# Subsurface Ocean Climate Data Records: Global Ocean Heat and Freshwater Content

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Acknowledgement to Syd Levitus who started this project and John Antonov for implementing many of the concepts.

# OUTLINE

- What are we calculating and why?
- How are the calculations made?
- What are the results and how can they be used?
- Ongoing validation, improvements, and future work

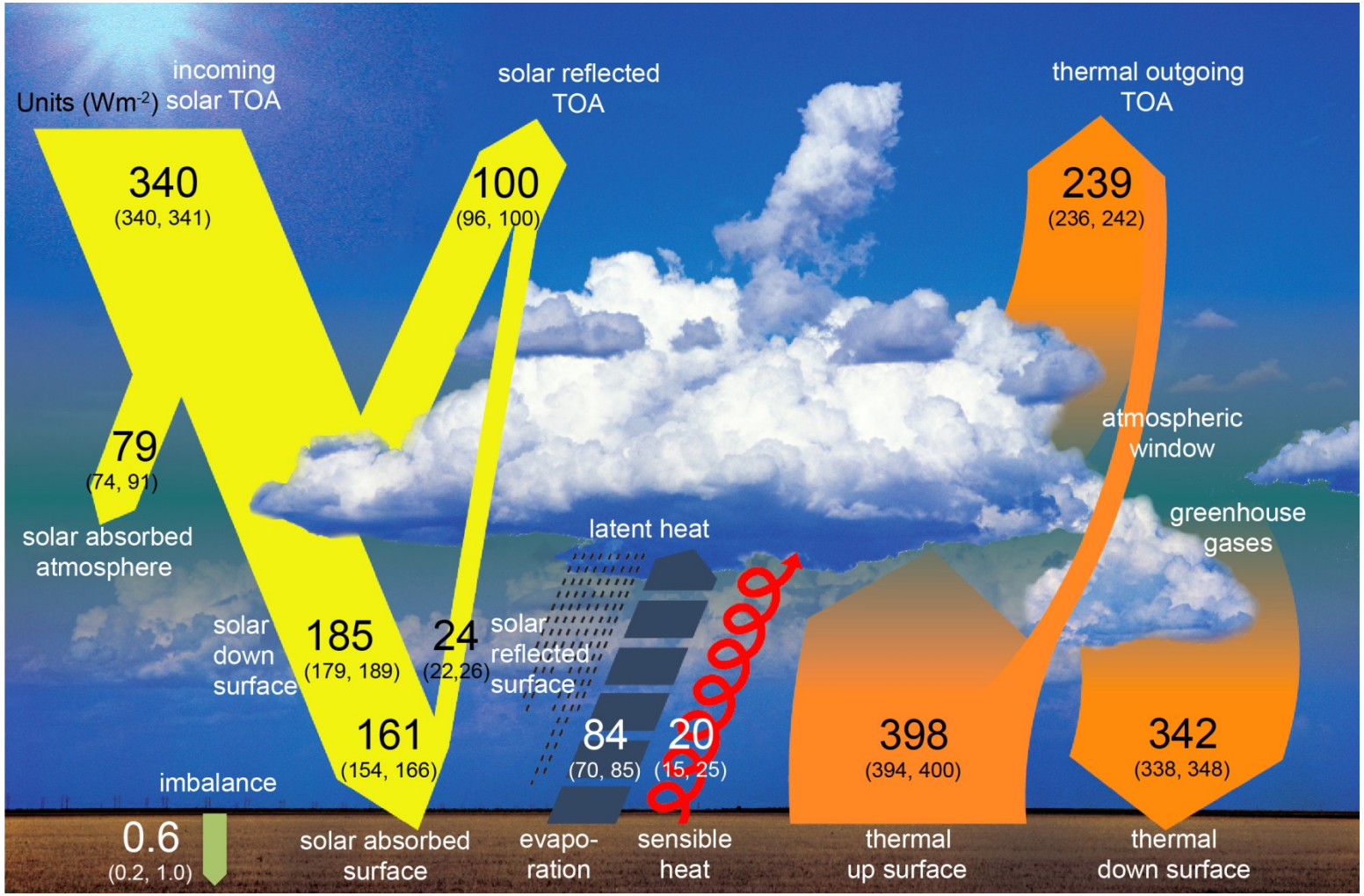


**Figure 2.11: |** Global mean energy budget under present-day climate conditions. Numbers state magnitudes of the individual energy fluxes in W m–2, adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the energy fluxes cover the range of values in line with observational constraints. (Adapted from Wild et al., 2013.)

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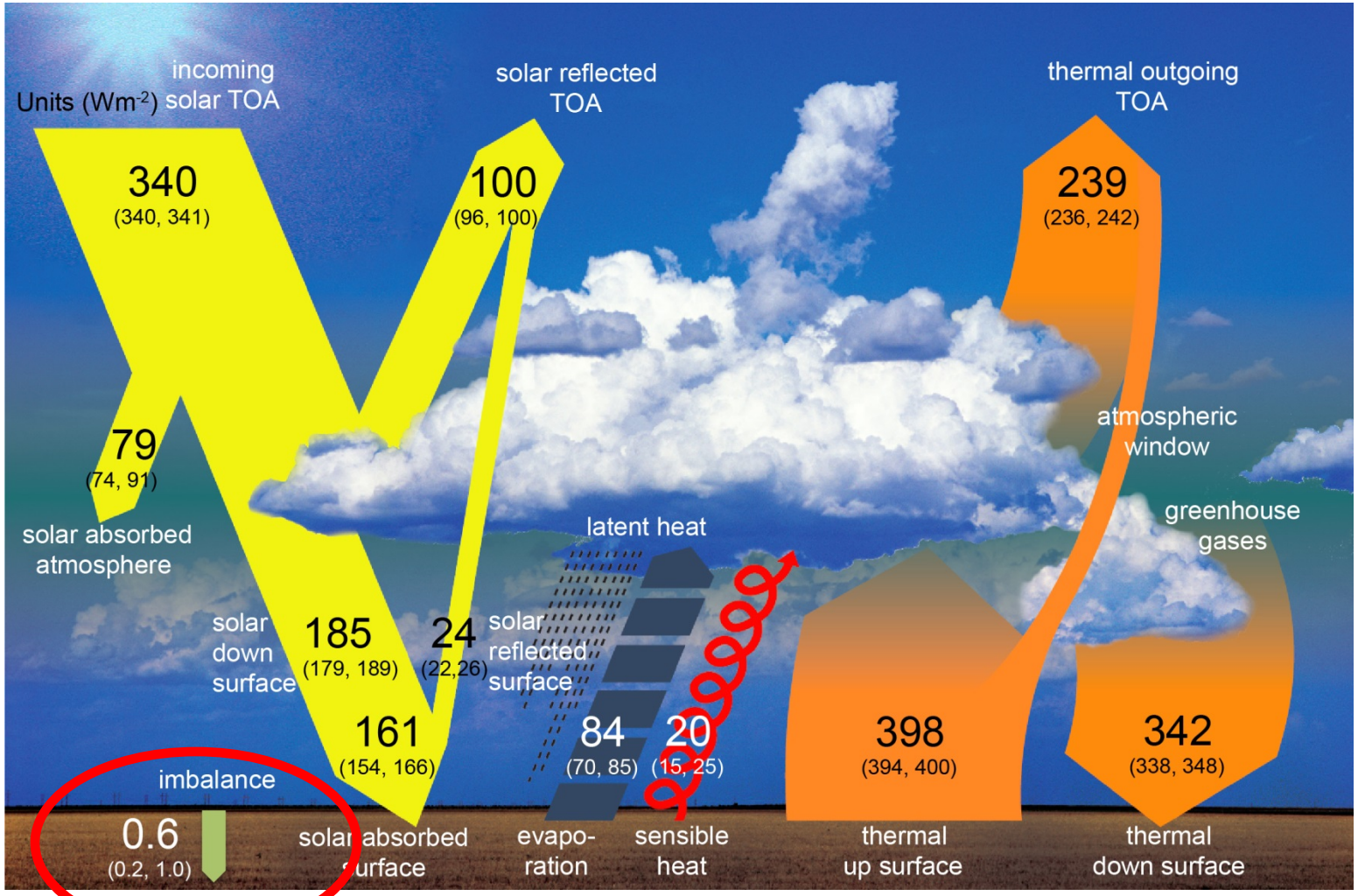


