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Title: The World Ocean Database: Connecting Ocean Observing Systems since 1998

Type of Presentation: Oral

Short Abstract: The World Ocean Database (WOD) is the world's largest in situ ocean profiling database that is available without restriction. The WOD contains over 14.5 million quality controlled, uniformly formatted profiles that date back to Captain Cook's second voyage in 1772. The WOD merges data from many different observing systems and instruments. There are three general steps that each dataset received for inclusion in WOD goes through: the dataset is converted into a common format, automatic and manual quality control checks are applied, and any incoming data that is already in WOD is removed before merging (i.e., duplicate checking). The direct uses of WOD data are plentiful, ranging from oceanographic and climate research to serving as environmental variables in biological studies. The WOD also serves as the foundational dataset in calculating the World Ocean Atlas, a globally gridded climatology of multiple oceanographic variables. Furthermore, WOD is also used to calculate ocean heat and salt content products. While the WOD itself connects multiple ocean observing systems, the data and products derived from WOD can also serve as validation datasets for various satellite missions, ultimately connecting in situ observations to remotely sensed observations. The WOD and its utility in both the in situ and remote sensing fields will be discussed.

The World Ocean Database: Connecting Ocean Observing Systems since 1994

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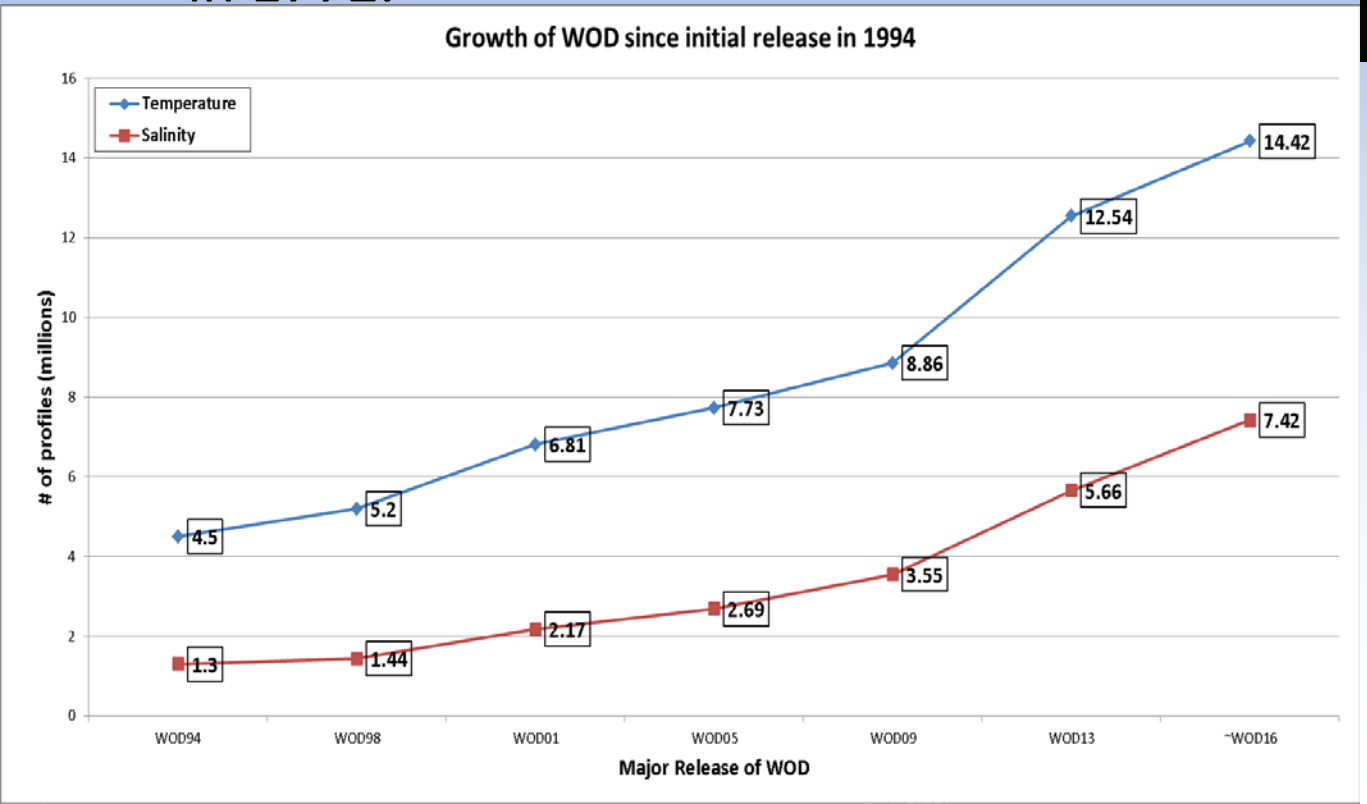
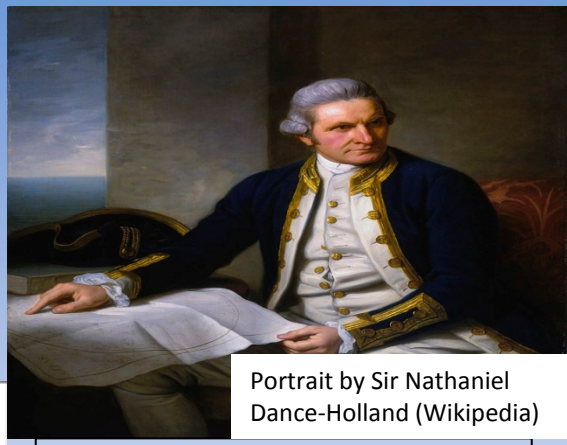
Outline

- WOD Background
- WOD Processing
  - Conversion to standard format
  - Quality control checks
  - Duplicate checking
- WOD Uses
  - Develop climatological products
  - Climate and oceanographic research
  - Satellite calibration/validation

What is the World Ocean Database?

- A hydrographic database that contains over 14.8 million unique, quality controlled, and uniformly formatted oceanic profiles dating back to Captain James Cook's second voyage in 1772.



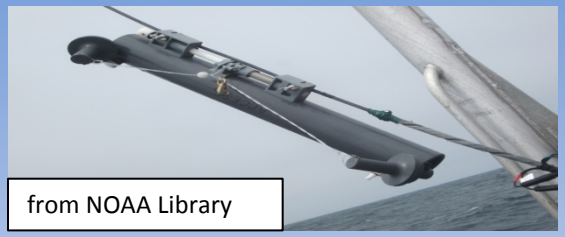


Portrait by Sir Nathaniel Dance-Holland (Wikipedia)

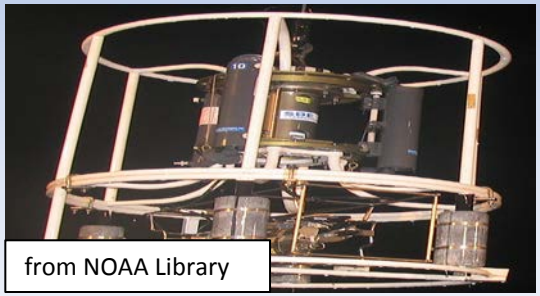
Captain James Cook – His first measurements of subsurface temperature in the far Southern Ocean revealed water temperatures 100 fathoms (~183 meters) below the surface were warmer than water temperatures at the surface (Cook, 1777).

