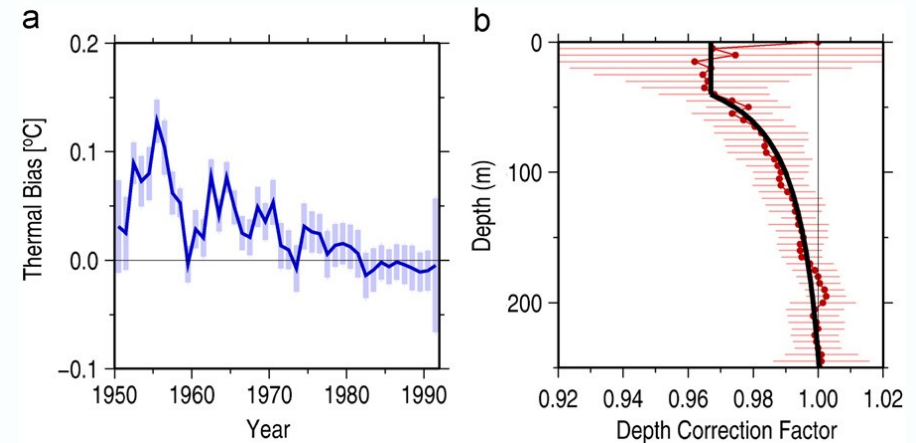


Residual bias

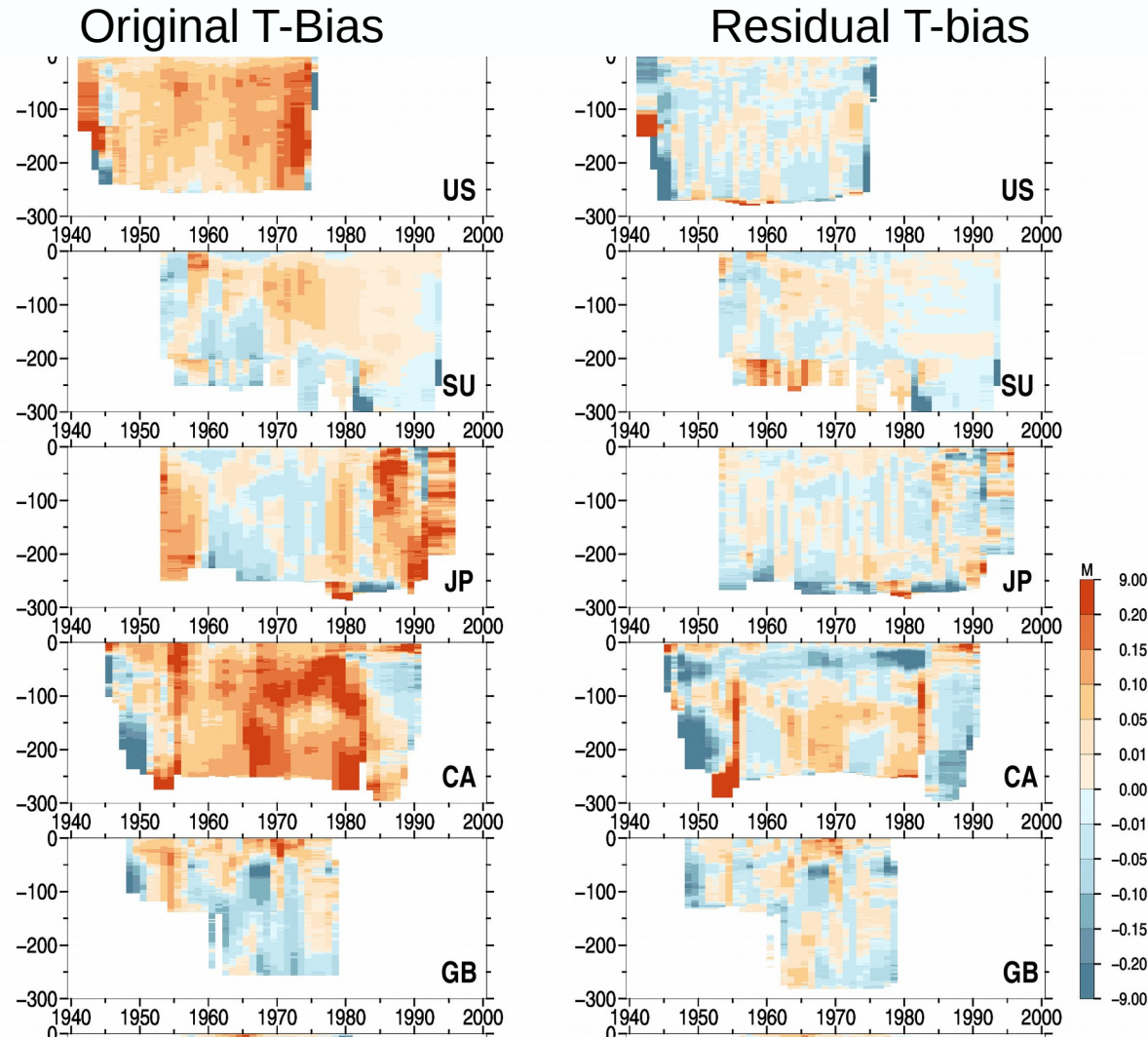


Gouretski&Reseghetti, 2010

- MBT has two sensors:
for depth (pressure) and temperature
- corrections
for pure thermal bias (a) and
depth bias (b) needed



MBT-biases are country specific

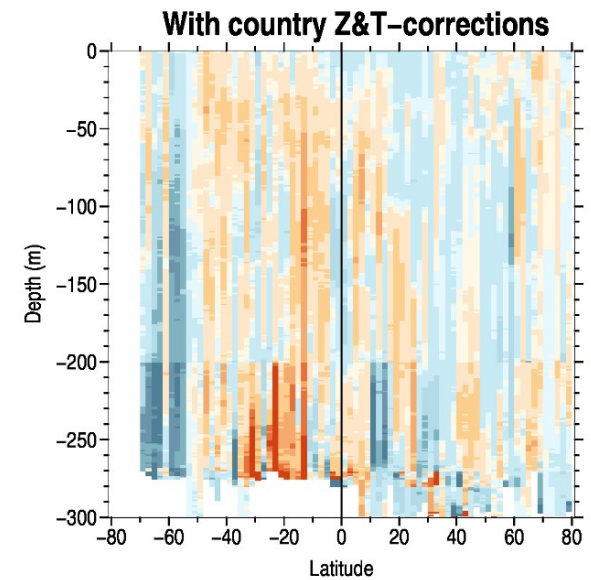
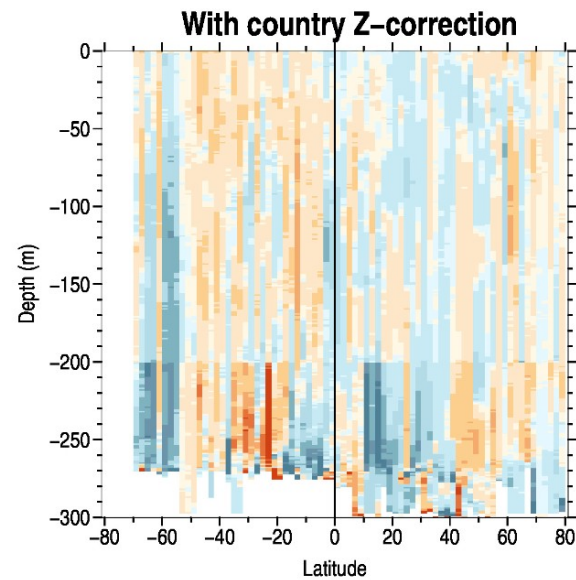
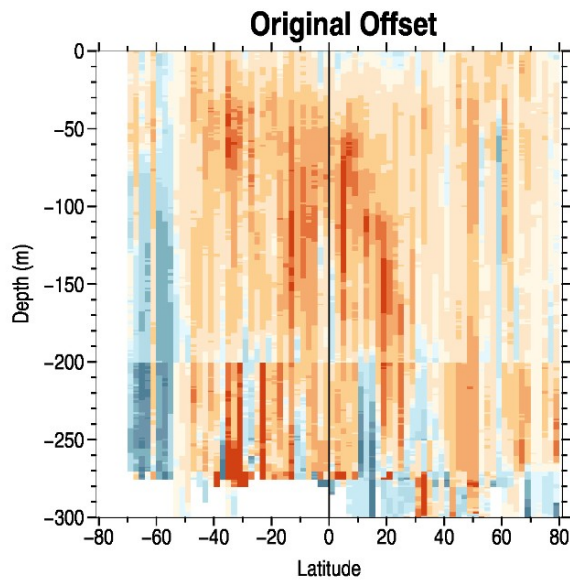
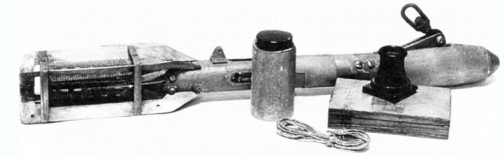