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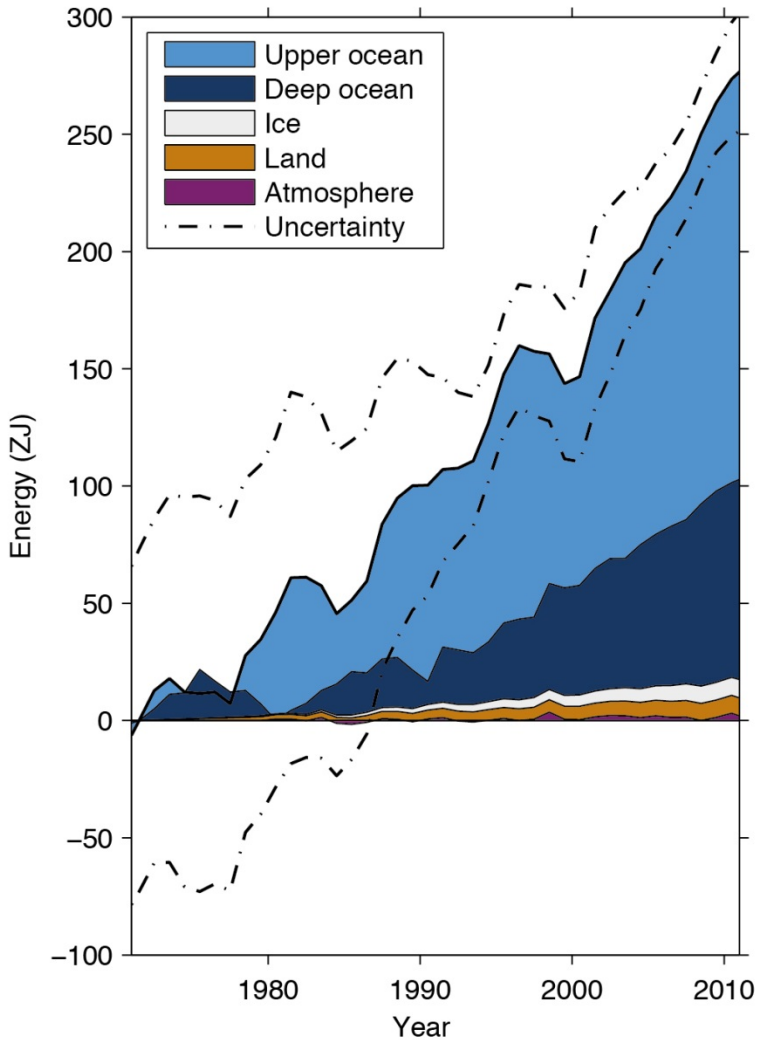
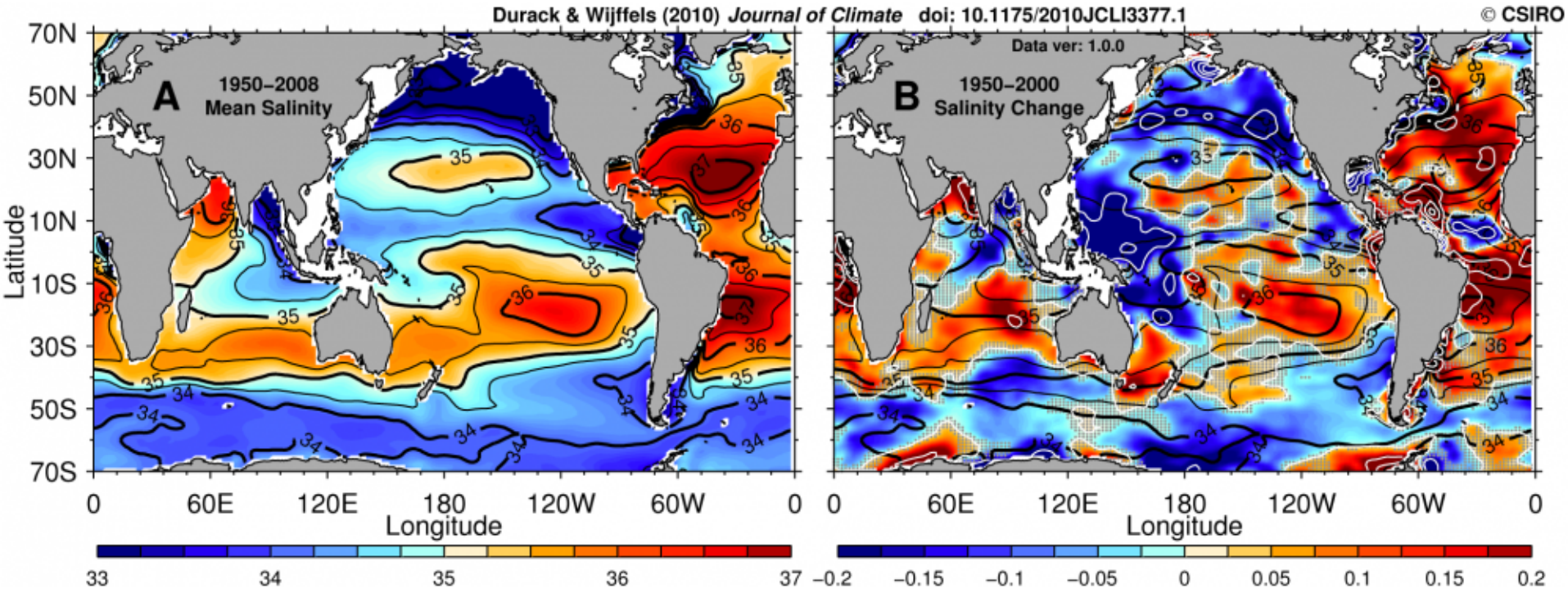
# The Ocean Absorbs ~90% of Earth's radiation imbalance




**Box 3.1, Figure 1 |** Plot of energy accumulation in ZJ (1 ZJ = 1021 J) within distinct components of the Earth's climate system relative to 1971 and from 1971 to 2010 unless otherwise indicated. See text for data sources. Ocean warming (heat content change) dominates, with the upper ocean (light blue, above 700 m) contributing more than the mid-depth and deep ocean (dark blue, below 700 m; including below 2000 m estimates starting from 1992). Ice melt (light grey; for glaciers and ice caps, Greenland and Antarctic ice sheet estimates starting from 1992, and Arctic sea ice estimate from 1979 to 2008); continental (land) warming (orange); and atmospheric warming (purple; estimate starting from 1979) make smaller contributions. Uncertainty in the ocean estimate also dominates the total uncertainty (dot-dashed lines about the error from all five components at 90% confidence intervals).

Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang, 2013: Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.




**Water Cycle Intensification:**
**The salty getting saltier, the fresh getting fresher**

# Heat/Freshwater content equations for a water column

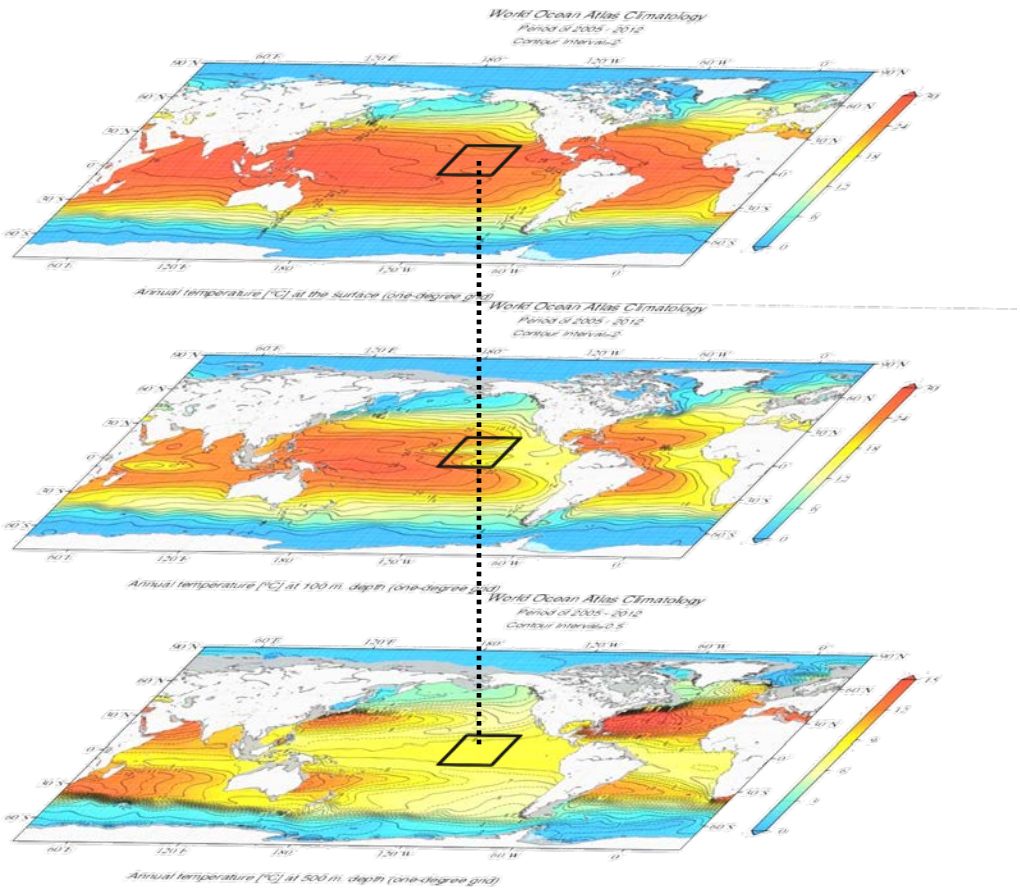
$$Heat\ \ Content = \int_{z1}^{z2} \rho c_p \Delta T dz$$

$$Freshwater = -\int_{z1}^{z2} \frac{\rho(T,S,p)}{\rho(T,0,p)} \frac{\Delta S}{S} dz$$

*$\rho$ = density of seawater*
*$c_p$ = specific heat of seawater*

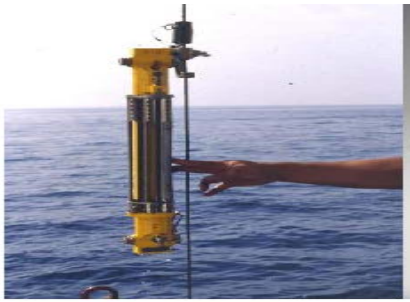
*$\Delta T$ = temperature difference*
*$T$ = temperature*
*$S$ = salinity*

*$p$ = pressure*
*$z$ = depth*
*$\Delta S$ = salinity anomaly*




*Individual temperature differences calculated relative to climatological baseliine mean (World Ocean Atlas 2009) at 26 standard depths surface to 2000m and summed over one-degree lat/lon boxes. After integration of heat content over depths, heat content is integrated over all one-degree ocean boxes.*