What instruments are in the World Ocean Database?

- Bottles (OSD)


from NOAA Library

- Conductivity, Temperature, and Depth (CTD)


from NOAA Library

- Expendable Bathythermograph (XBT)

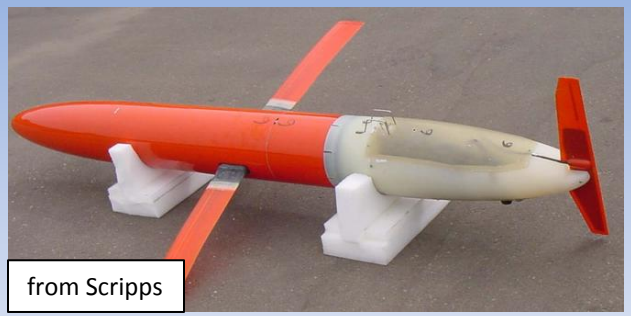

from NOAA Library

Instruments cont…

- Argo profiling floats (PFL)


from NOAA Library

- Gliders (GLD)

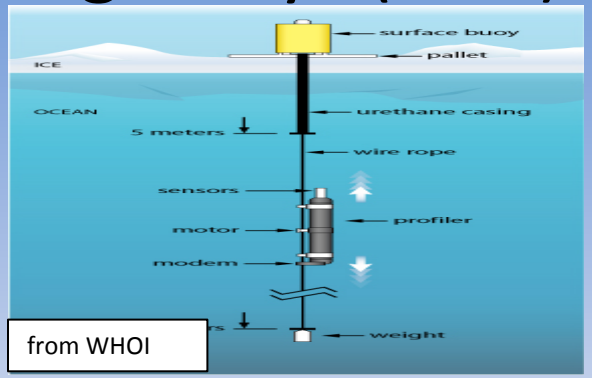

from Scripps

- Autonomous pinniped bathythermograph (APB)


from Boehlert *et al.* (2001)

Instruments cont…

- Drifting Buoys (DRB)

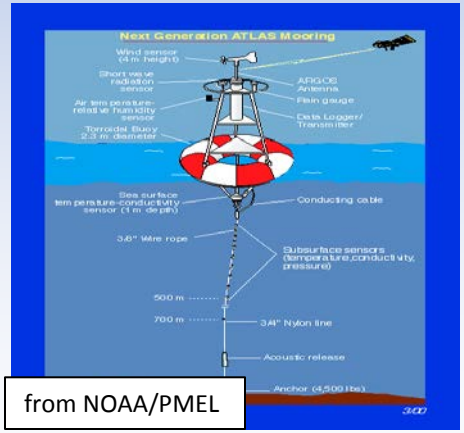


from WHOI

- Undulating Oceanographic Recorders (UOR)

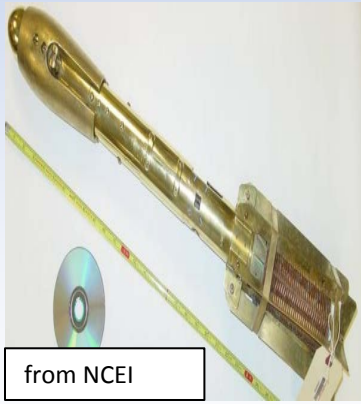

from WHOI

- Moored Buoys (MRB)

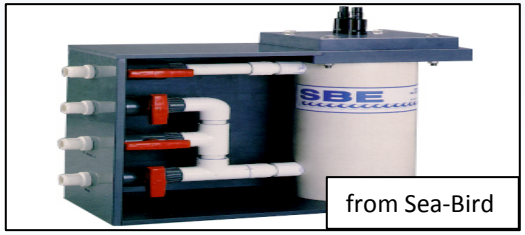


from NOAA/PMEL

- Mechanical Bathythermograph (MBT)


from NCEI

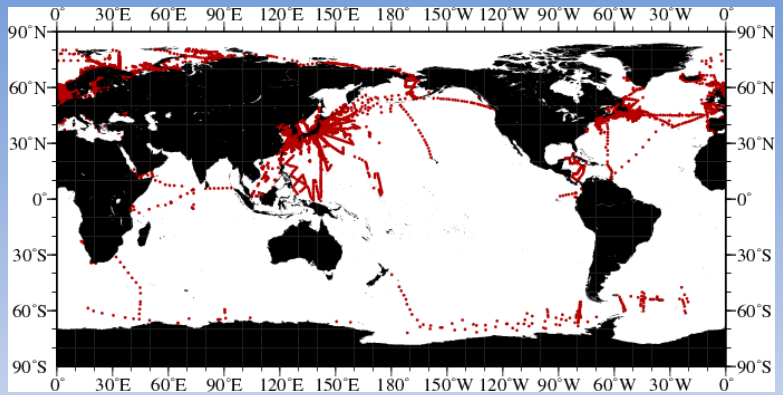
- Surface Data (SUR)