Limited metadata
available only for the
US, Soviet, and
Japanese data

A total of 2,43 mill.
profiles

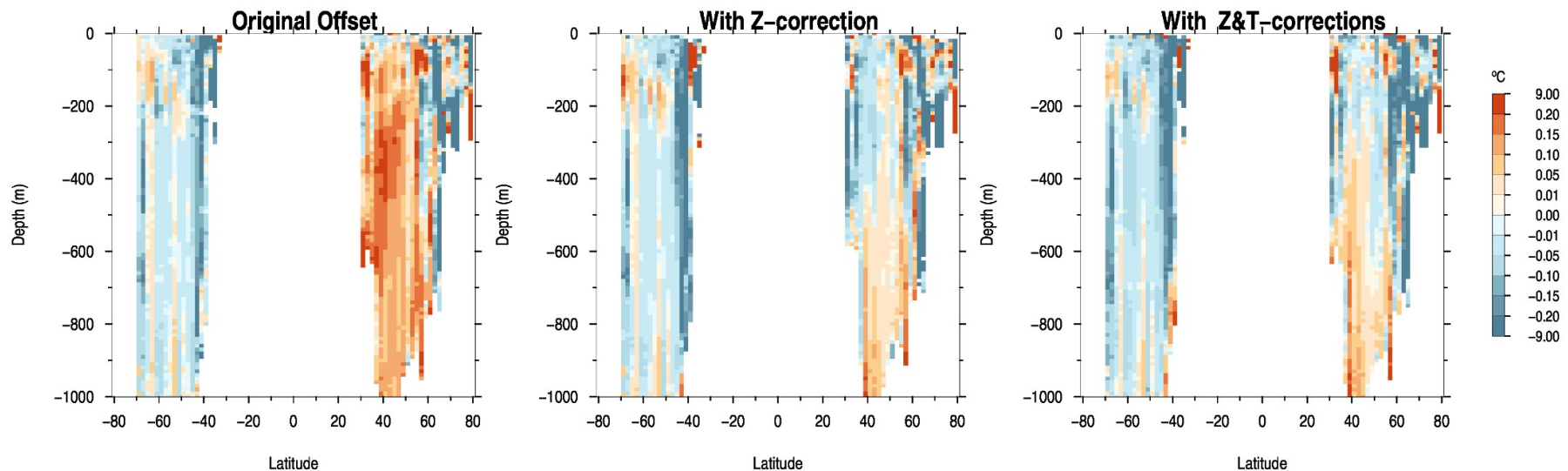
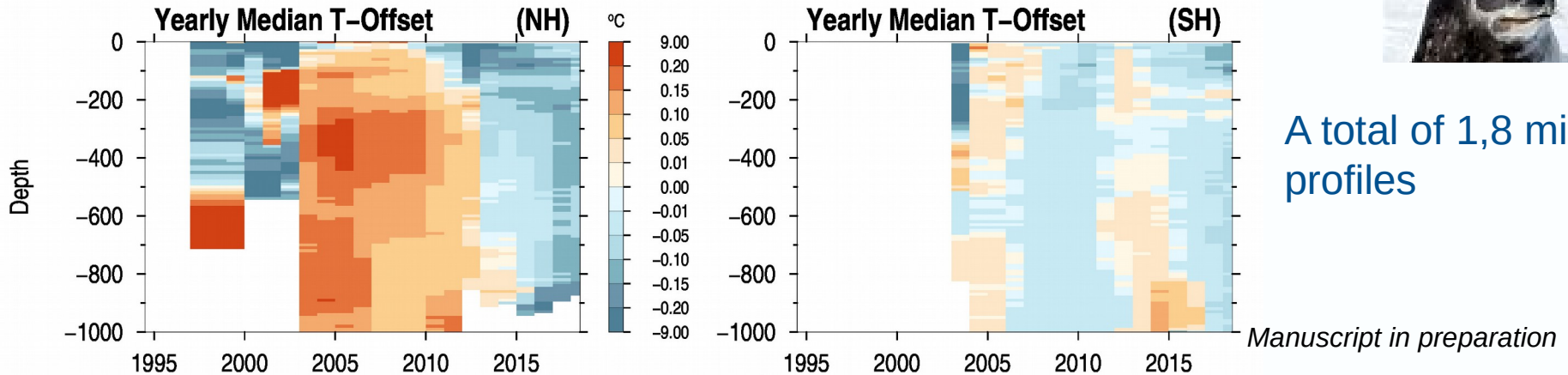
Manuscript in preparation

Corrections reduce the bias

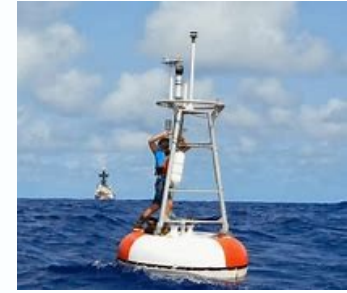


Manuscript in preparation

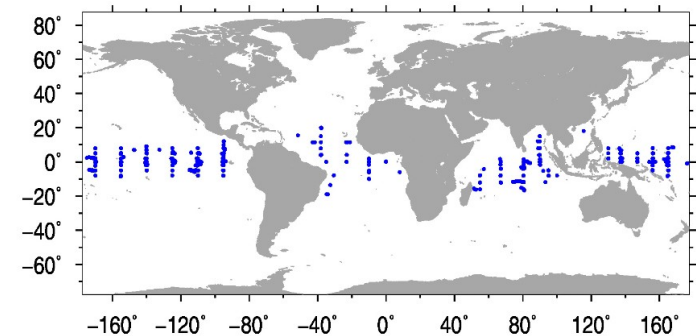
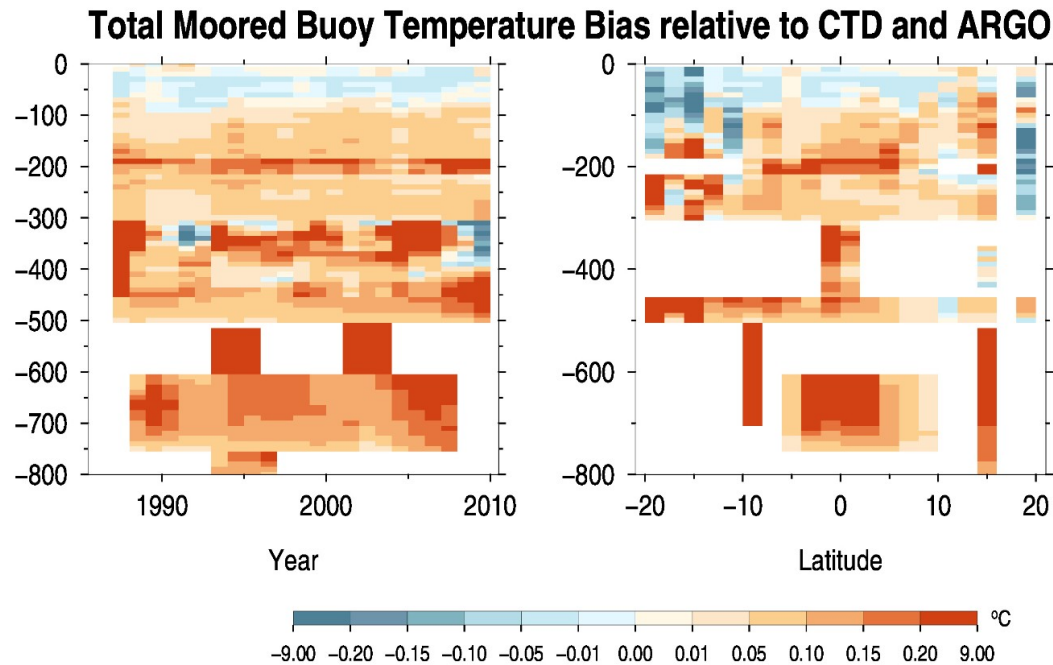
Biases in CTD Satellite Relay Data Loggers attached to Marine Mammals