# World Ocean Database: World's largest publicly available oceanographic profile database

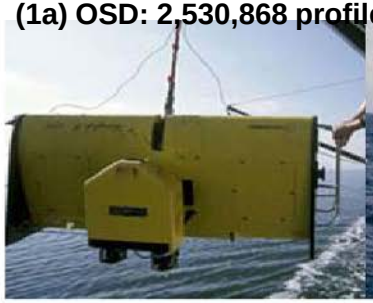


(1a) OSD: 2,530,868 profiles

(1b) MBT: 2,427,277 profiles

(1c) XBT: 2,109,400 profiles

(1d) CTD: 634,976 profiles



(1e) UOR: 88,184 profiles

(1f) PFL: 520,816 profiles

(1g) MRB: 566,540 profiles

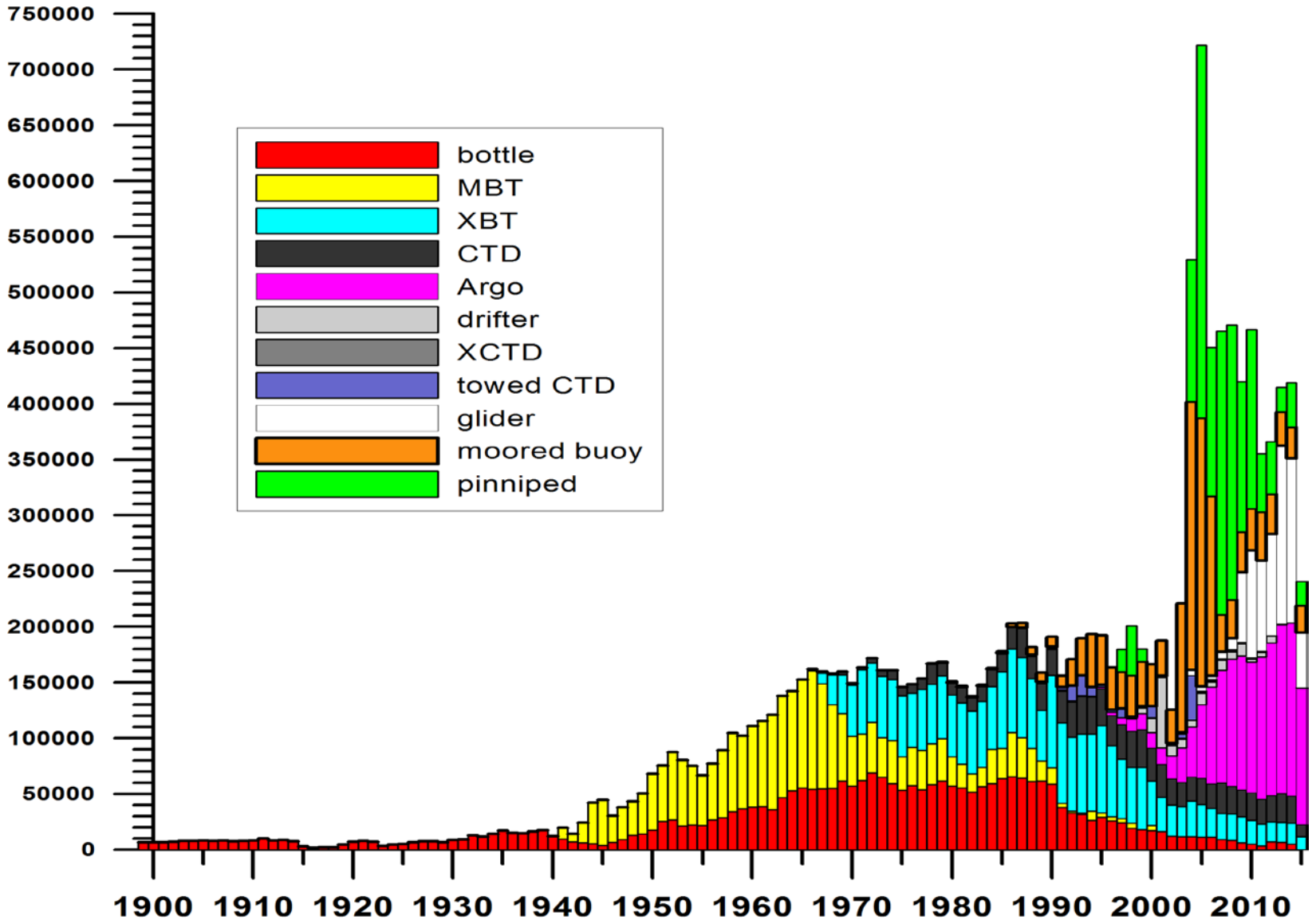
(1h) DRB: 122,226 profiles

(1i) APB: 89,558 profiles

(1j) GLD: 5,857 profiles

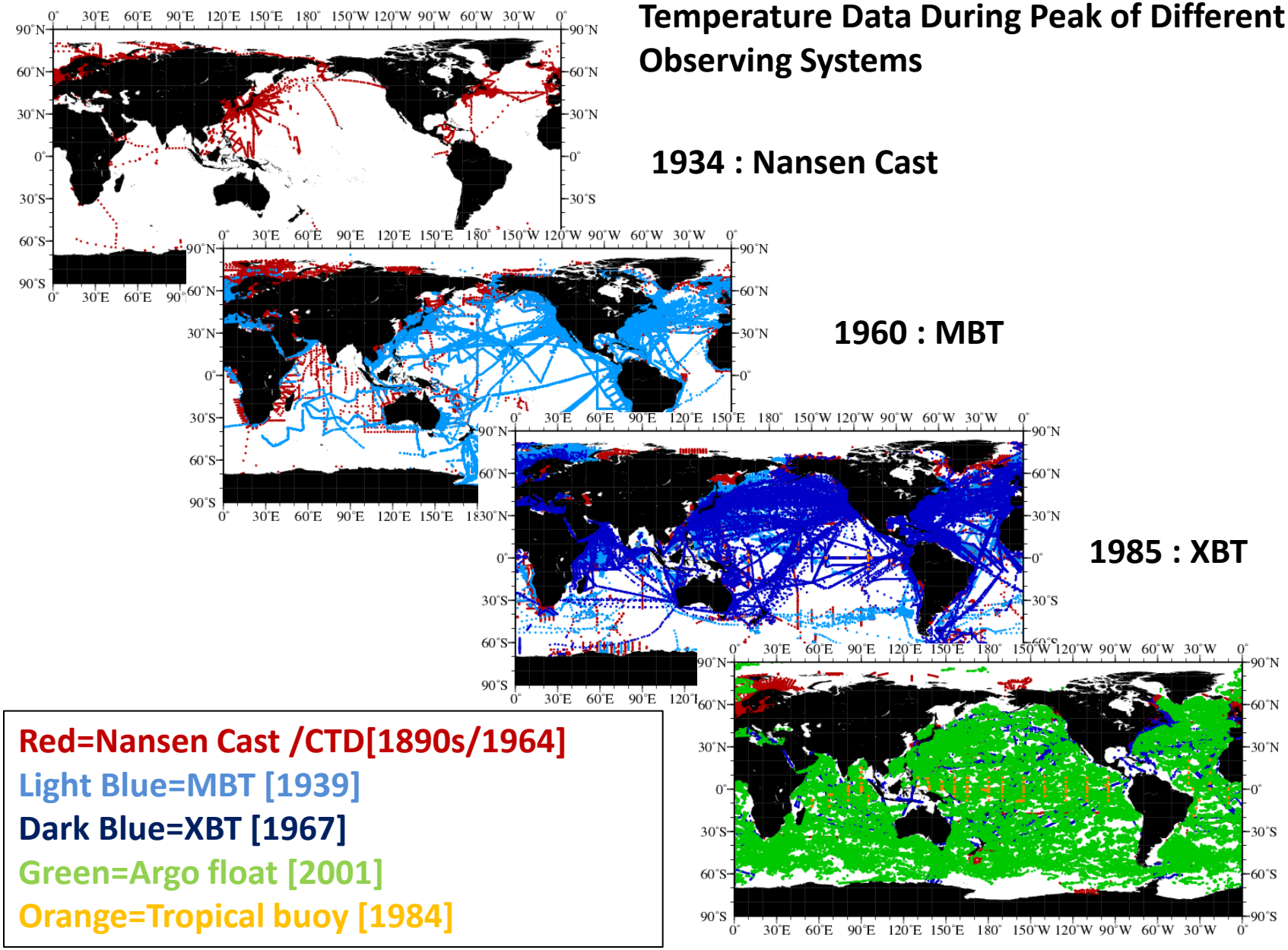
(1k) SUR: 9,178 profiles

(1l) Plankton: 230,944 profiles

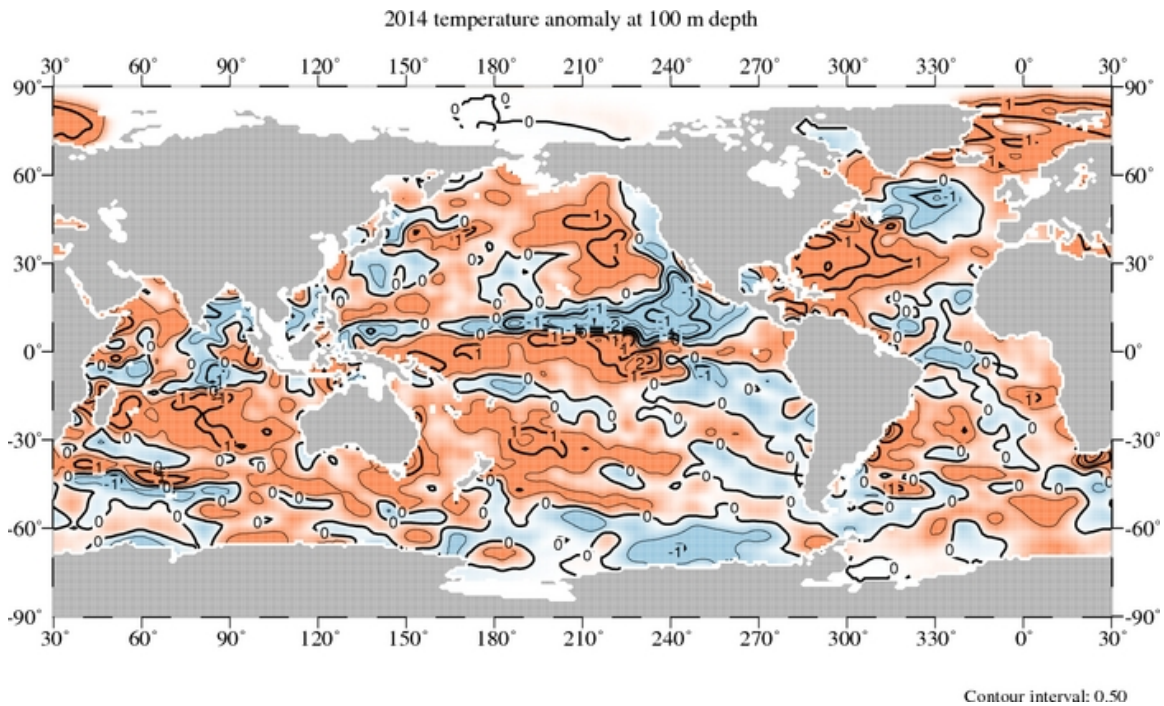


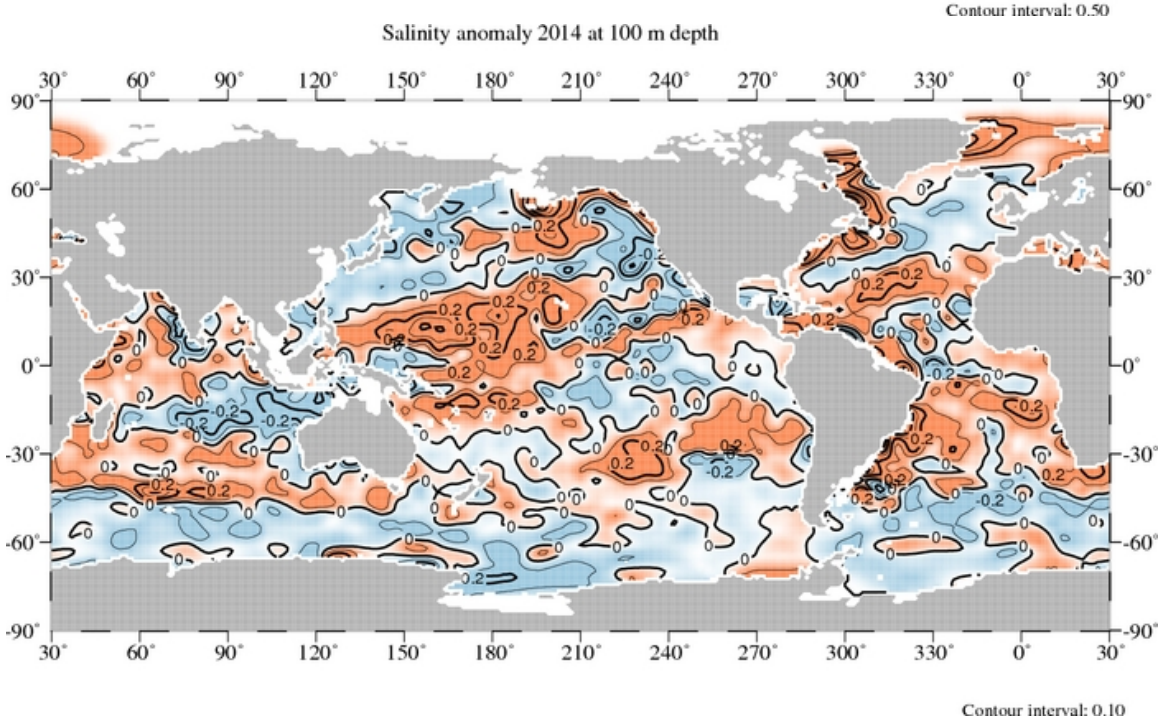