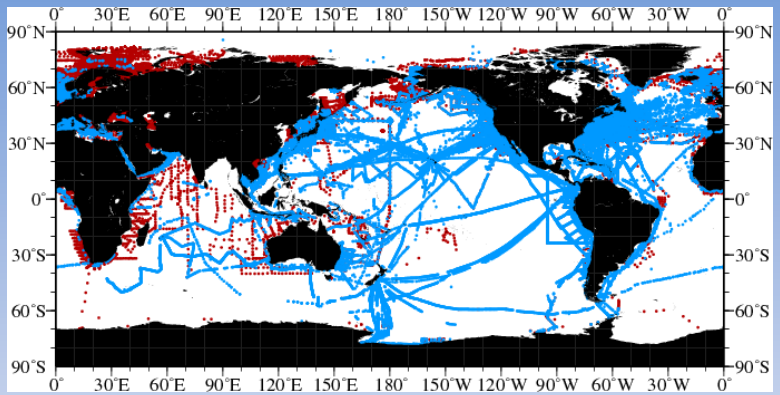
from Sea-Bird

Temperature observing systems through the 20th and early 21st Century

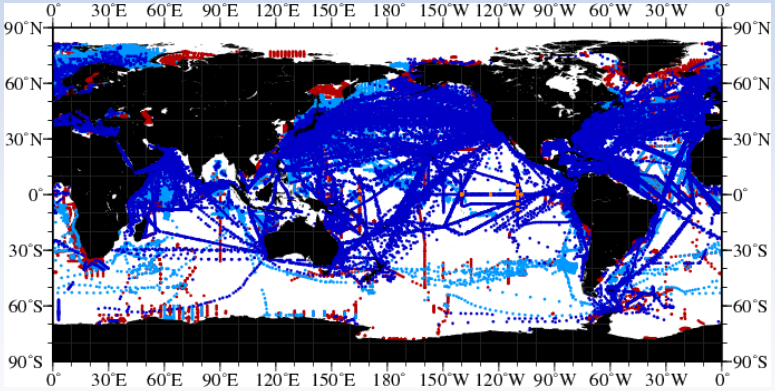
1934 : Nansen Cast



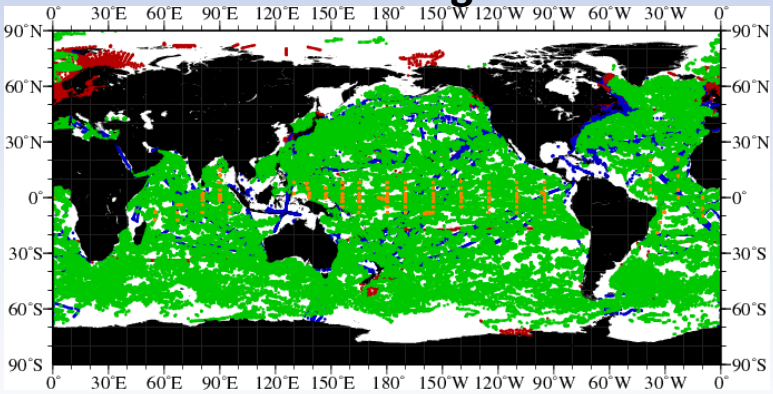
1960 : MBT



1985 : XBT



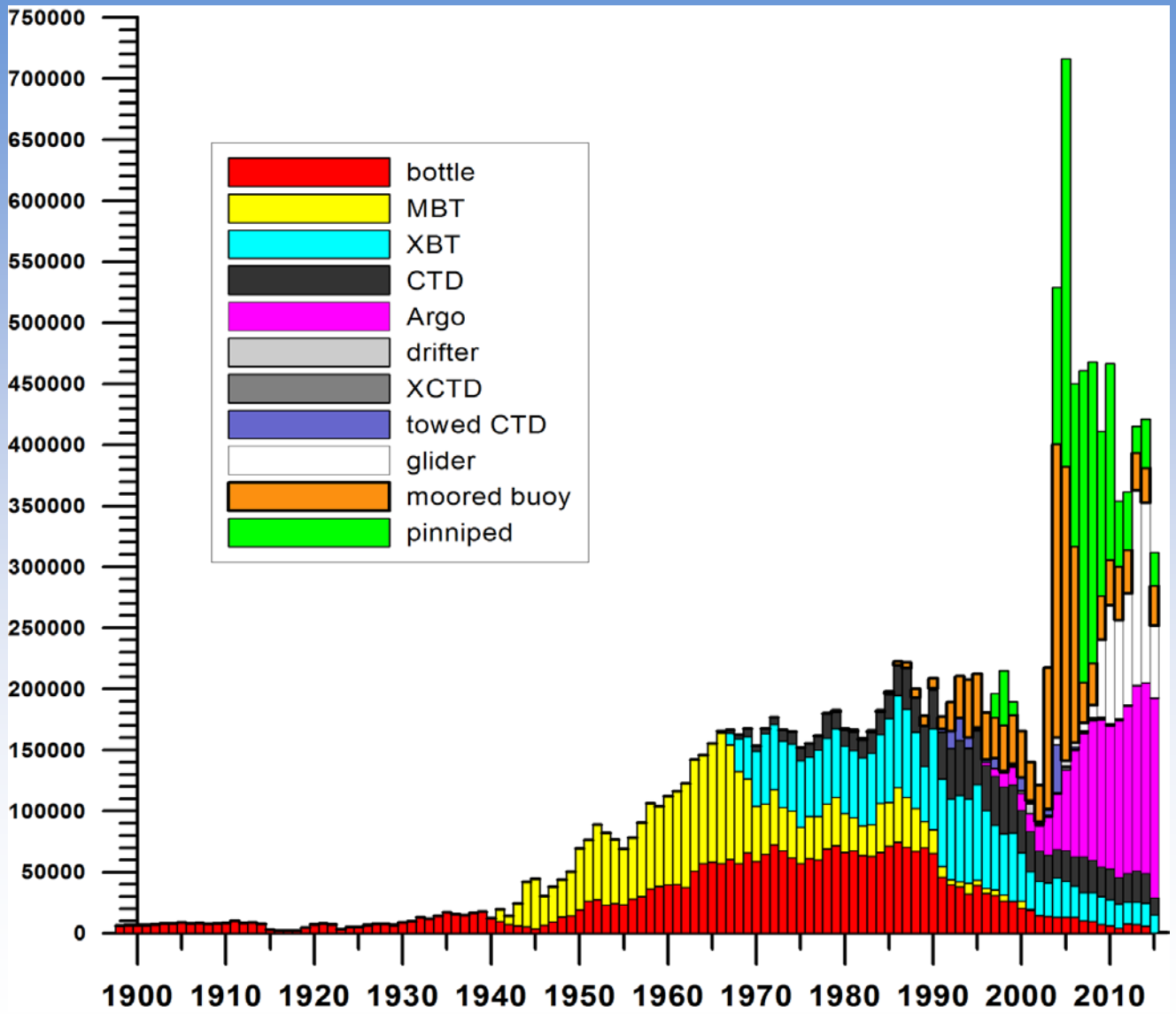
2009 : Argo



(Abraham *et al.*, 2013)

Red=Nansen Cast /CTD[1890s/1964], Light Blue=MBT [1939]
Dark Blue=XBT [1967], Green=Argo float [2001]
Orange=Tropical buoy [1984]

Time Series of Data Additions to WOD by Instrument Type



(Chart courtesy of M. Zweng)

WOD Variables

Variables in WOD
1) Temperature
2) Salinity
3) Oxygen
4) Phosphate
5) Nitrate
6) Nitrate + Nitrite
7) Silicate
8) Chlorophyll
9) pH
10) Alkalinity
11) pCO_2
12) TCO_2
13) Plankton
14) CFCs 11, 12, and 113
15) Tritium
16) Helium (noble gas)
17) ΔHe-3 (isotope)
18) ΔC-13 (isotope)
19) ΔC-14 (isotope)
20) Argon (noble gas)
11) Neon (noble gas)
22) O-18 (isotope)
23) Beam Attenuation Coefficient (transmissivity)

- Multiple variables (e.g., temperature, salinity, oxygen, etc.) come from multiple instrument types.
- **Blue** indicates variables that undergo manual quality control in addition to automatic quality control checks (more on this later).