Moored Buoys

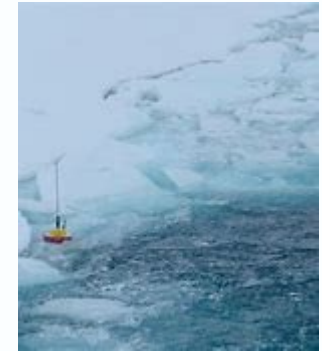


A total of 1,6 mill. profiles

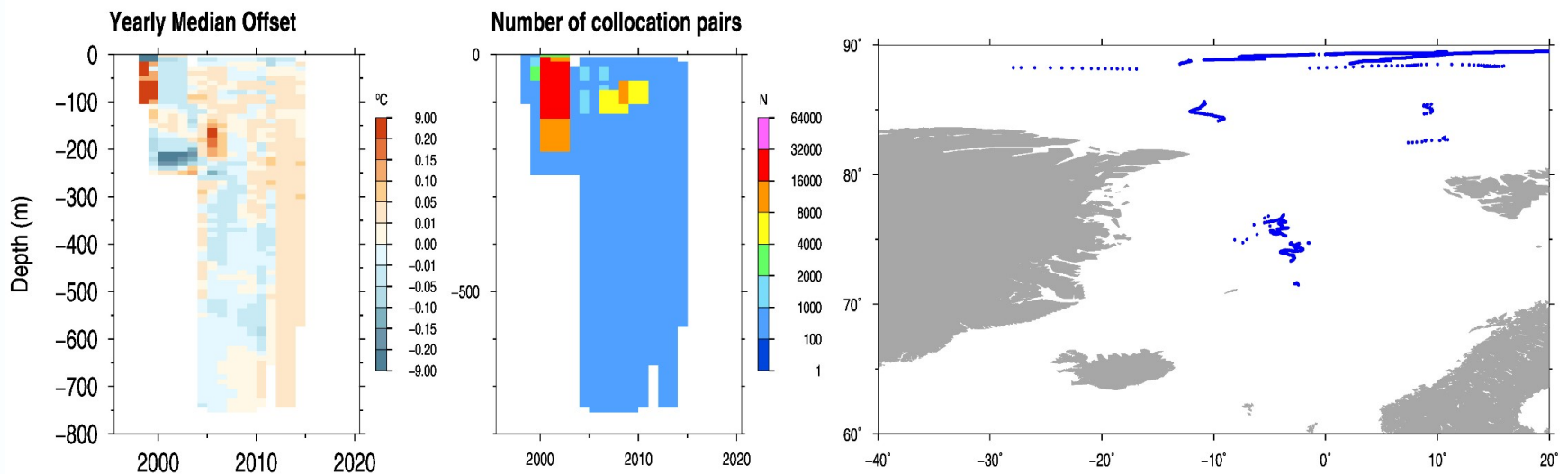


Manuscript in preparation

Drifting Buoys

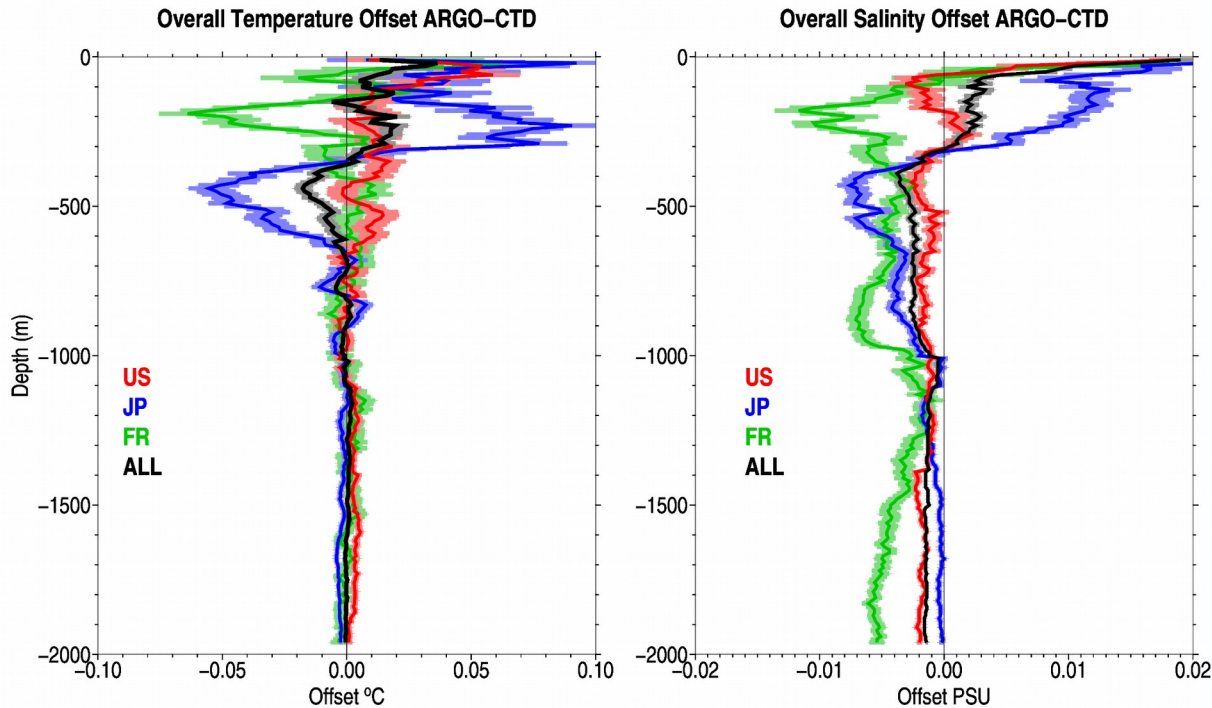


A total of
230,000 profiles



Manuscript in preparation

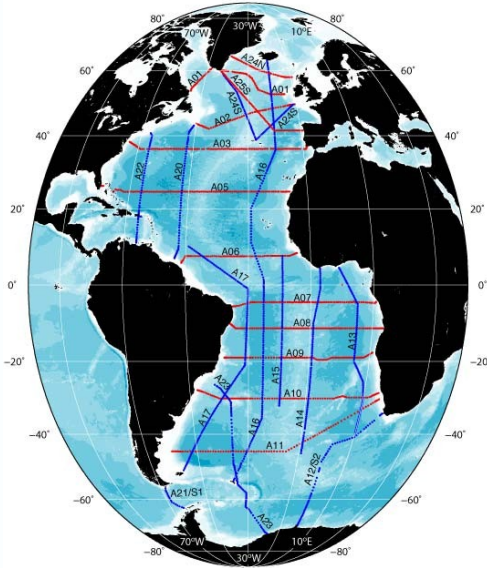
ARGO temperature and salinity biases



A total of 1,8 mill.
Argo profiles

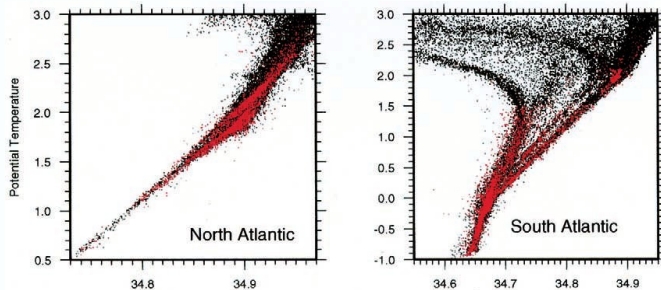
High-quality ship CTD observations crucially important!

Internal Consistency of the WOCE dataset



Koltermann et al., 2011

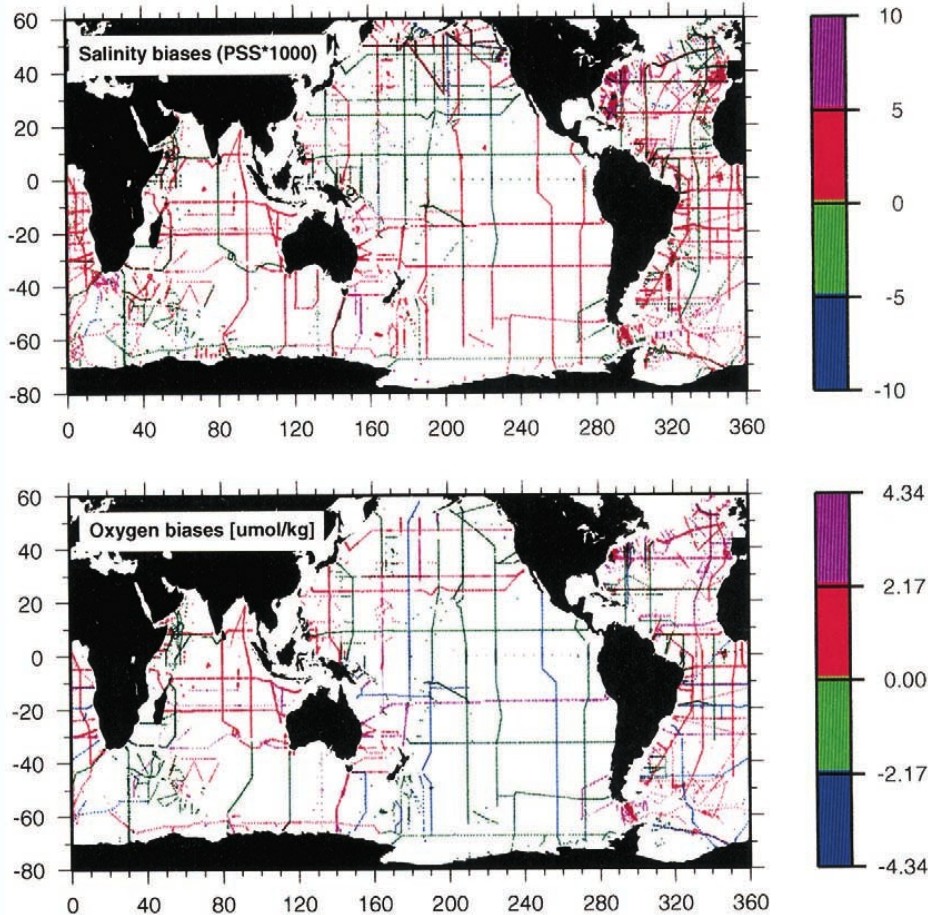
- In spite of stringent quality requirements discrepancies between the WOCE cruises (e.g. observational teams) were expected
- Comparison of water properties (S, O_2 , Nutrients) was done for **cross-over areas**
- **Assumption:** on the time-scale of several years temperature-property relations in the deep water remain stable