**Number of Casts by Year and Instrument in the World Ocean Database**

# Temperature Data During Peak of Different Observing Systems




Abraham, J. P., M. Baringer, N. L. Bindoff, T. Boyer, L. J. Cheng, J. A. Church, J. L. Conroy, C. M. Domingues, J. T. Fasullo, J. Gilson, G. Goni, S. A. Good, J. M. Gorman, V. Gouretski, M. Ishii, G. C. Johnson, S. Kizu, J. M. Lyman, A. M. Macdonald, W. J. Minkowycz, S. E. Moffitt, M. Palmer, A. Piola, F. Reseghetti, K. E. Trenberth, I. Velicogna, S. E. Wijffels, J. K. Willis: Monitoring systems of global ocean heat content and the implications for climate change, a review. - Review of Geophysics, Vol. 51, pp 450-483

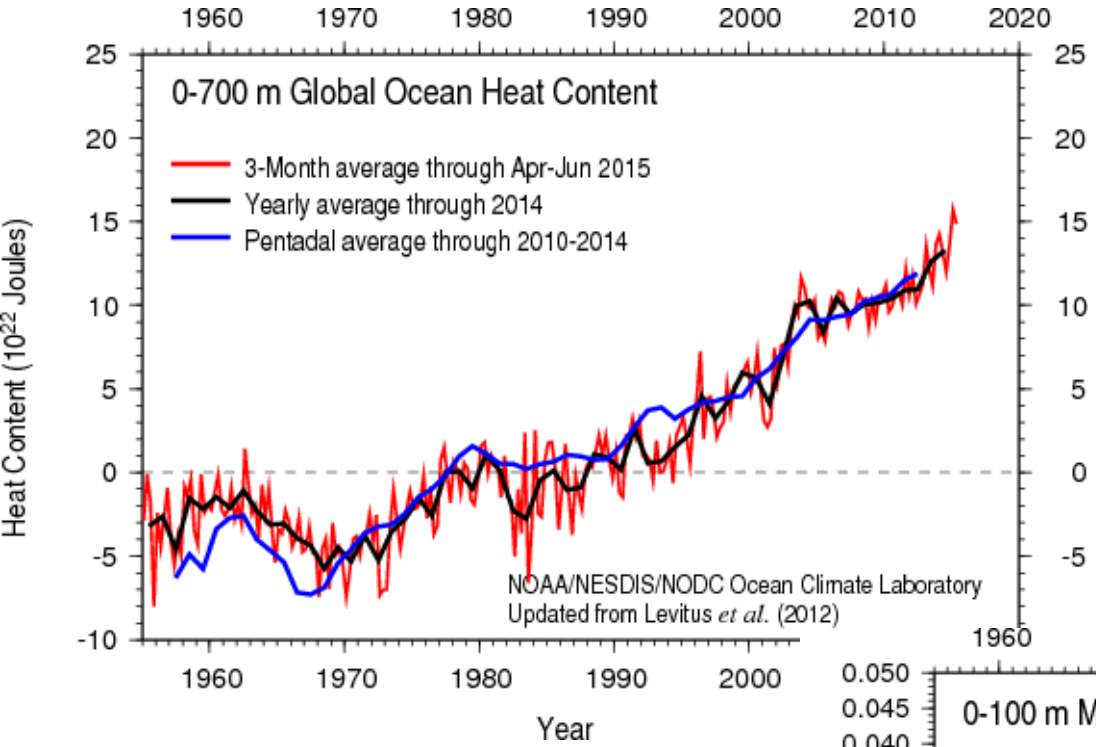



**Temperature and salinity anomaly fields (from mean World Ocean Atlas 2009 climatology) calculated using input data for 2014.**