(Table courtesy of M. Zweng)

WOD Processing

Conversion to a Common Format

- Suite of Fortran tools to extract relevant data and metadata from files, convert to standard units, and store in the WOD binary format
- Standard formats make conversion easier!
  - Over the years, conversion routines have been written for many different formats
  - Best case, the submitter used a standard format so the converter can use existing code
  - Worst case, they used a non-standard format and provided little metadata on that format
  - NetCDF templates are nice!

```
FILE:,SW4NUT-7.CSV
DATE:,12AUG09
BY:,J.P.CHRISTENSEN
# OF ROWS:,166
# OF COLS:,17
--,--,--,--,--,--,--,--,--,--,|,--,--,--,--,--,--,--,--
--,--,--,--,--,--,--,--,--,--,|,--,--,--,--,--,--,--,--
CRUISE,CTD#,PBIN,PAV,DEPTH,TEMP,POTEMP,SAL,SIGMAT,|,BTLCTD#,BTLDEPTH,[NO3],[NO2],[NH4],[PO4],[SI]
--,FOR T&S,--,--,--,--,--,--,--,--,|,FOR NUT,--,--,--,--,--,--,--
NAME,#,DBAR,DBAR,M,DEGC,DEGC,PSU,KG/M3,|,#,M,UMOL/L,UMOL/L,UMOL/L,UMOL/L,UMOL/L
SW2004,1,5.5,5.5,5.486,5.4264,-1.60613,-1.60619,29.21066,23.47318,|,1,5.3,0.35,0.11,0.17,0.71,2.4
SW2004,1,26,26,25.7195,-1.61908,-1.61938,29.72725,23.8927,|,1,25.6,0.73,0.08,0.03,0.76,3
SW2004,1,51,51,50.44955,-1.19597,-1.19693,31.8019,25.56728,|,1,50.5,6.19,0.03,0.09,1.22,12.4
SW2004,1,82.5,82.54,81.63308,-1.5179,-1.51942,32.49196,26.13542,|,1,81.8,11.09,0.04,0.18,1.54,22.6
SW2004,1,144.5,144.5,142.8907,-1.36861,-1.3718,33.30156,26.78863,|,1,142.7,14.57,0.03,0.22,1.71,29.5
SW2004,1,207.5,207.5,205.1559,-0.34864,-0.35566,34.47018,27.69595,|,1,205.1,13.68,0.03,0.14,1.22,16.9
SW2004,1,517.5,517.5,511.3302,0.49756,0.47458,34.84664,27.95419,|,1,511.5,13,0.03,0.19,0.94,7.3
```

```
    Longitude      Latitude      Year  Month  Day   Time      Cruise#   CC Prof_#
     -149.780 (8)    71.573 (6)  2004      4    2  11.23 (4)  902004    US 1

Num   Depth     Temp         Sal          PO4          Sil          NO2          NO3          NH3
  1    5.30  -1.606 (4)  29.211 (5)   0.710 (2)    2.400 (2)    0.110 (2)    0.350 (2)    0.170 (2)
  2   25.60  -1.619 (4)  29.727 (5)   0.760 (2)    3.000 (1)    0.080 (2)    0.730 (2)    0.030 (2)
  3   50.50  -1.196 (4)  31.802 (5)   1.220 (3)   12.400 (3)    0.030 (2)    6.190 (3)    0.090 (2)
  4   81.80  -1.518 (4)  32.492 (5)   1.540 (3)   22.600 (3)    0.040 (2)   11.090 (4)    0.180 (2)
  5  142.70  -1.369 (4)  33.302 (5)   1.710 (3)   29.500 (3)    0.030 (2)   14.570 (4)    0.220 (2)
  6  205.10  -0.349 (3)  34.470 (5)   1.220 (3)   16.900 (3)    0.030 (2)   13.680 (4)    0.140 (2)
  7  511.50   0.498 (3)  34.847 (5)   0.940 (2)    7.300 (2)    0.030 (2)   13.000 (2)    0.190 (2)


[ Secondary Headers: ]

Access#            59292 (5)
Project              636 (3)
Platform            2635 (4)
Institution          390 (3)
Station_Number        -1 (1)
depth_prec         1.000 (1)
T-S_Probe          7.000 (1)
```

(Slide courtesy of M. Zweng)

Quality Control Checks

- Automatic QC Checks
  - Standard deviation checks based on 5°x5° box statistics computed from all data in WOD
  - Range checks
  - Density inversion checks
  - Cruise speed, significant figure, depth checks
- Manual QC Checks
  - "Bullseye" Checking
    - Performed on gridded products (e.g., WOA13) produced from in situ data within WOD.
    - Removal of offending profile causing the "bullseye".