Gouretski & Jancke, 2001

Cross-over analysis: WOCE standards confirmed

Biases assigned to the WOCE cruises

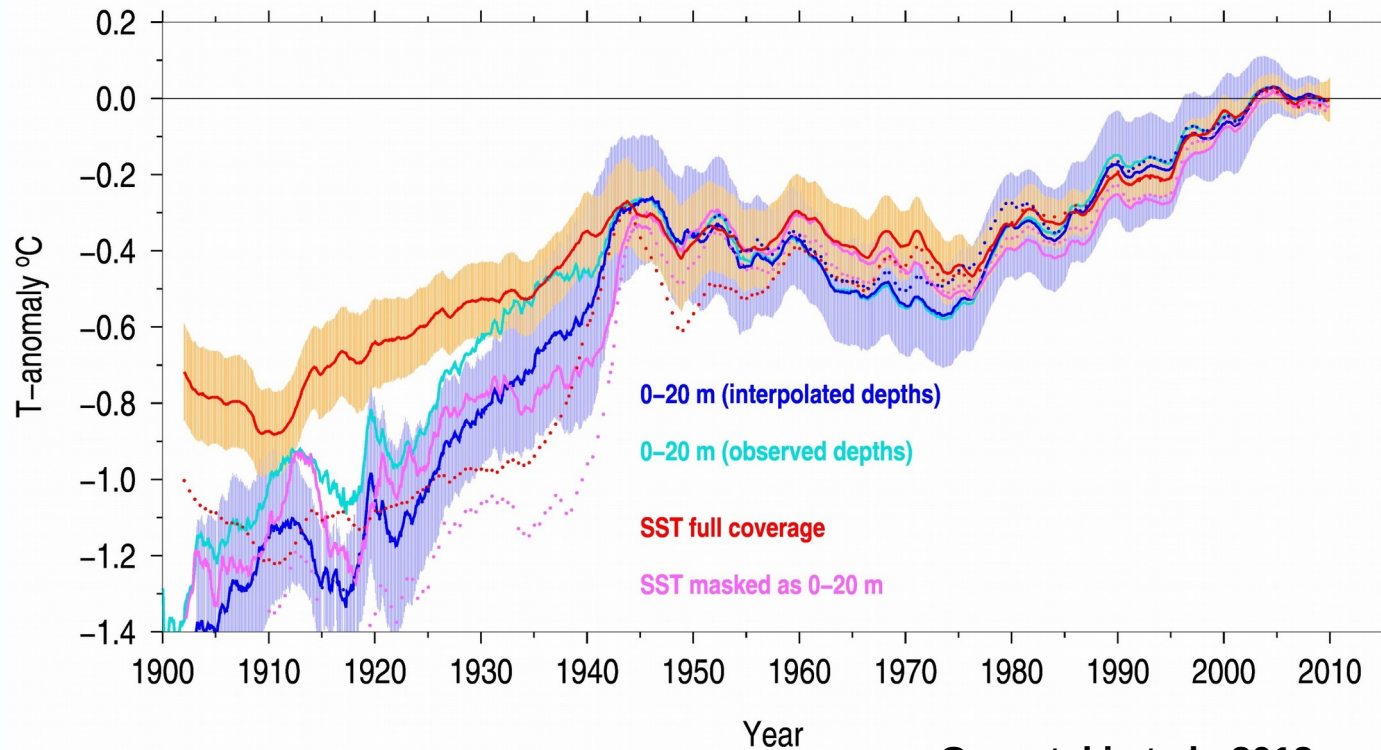


Gouretski & Jancke, 2001

- The crossover analysis confirmed: the WOCE accuracy standards have been achieved on average
- Average inter-cruise property offsets:
 - Salinity 1.90×10^{-3}
 - Oxygen $2.40 \mu\text{mol/kg}$

Comparison of the hydrographic data with independent observational networks

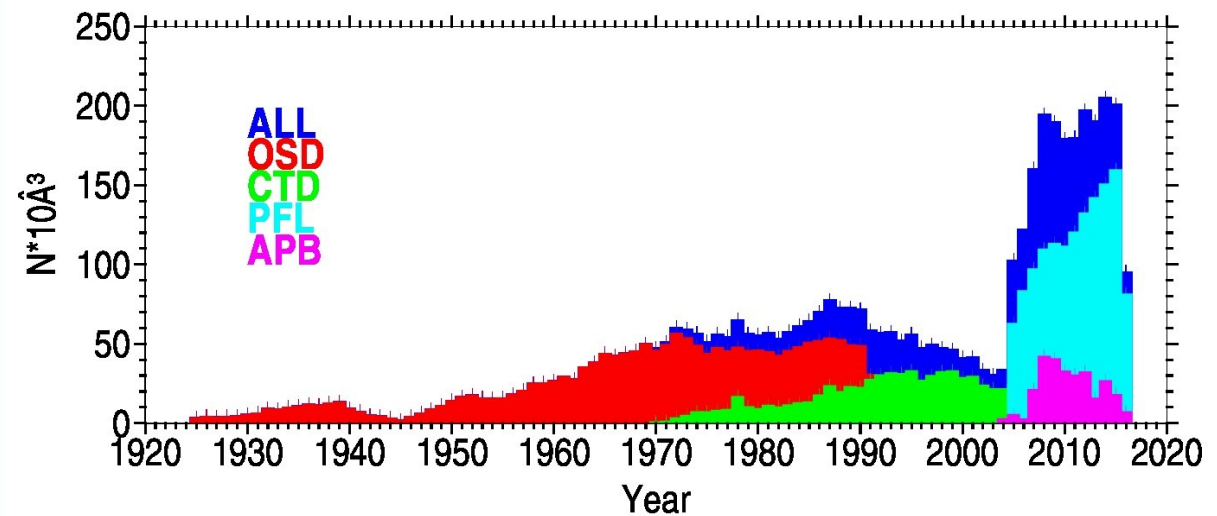
SST and mixed-layer temperature time series



Gouretski et al., 2012

World Ocean Circulation Experiment - Argo Global Hydrographic Climatology (WAGHC)

Data sources: WOD13+AWI+Canadian Institutes
A total of 4,7 millions of T,S-profiles



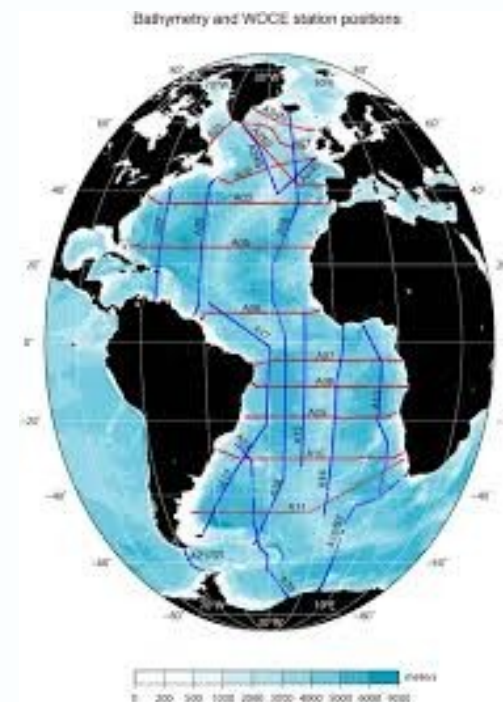
Gouretski, 2018

Predecessor: WOCE Global Hydrographic Climatology (WGHC)