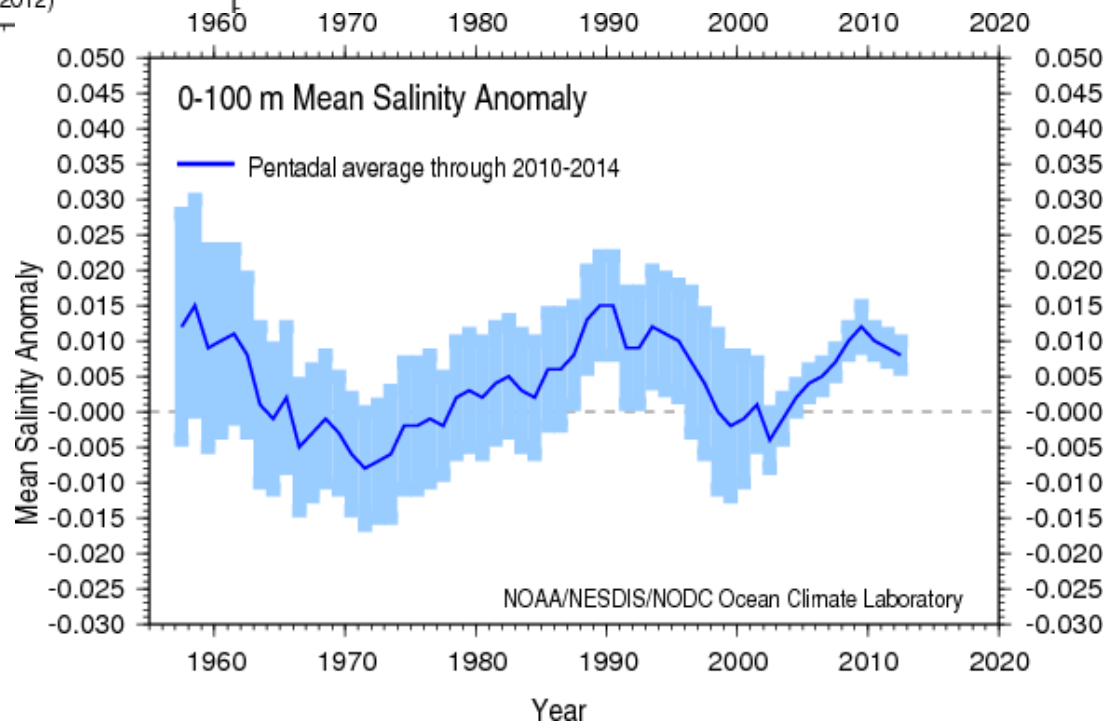
**Shown are annual anomaly fields for 2014 at 100 m depth. Fields are calculated for 26 discrete depths surface to 2000 m for seasonal, annual, and pentadal (five year) time periods.**

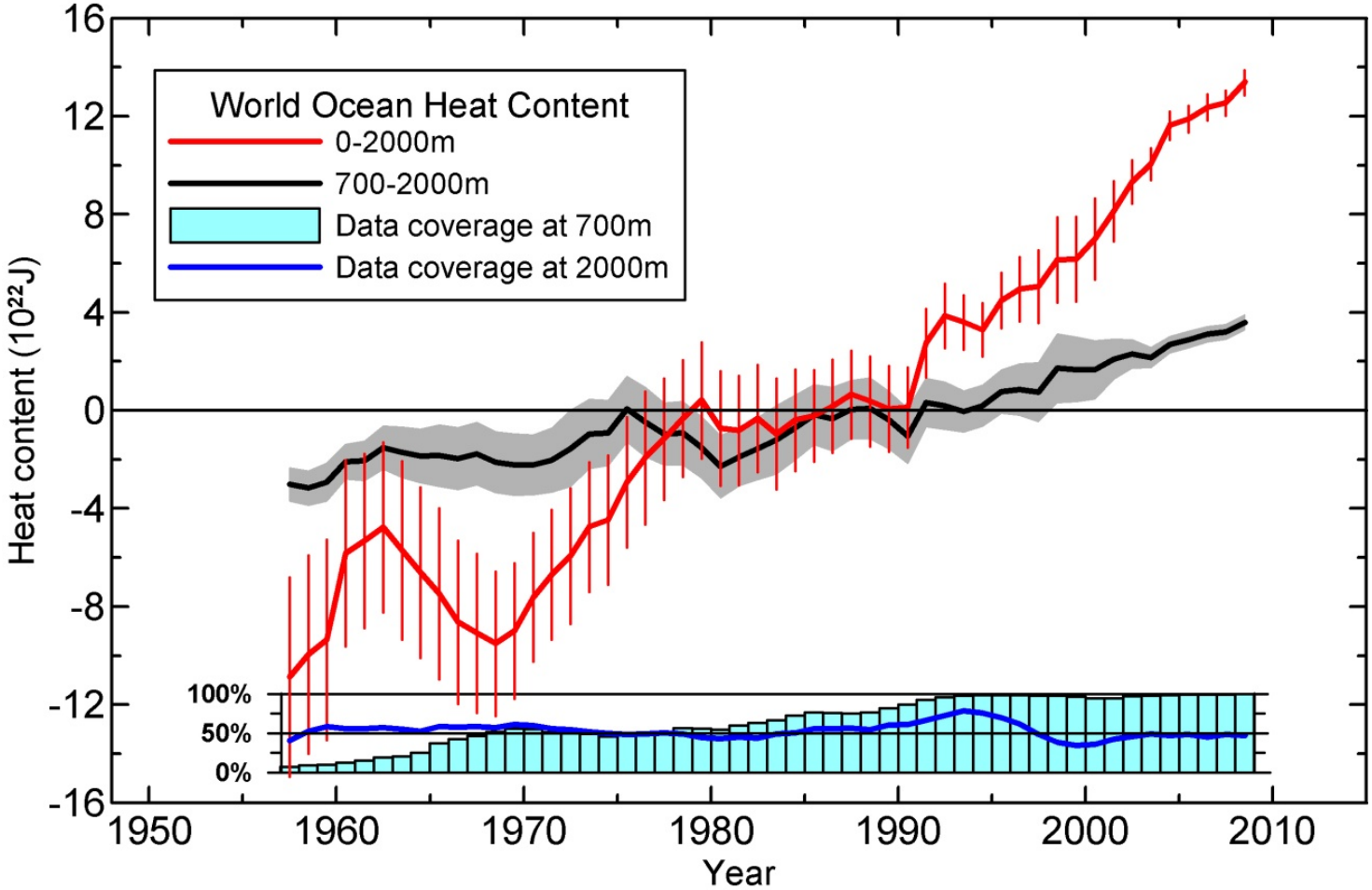
**Blue=colder/fresher than mean**
**Red=warmer/saltier than mean**