July 2011 Salinity Anomaly at 0m

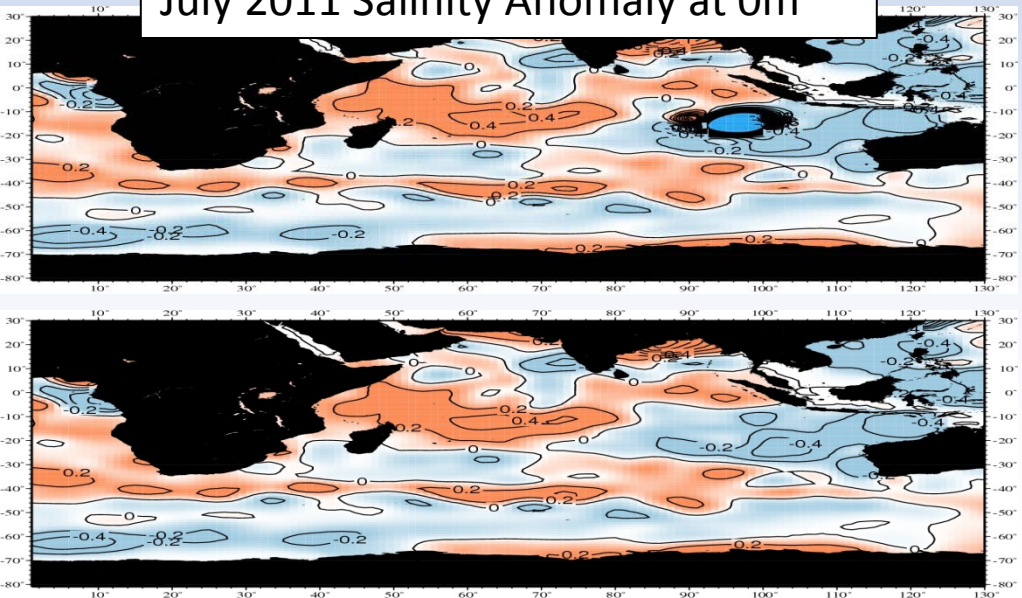
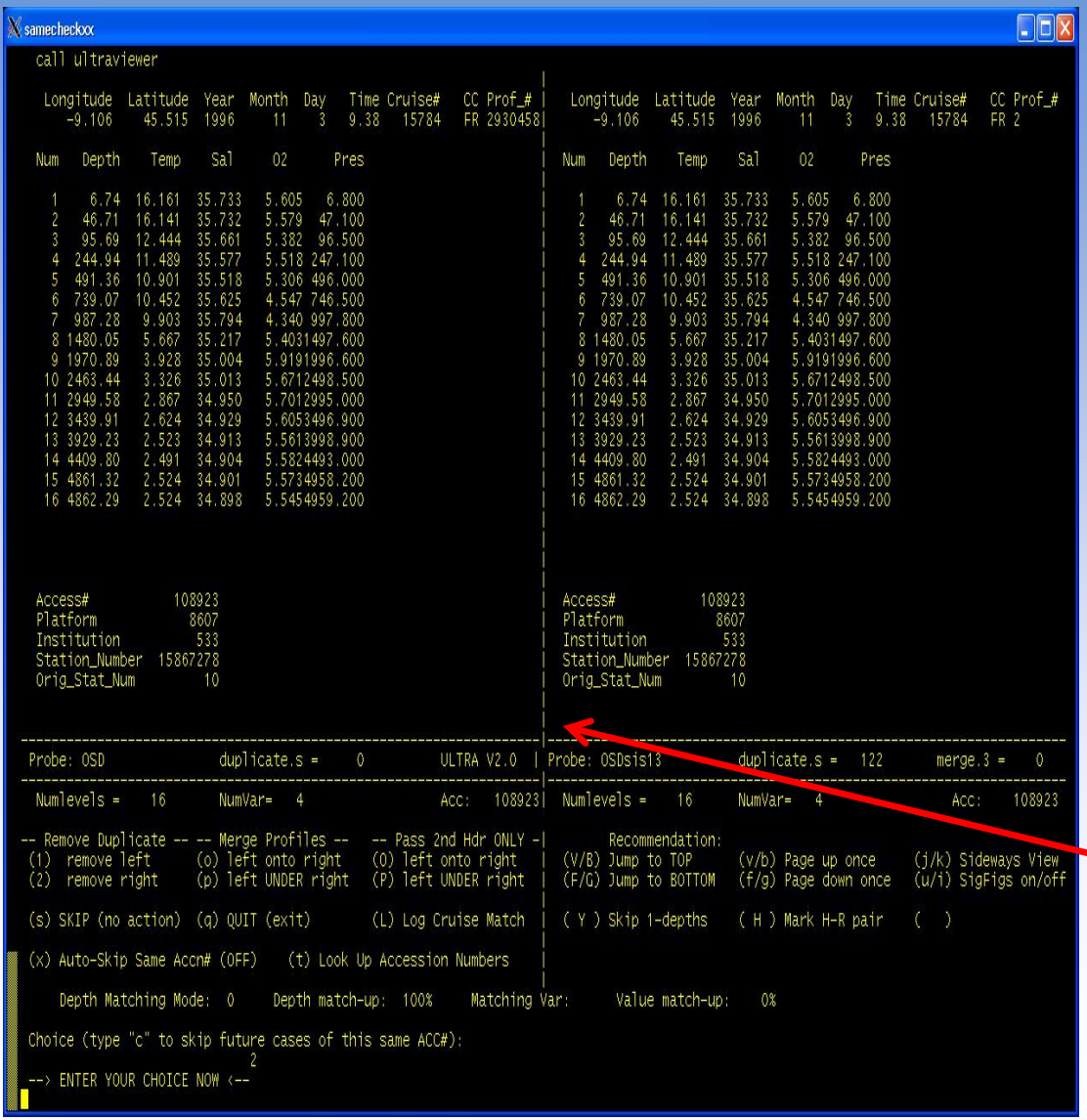


Table 12. Definition of WOD Quality Flags

(1) FLAGS FOR ENTIRE CAST (AS A FUNCTION OF VARIABLE)	
0	accepted cast
1	failed annual standard deviation check
2	two or more density inversions (Levitus, 1982 criteria)
3	flagged cruise
4	failed seasonal standard deviation check
5	failed monthly standard deviation check
6	failed annual and seasonal standard deviation check
7	bullseye from standard level data or failed annual and monthly standard deviation check
8	failed seasonal and monthly standard deviation check
9	failed annual, seasonal and monthly standard deviation check
(2) FLAGS ON INDIVIDUAL OBSERVATIONS	
(a) Depth Flags	
0	accepted value
1	duplicates or inversions in recorded depth (same or less than previous depth)
2	density inversion
(b) Observed Level Flags	
0	accepted value
1	range outlier (outside of broad range check)
2	failed inversion check
3	failed gradient check
4	observed level "bullseye" flag and zero gradient check
5	combined gradient and inversion checks
6	failed range and inversion checks
7	failed range and gradient checks
8	failed range and questionable data checks
9	failed range and combined gradient and inversion checks
(c) Standard Level Flags	
0	accepted value
1	bullseye marker
2	density inversion
3	failed annual standard deviation check
4	failed seasonal standard deviation check
5	failed monthly standard deviation check
6	failed annual and seasonal standard deviation check
7	failed annual and monthly standard deviation check
8	failed seasonal and monthly standard deviation check
9	failed annual, seasonal and monthly standard deviation check
(d) Biological data flags (applied only to Comparable Biological Value - CBV Taxa code 27)	
0	accepted value
1	range outlier (outside of broad range check)
2	questionable value ("bullseye flag")
3	group was not reviewed
4	failed annual standard deviation check

Duplicate Checking



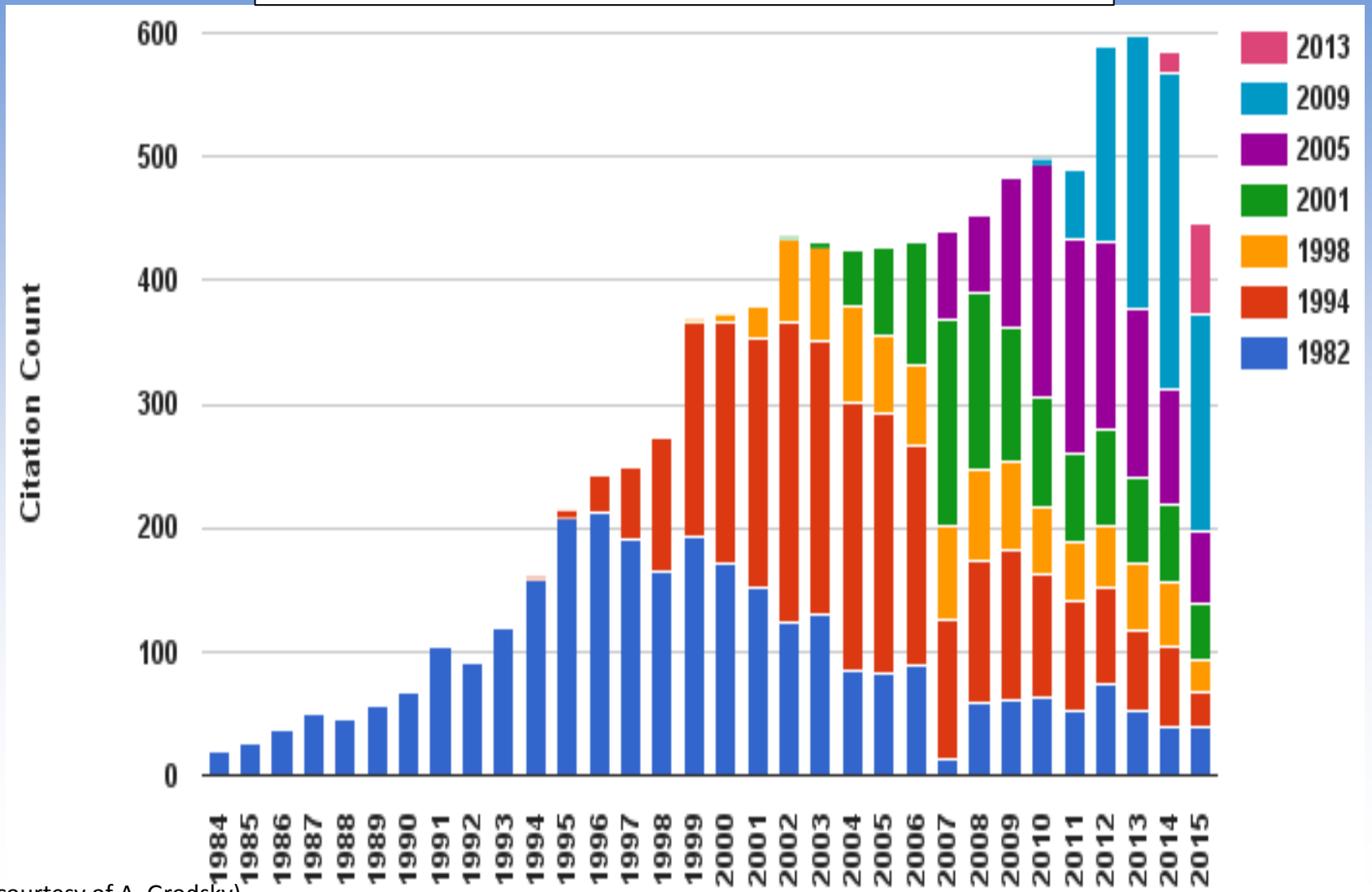
- Self-Check
  - Check to see if any incoming profiles are duplicates of another incoming profile
- Main Database Check
  - Check to see if any incoming profiles are duplicates of profiles already in the main database (WOD)
- Multiple criteria are used
  - Value check(s)
  - Location/time check(s)