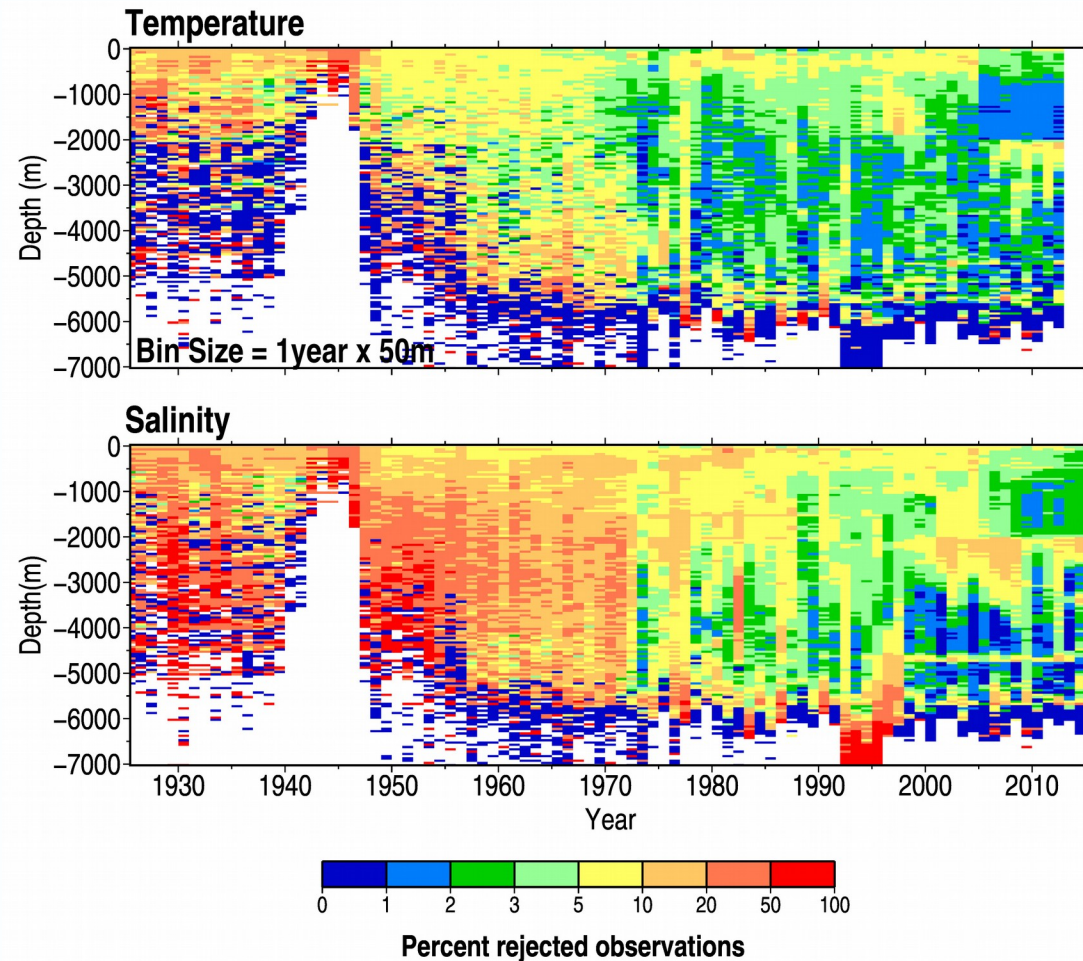
Gouretski&Koltermann, 2004

- WGHC served as a digital basis for the WOCE Atlantic Ocean Atlas
- Was used in neutral density calculations
- It is an all-data-mean climatology: no seasonality



Koltermann et al., 2011

First Step: Data Quality Control



Gouretski, 2018

Improvement of the data quality with time

Instrumentation changes visible

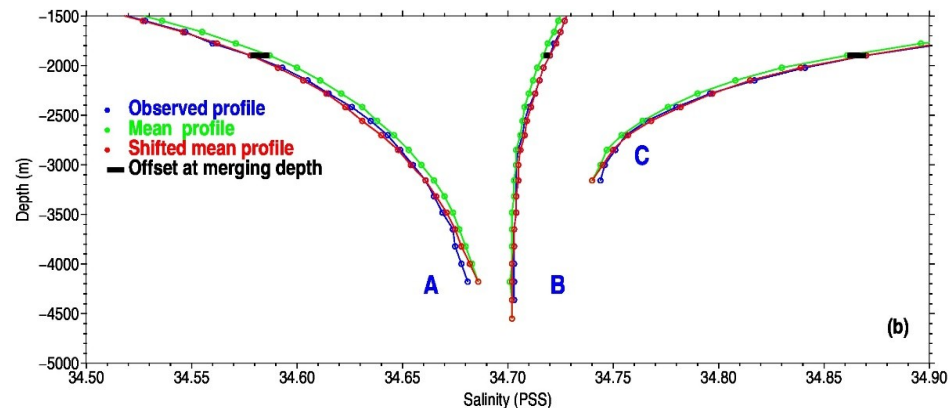
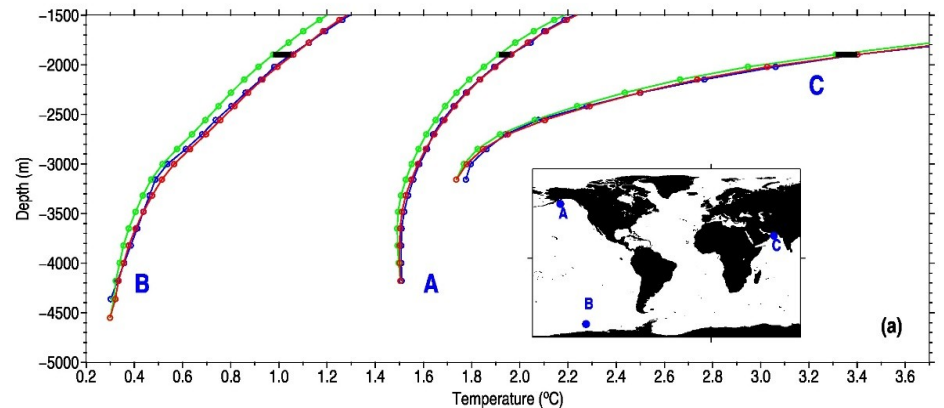
Overall rejection rate:

Temperature 3.7%

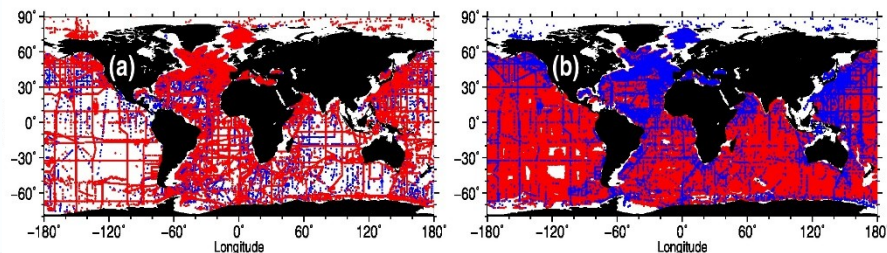
Salinity 5.3%

Profile extrapolation

- Needed to avoid artifacts due to the step-like decrease of data at the Argo maximum depth
- Applied to profiles deeper than 1500 m
- Adjusted mean local full-depth profile represents the extrapolated part of the water column



Gouretski, 2018



Spatial interpolation

Optimal interpolation (Gandin, 1964)

Normalized spatial covariance:

$$C_{xyh} = \exp[-(r_x/L_x)^2 + (r_y/L_y)^2 + (h/H)^2] \quad (\text{isobaric case})$$

$$C_{xyz} = \exp[-(r_x/L_x)^2 + (r_y/L_y)^2 + (r_z/Z)^2], \quad (\text{isopycnal case})$$

Correlation length scales:

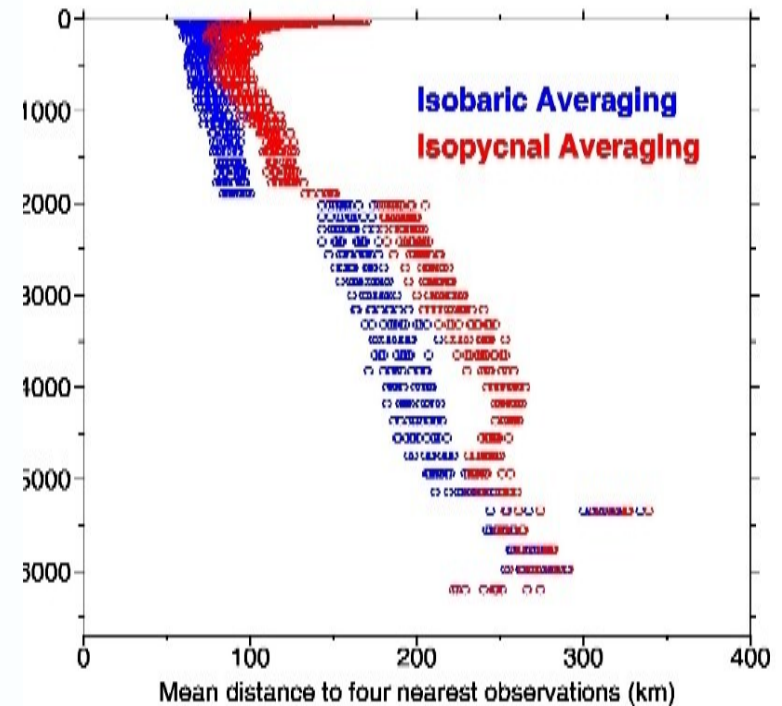
$L_x = L_y = 333$ km polewards from 20N/S

L_x increases from L_y at 20N/S to $4/L_y$ at the equator

Penalty:

H – distance penalty for crossing isobaths

Z – distance penalty for isopycnal depth deviation
from the analyzed level

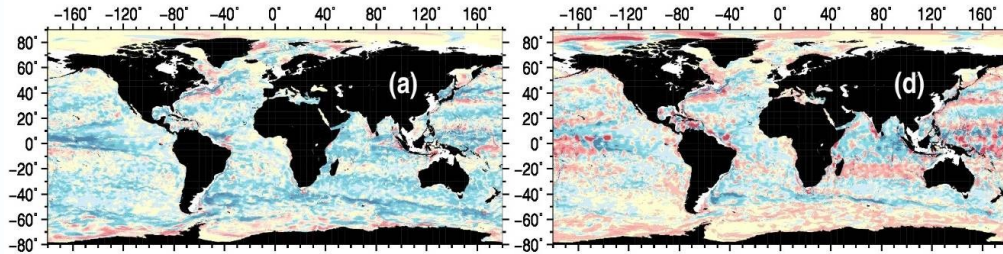


Data sparseness is a limiting factor by the choice of the correlation length scales

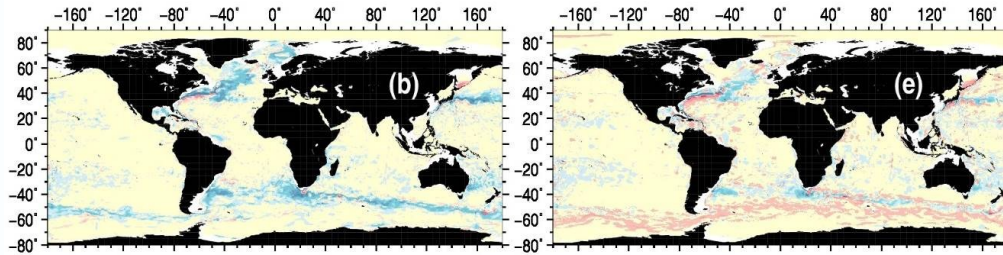
Gouretski, 2018

Isobarically- vs isopycnally-averaged mean temperature and salinity at selected levels (January)

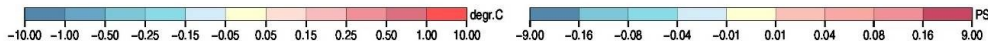
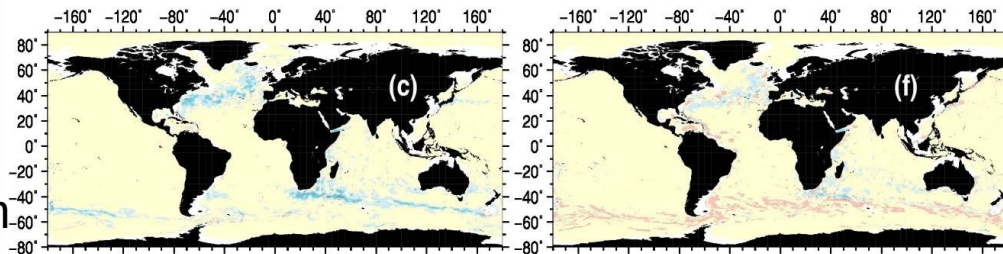
150 m



518 m



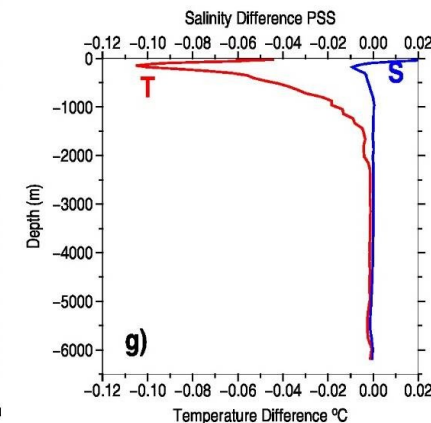
1050 m



OI acts as a low-pass filter

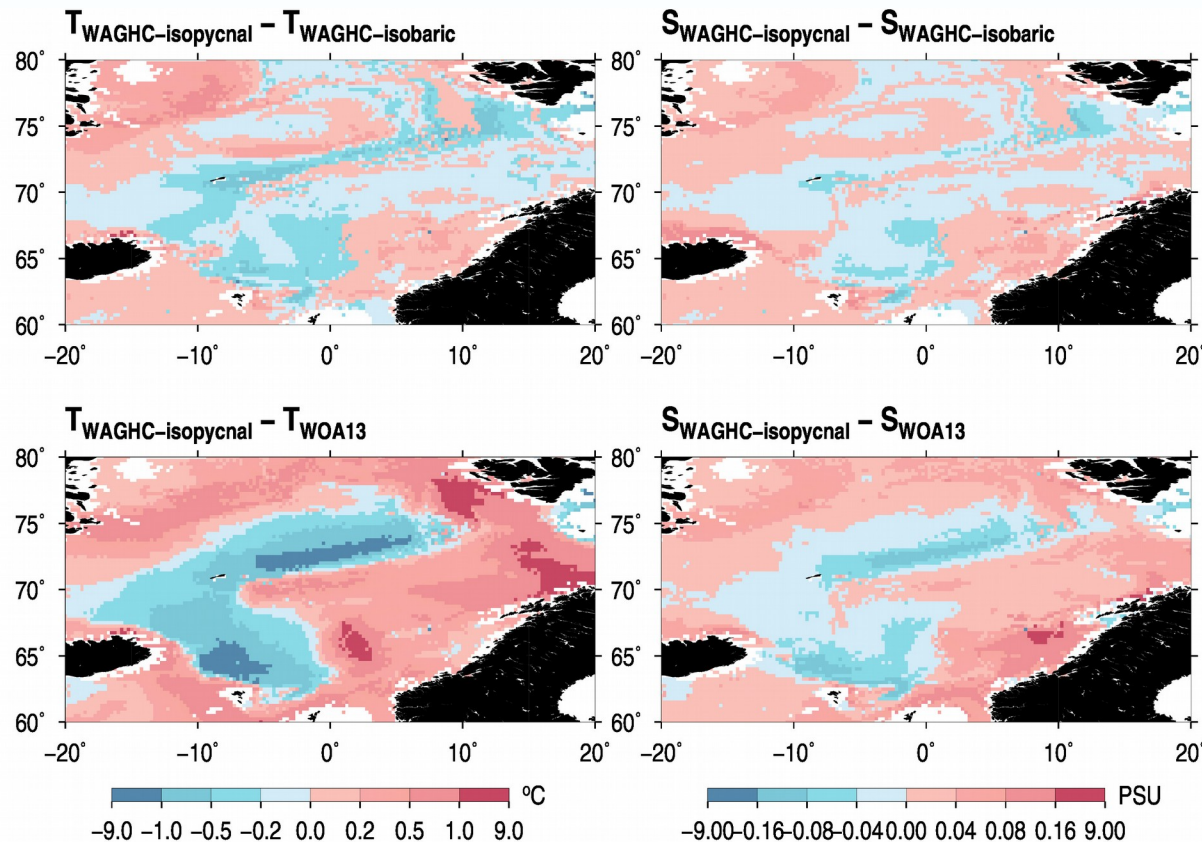
Averaging on isobars leads to artificial water masses