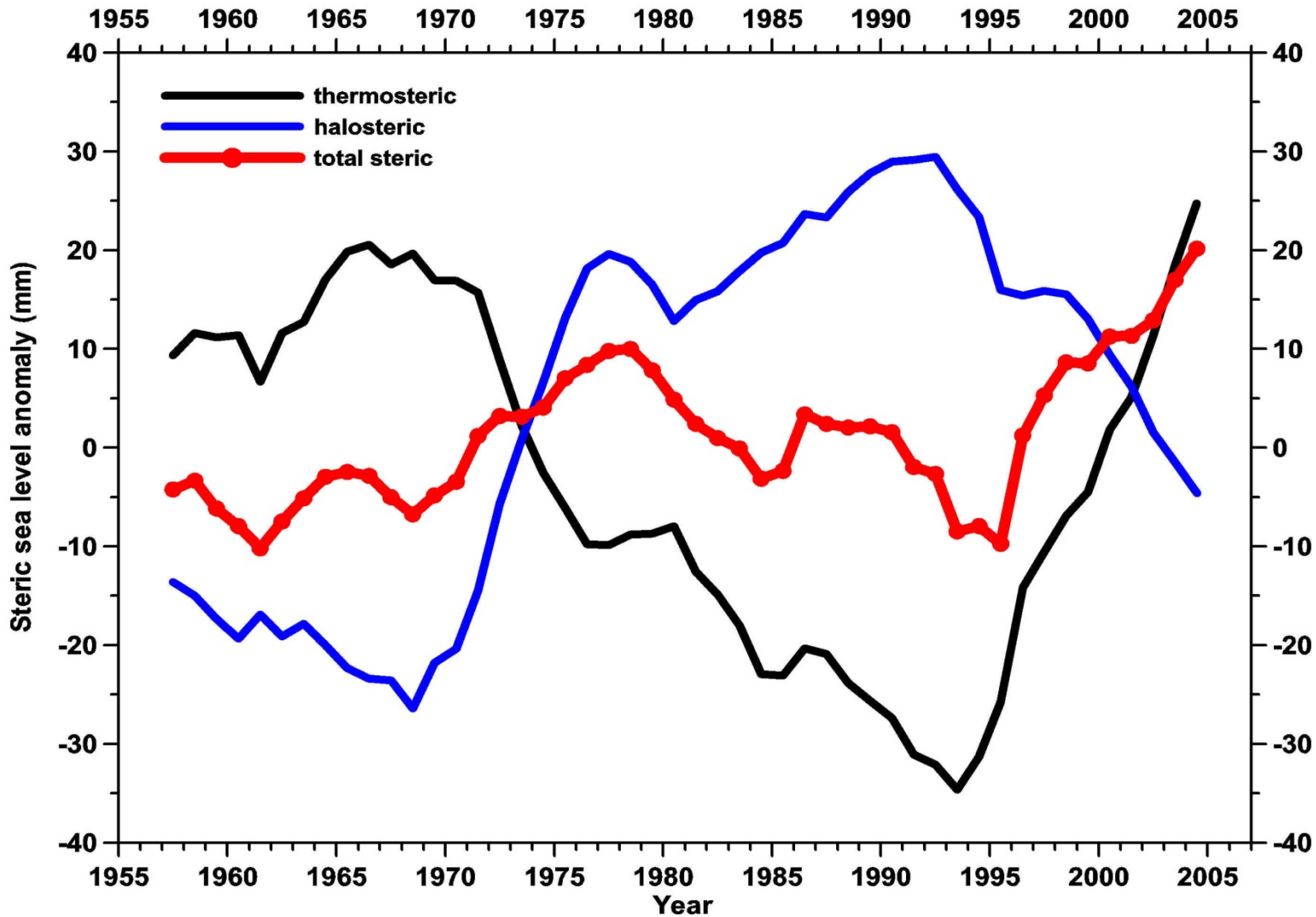

**Integrated ocean heat content (0-700m, 0-2000m) (left), thermosteric sea level change (0-700m, 0-2000m), and vertically averaged temperature anomaly (0-100m, 0-700m, 0-2000m) are calculated from temperature anomalies.**

**Halosteric sea level change (0-700m, 0-2000m) and vertically averaged salinity anomalies (0-100m, 0-700m, 0-2000m) (right) are calculated from salinity anomalies.**



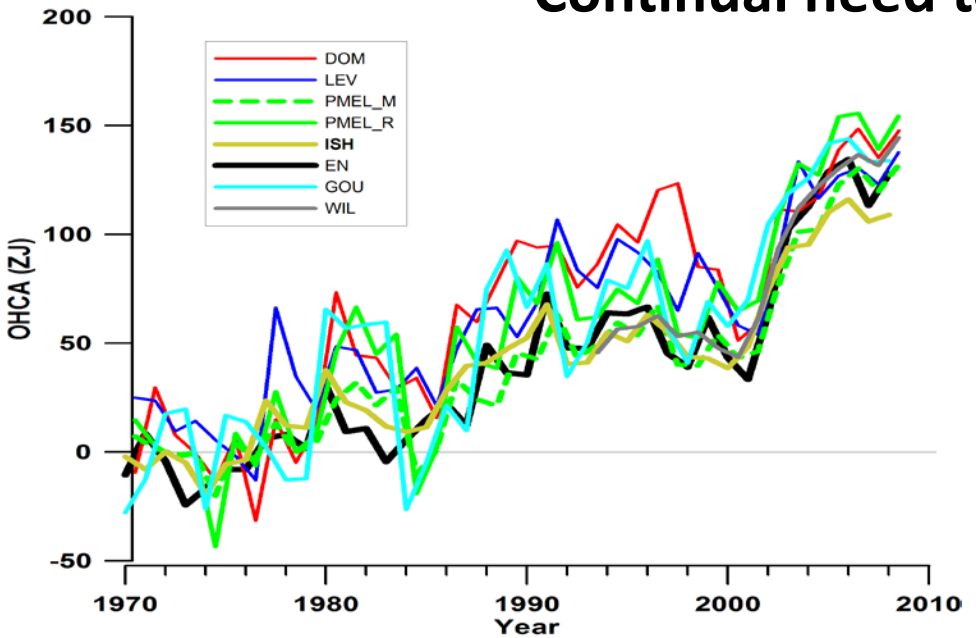



*Levitus, S., et al. (2012), World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010, Geophys. Res. Lett., 39, L10603, doi:10.1029/2012GL05110*