xultra tool used for duplicate checking

(Graphic courtesy of M. Zweng)

WOD Uses

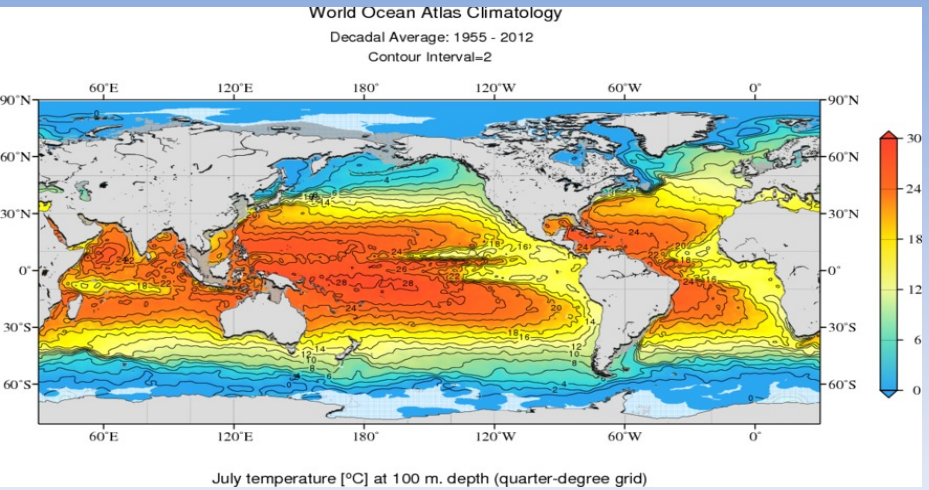
WOD/WOA Citation Count by Year

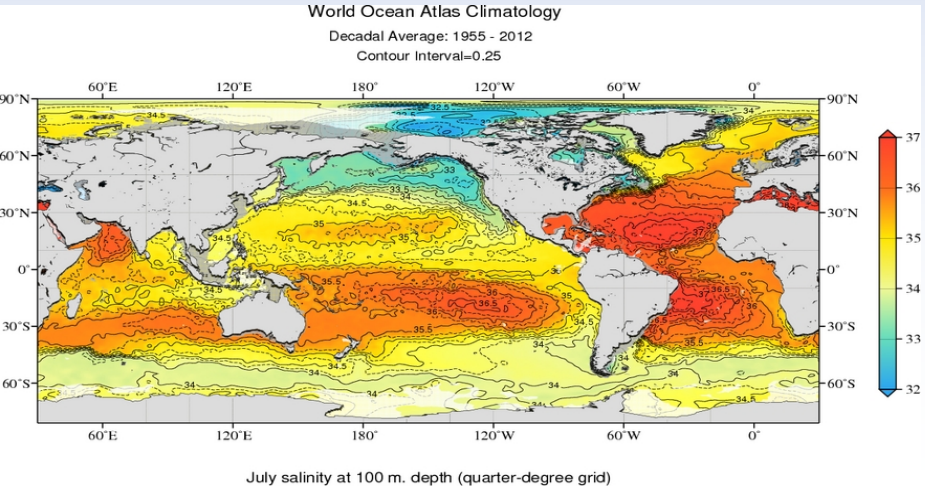


(Graph courtesy of A. Grodsky)

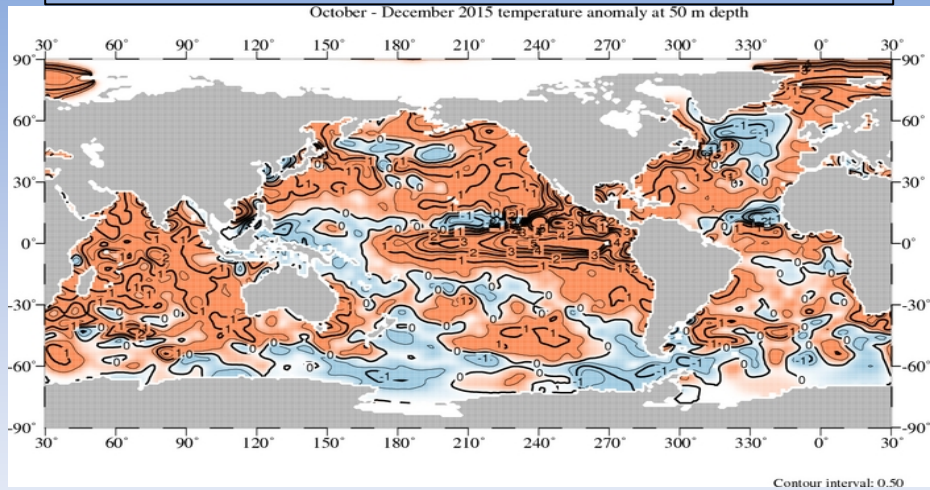
WOD: Foundation for the Development of Global Ocean Climatologies and Anomalies