Averaging on isopycnals mimics mixing in the ocean

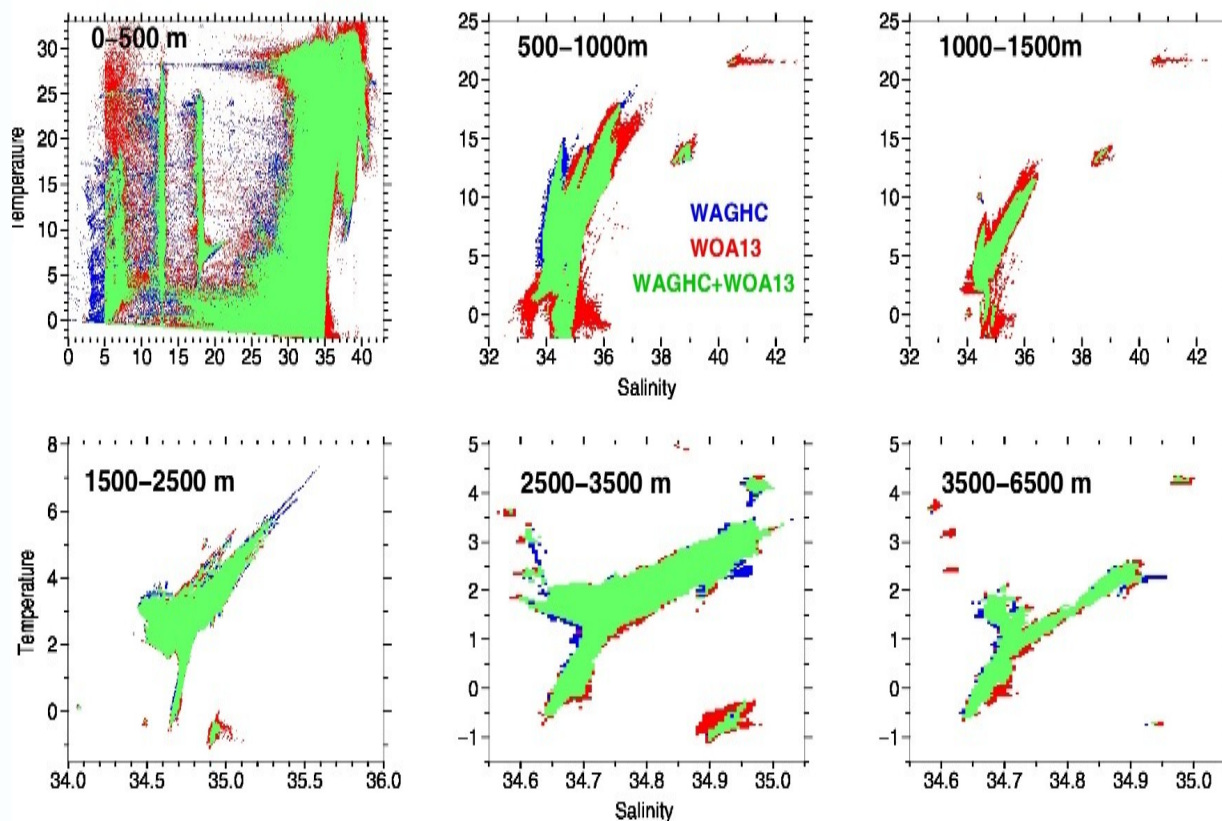


Gouretski, 2018

Isobarycally vs isopycnally averaged mean temperature and salinity at 150 m (January) in the Nordic Seas



WAGHC vs WOA13: global T,S-diagrams

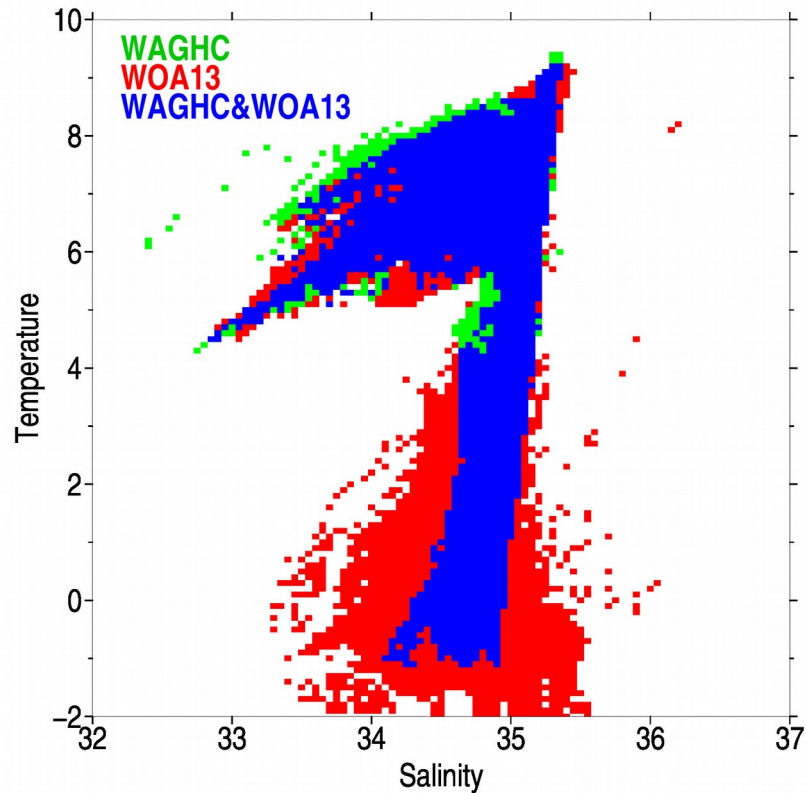


Gouretski, 2018

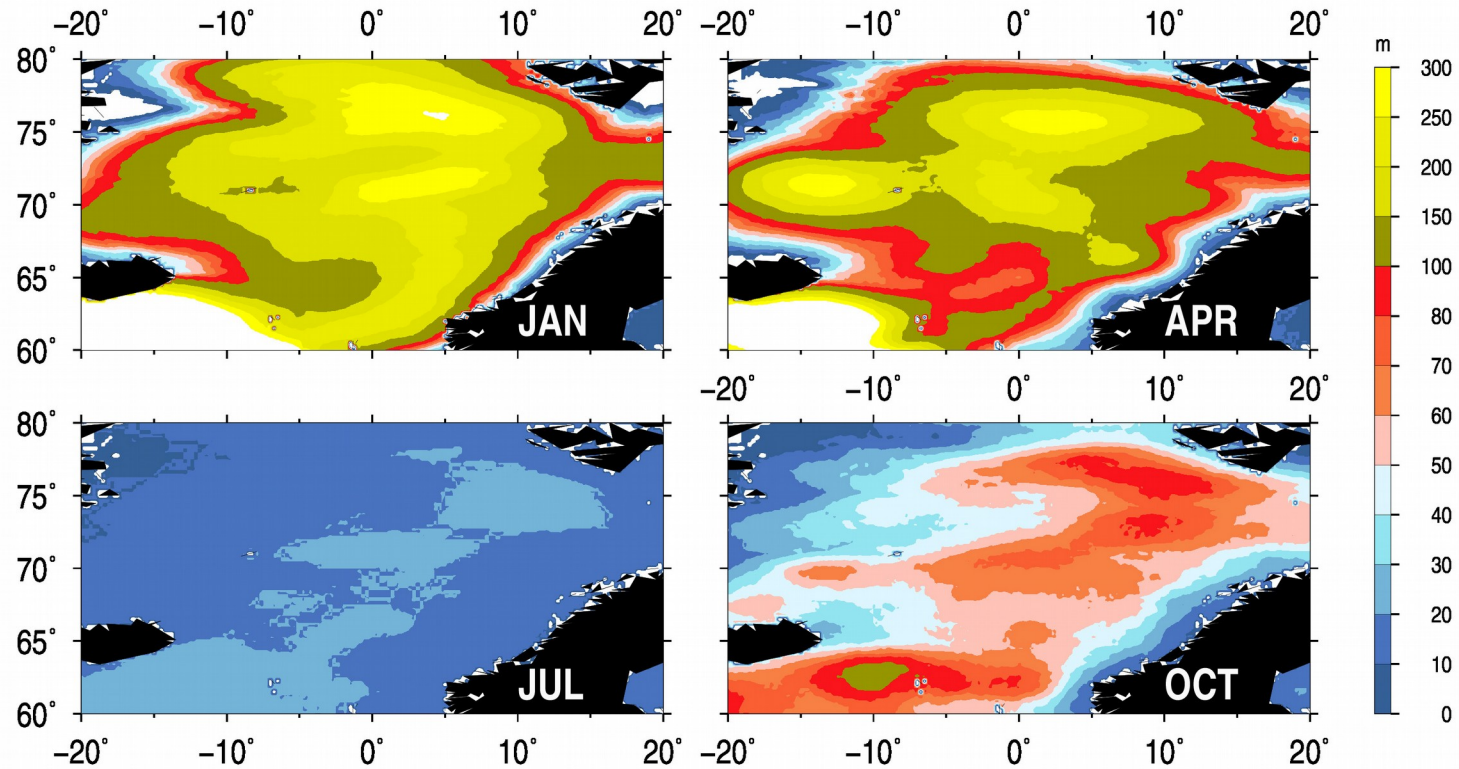
Better agreement between the two climatologies for the deeper part of the water column

Typically narrower salinity ranges for the WAGHC

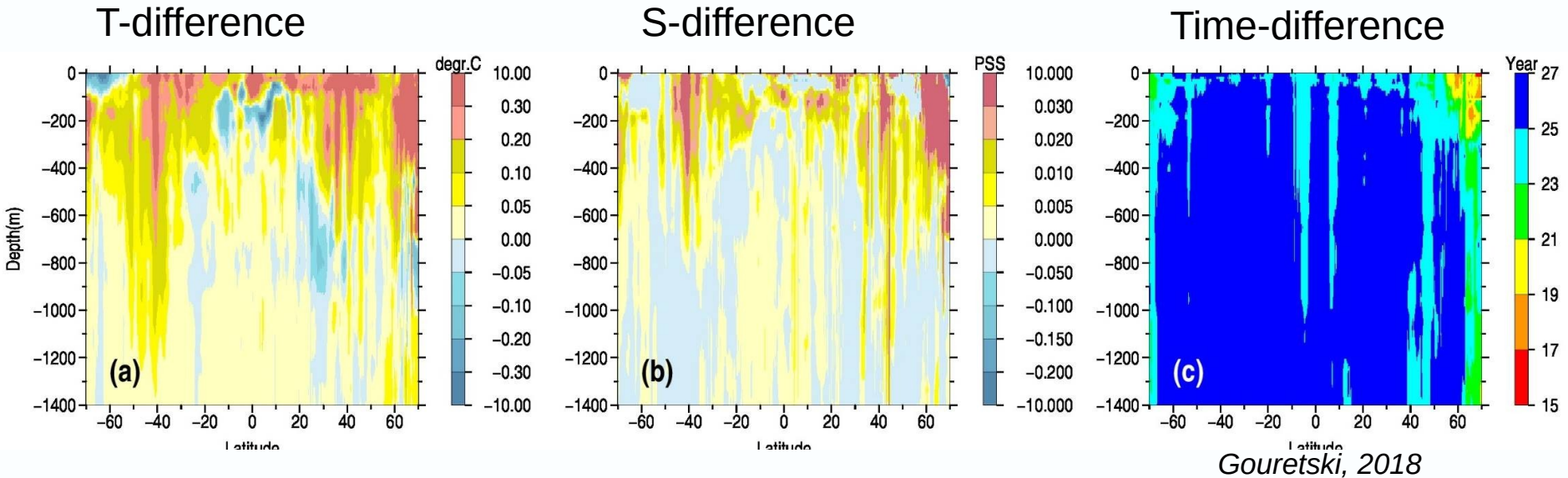
T,S scatter diagram for WAGHC and WOD13 gridded data for the Nordic Seas (20W-20E; 60-80N) (January)