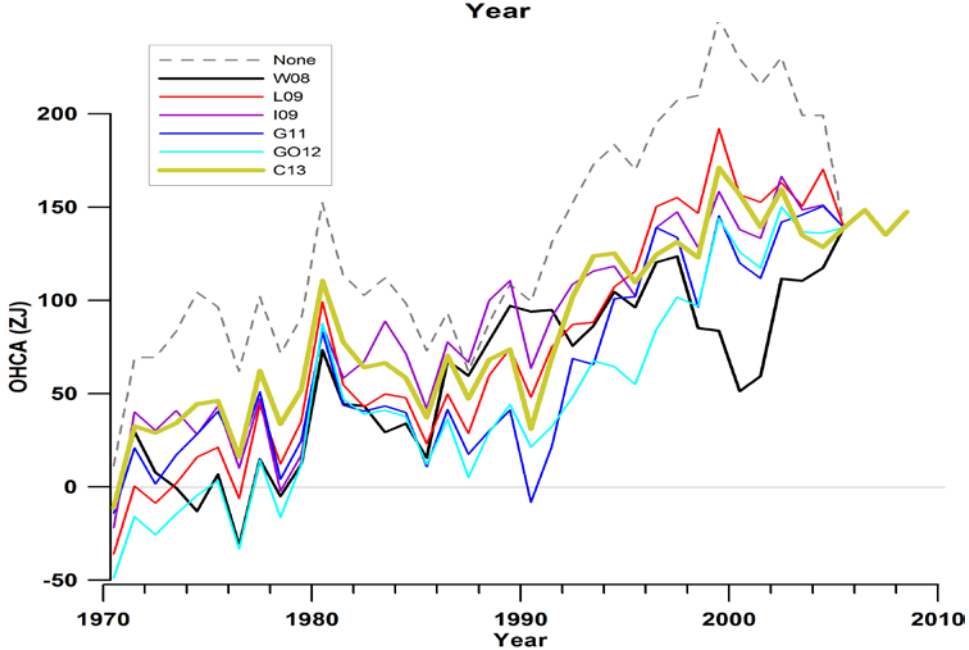



**Sea level anomaly in the subpolar North Atlantic + GIN Seas (50°N-66°N) from *in situ* temperature and salinity profiles (0-2000 meters)**

# Continual need to test and improve techniques



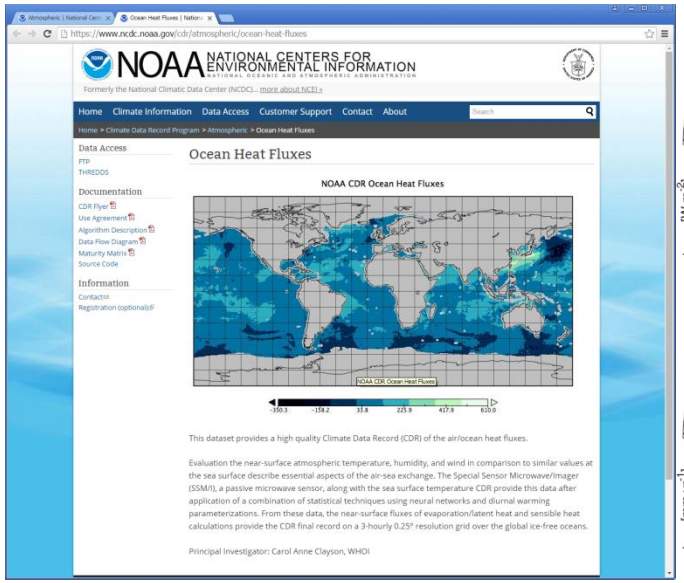

**8 different methods for calculating ocean heat content (yearly, 0-700m depth) using same data/quality control/XBT correction/baseline climatology Uncertainty= 17.2 ZJ**




**Domingues method for calculating ocean heat content (yearly, 0-700m depth) using same data/quality control/baseline climatology and 7 different XBT correction Uncertainty= 17.9 ZJ**

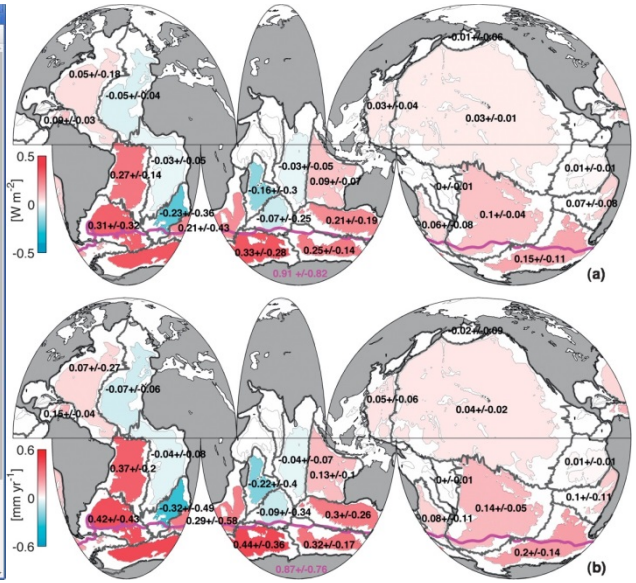
Boyer, T., C. M. Domingues, S. A. Good, G. C. Johnson, J.M. Lyman, M. Ishii, V. Gouretski, J. K. Willis, J. Antonov, S. Wijjfels, J. A. Church, R. Cowley, N. Bindoff, Sensitivity of Global Upper Ocean Content Sensitivty to Mapping Methods, XBT corrections, and Baseline Climatologies, submitted.

# FUTURE WORK

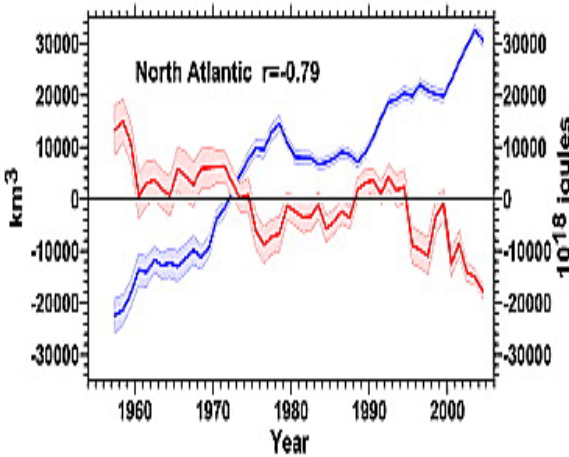



**Ocean Heat Flux CDR:**
PI Carol Ann Clayson (WHOI).

Compare ocean heat flux (from surface temperature and winds) to ocean heat content from subsurface temperature profiles




**Deep Ocean Heat: Mean local heat fluxes (a) and thermosteric sea level (b) through 4000 m implied by abyssal warming below 4000 m from the 1990s to the 2000s (Purkey and Johnson, 2010).** Deep Argo is coming – deep heat on a regular basis




**Add the Freshwater: Equivalent freshwater content (red) and heat content (blue) for the North Atlantic (0–80°N) 0–2,000 meters (1955–1959) to (2002–2006) with error estimates (2 × standard error) (Boyer *et al.*, 2007)**
Expand globally

# Summary

- **The Ocean absorbs ~90% of excess heat in the Earth's climate system. Ocean freshwater content dominates hydrological cycle: Ocean Heat and Freshwater Content are important variables for understanding our changing climate.**

- **Calculating ocean heat (freshwater) content relies on in situ ocean temperature (salinity) profiles irregularly distributed in time and space – techniques are needed to properly analyze**

- **We use the World Ocean Database and the World Ocean Atlas baseline climatology set to calculate temperature and salinity anomalies for the upper 2000m of the water column, from whence ocean heat content, mean temperature and salinity anomalies, and thermosteric, halosteric, and total steric sea level anomalies are calculated and made publicly available every three months.**

- **These data can be used to augment and understand satellite observations, or directly to quantify changes in the Earth's climate system.**

- **Comparison and improvement of calculation techniques, incorporation of new variables and new instrumentation is important and ongoing work.**