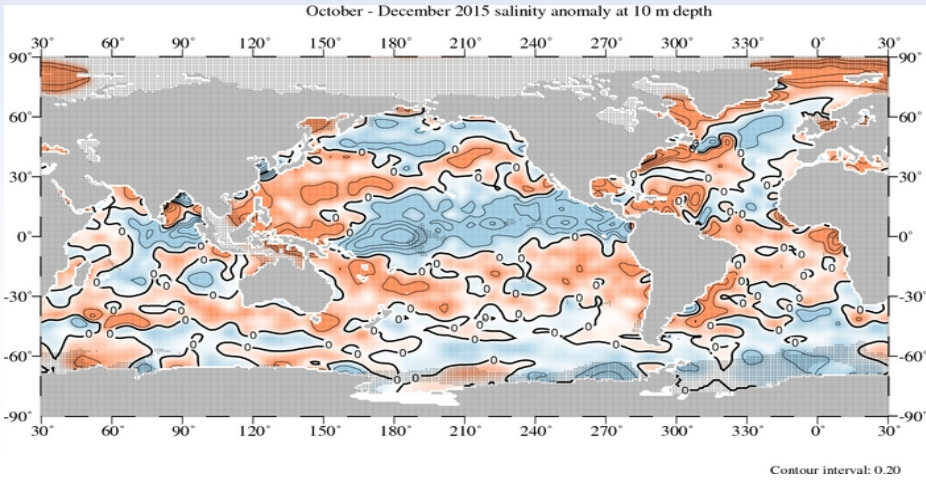
World Ocean Atlas





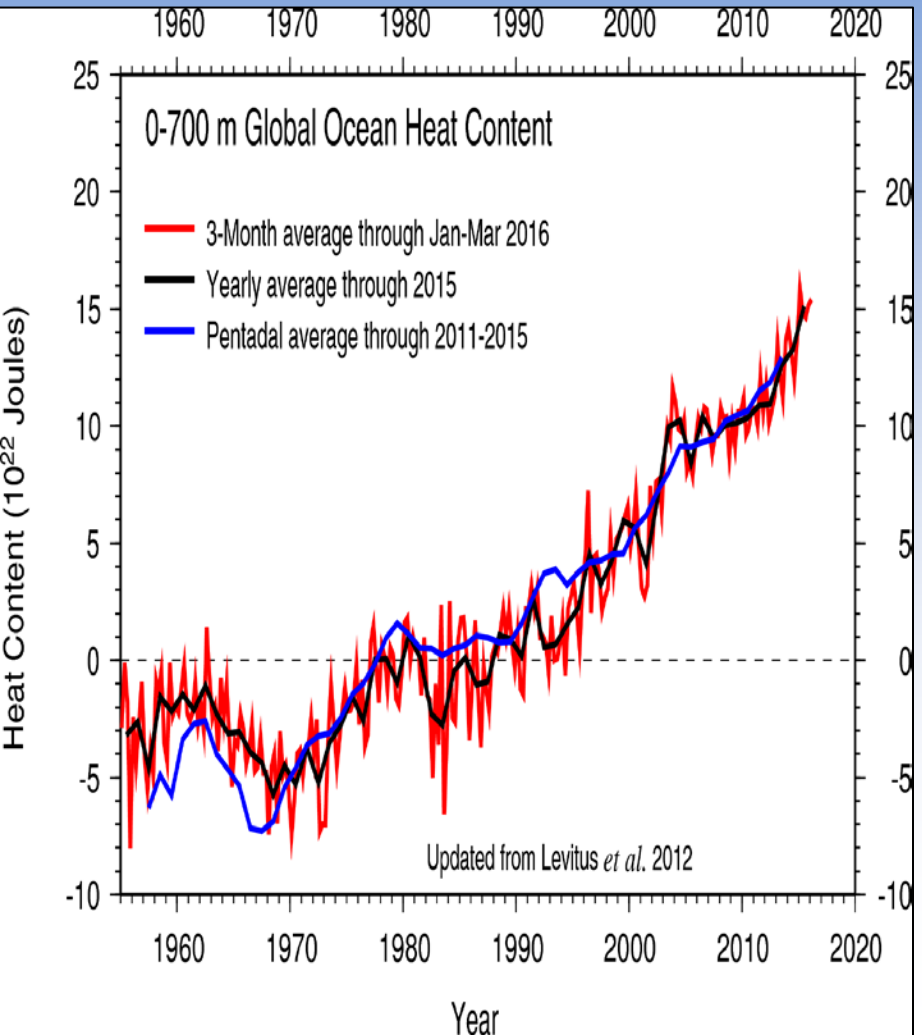
Ocean Heat and Salt Content Anomalies



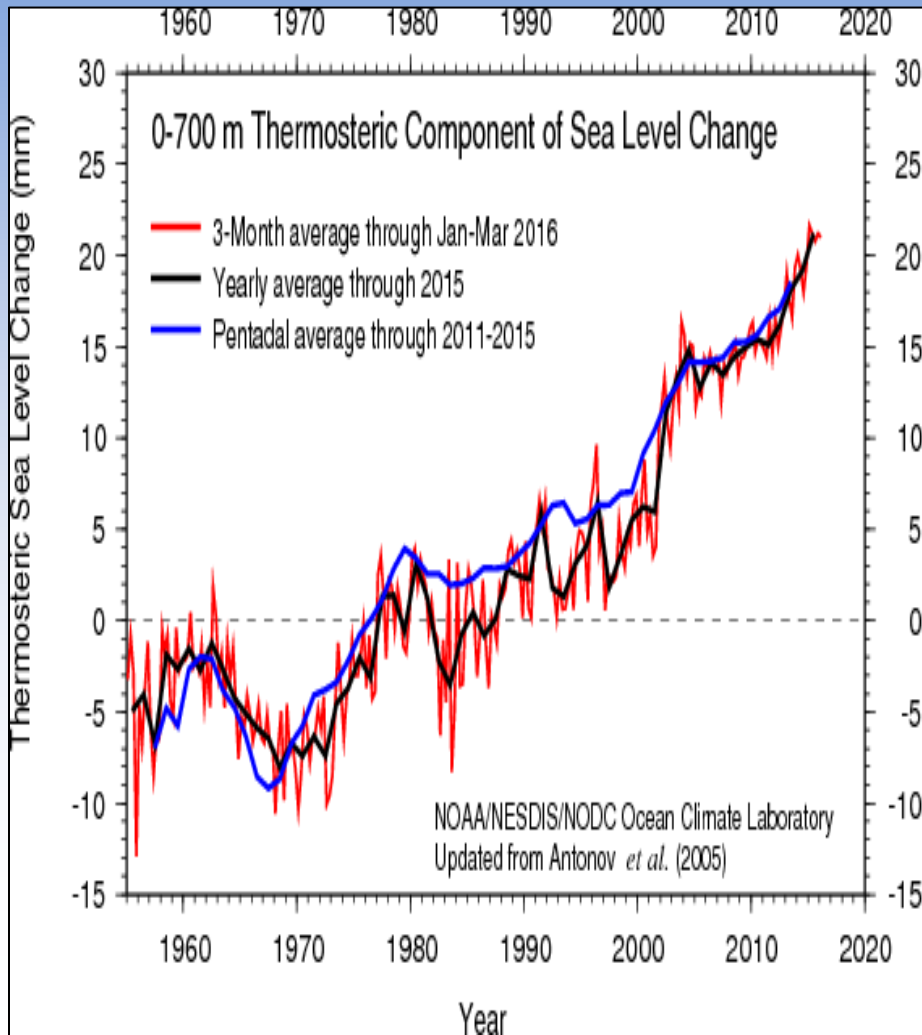


WOD: Foundation for Ocean Climate Research

Ocean Heat Content



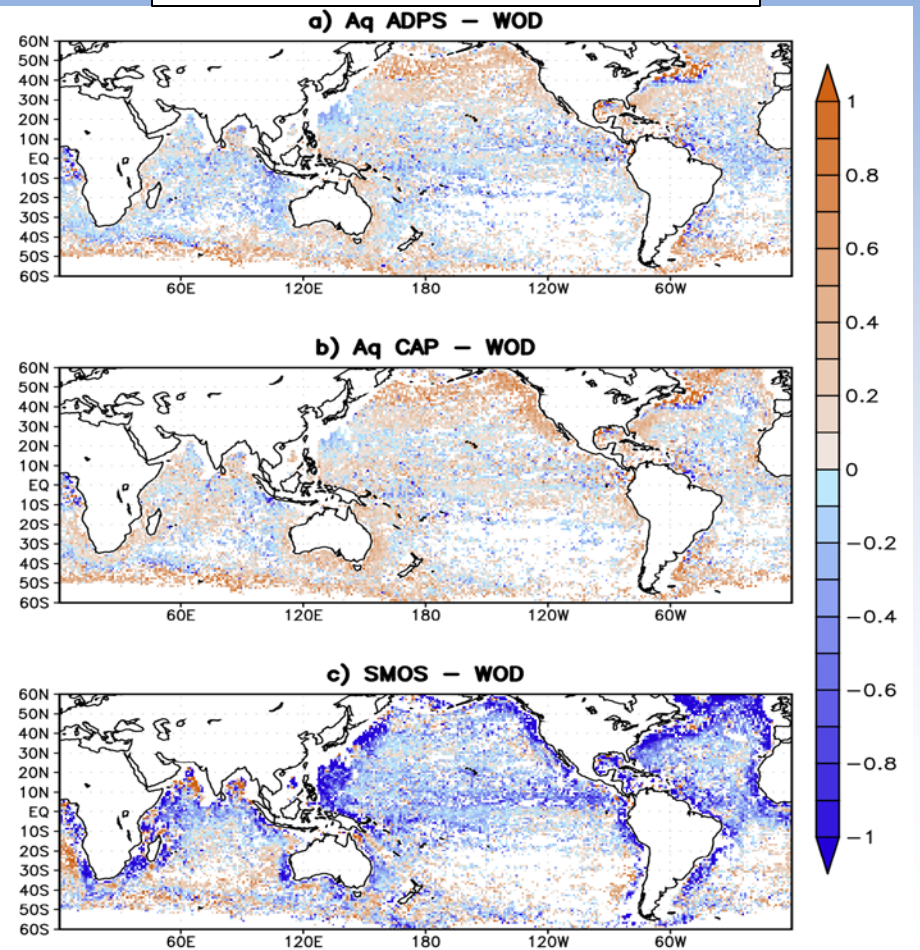
Sea Level Changes

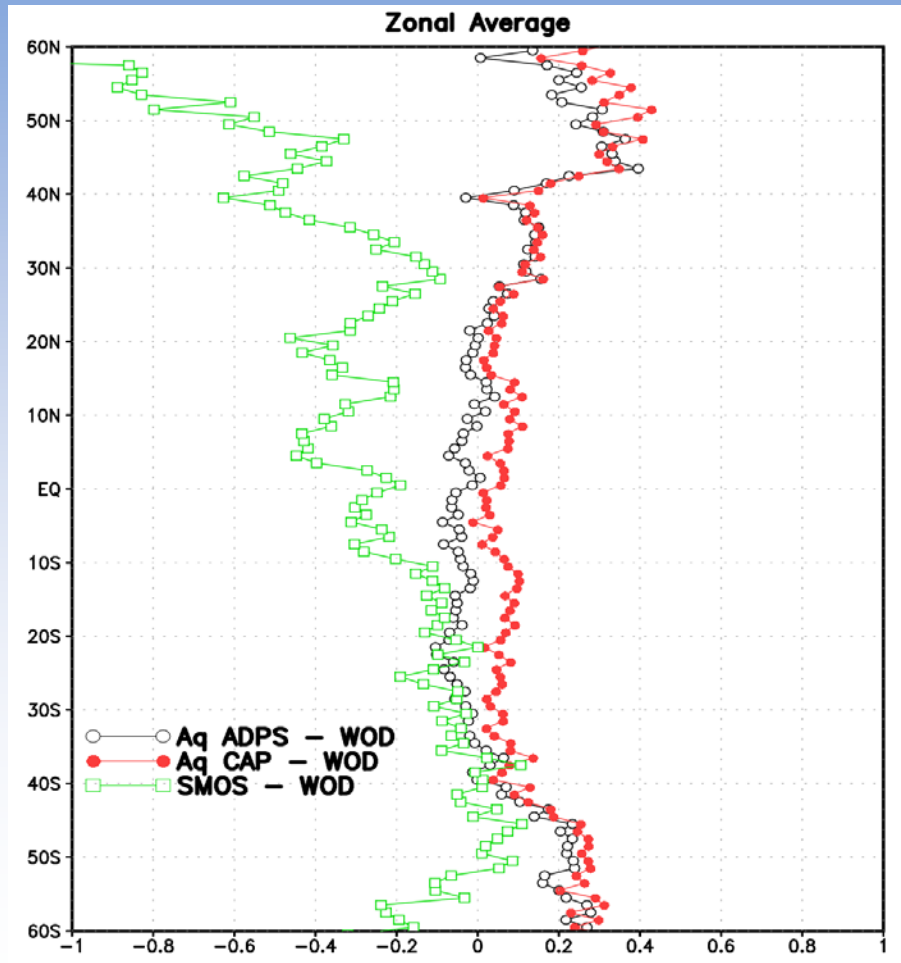


WOD: Cal/Val of Satellite Data

Aquarius/SMOS Validation with WOD-derived Salinity

September 2011 – May 2015





Updated from Reagan *et al.* 2014

Conclusions

- WOD has successfully integrated multiple in situ ocean observing systems into one large database
- Three basic steps are followed during WOD processing
  1. Data Conversion to Common Format
  2. Data Quality Control
  3. Data Duplicate Checking
- WOD has been utilized in the creation of multiple gridded oceanic products, ocean/climate research, and in the calibration and validation of satellite data.

Acknowledgements

Special thanks to Tim Boyer and Melissa Zweng for providing multiple figures/slides for this presentation.

I would also like to thank the data providers who continue to send NCEI their data, my NCEI colleagues who continue to archive this data, and my Ocean Climate Laboratory colleagues who continue to process this data for inclusion in WOD.

Thank You