Upper mixed layer depth (WAGHC climatology)



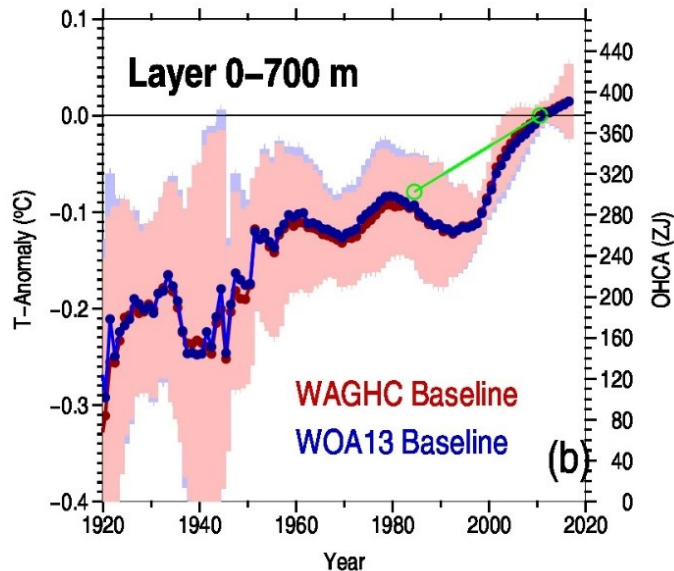
WAGHC minus WOA13 zonally-averaged sections



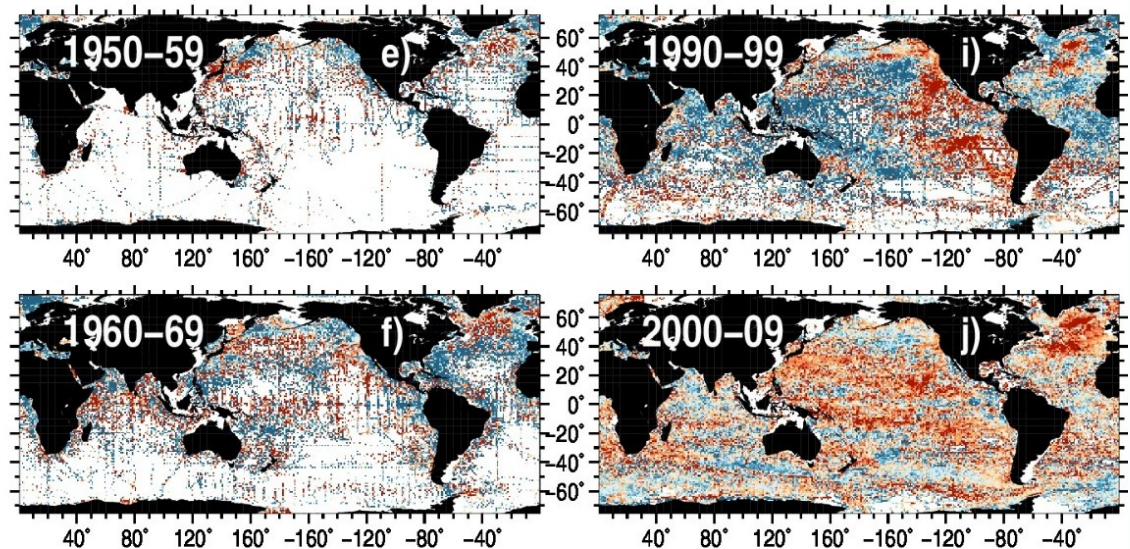
- WAGHC is on average warmer and saltier in the upper ~1,500 m
- Penetration of the warming signal into the deeper layers is most
- pronounced within the ACC and in the northern moderate and polar regions

WAGHC and WOA13 as baseline climatologies for the ocean heat content calculations

T-anomaly time series



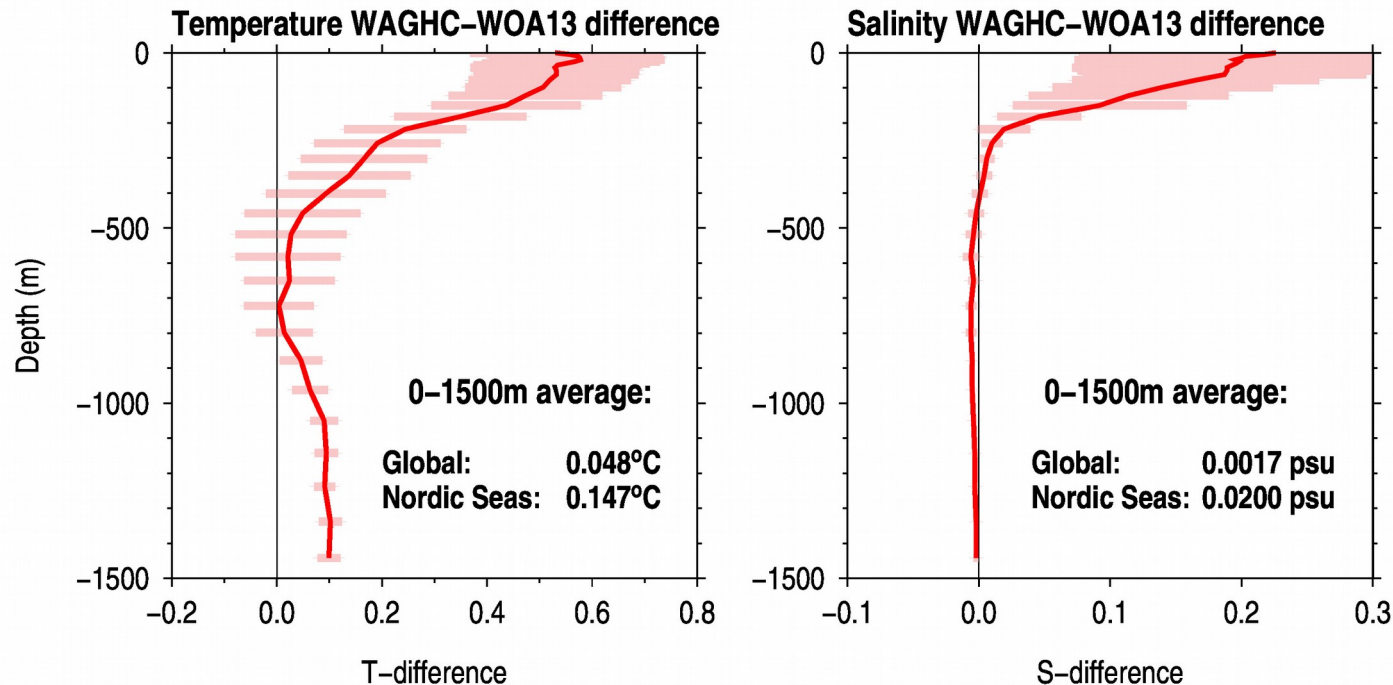
Decadal T-anomalies for the layer 0-700m



Gouretski, 2018

- OHCA increased by ~220 ZJ since 1920 for the layer 0-700m
- Only small differences due to the use of WAGHC / WOA13 as the baseline

WAGHC minus WOA13: Nordic Seas Area



- WAGHC is warmer within 0-1500 m layer
- WAGHC is saltier within 0- 400 m layer
- Stronger signals compared to the global-averaged values

• Conclusions

- Global archive is a mixture of data types, prone to instrument-specific biases
- IQuOD initiative developed algorithms for optimal set of automated quality control checks
- Comparison with reference data and between datasets helps to diagnose and quantify biases
- A new isopycnally-averaged global climatology (WAGHC) is available with monthly T&S fields on 1/4-degree grid
- Comparisons between WAGHC and WOA13 reveal similarities, but a number of improvements was achieved compared to WOA13 due to a larger data basis and a different methodology
- Comparisons quantify global-scale thermohaline changes between 1984 and 2010



Photo credit:
Kathryn
Hansen/NASA

Thank you!



www.blue-action.eu

The Blue-Action project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727852



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Zenodo: <https://www.zenodo.org/communities/blue-actionh2020>