Expendable Bathythermographs

Environmental impact assessment

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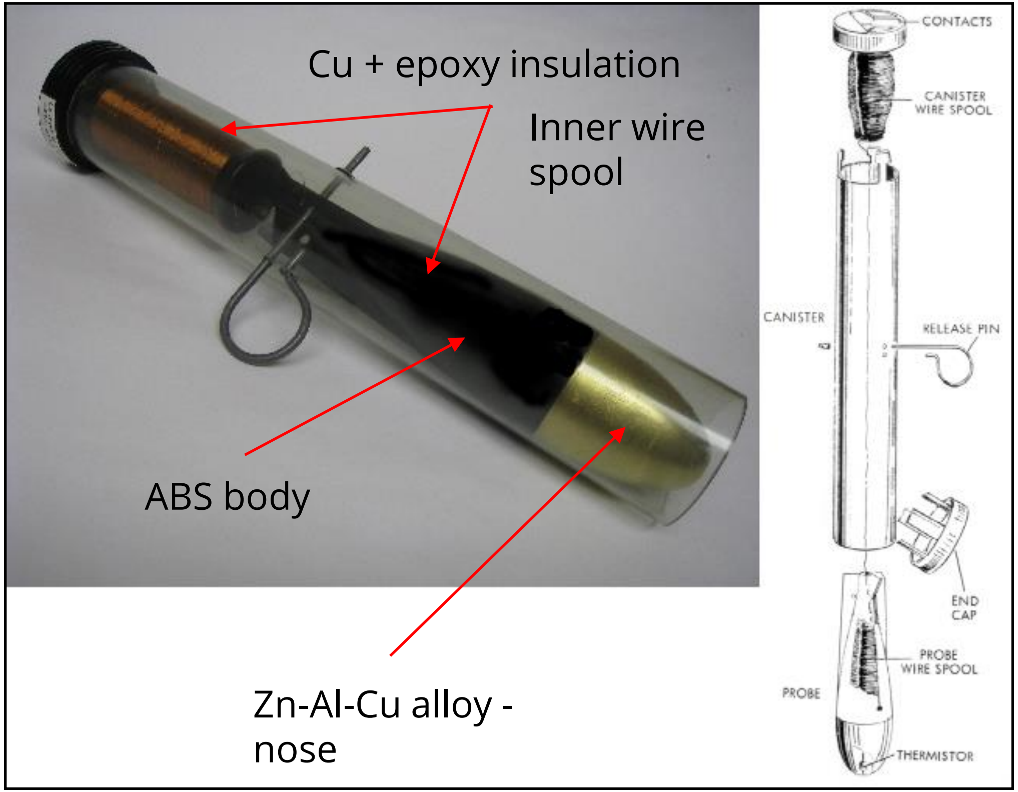
XBT features

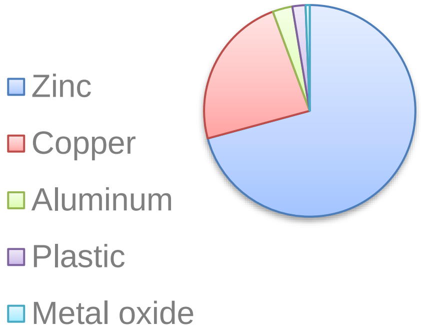


- Largest source of upper ocean temperature globally since 1970.
- Accounts for 40% of all temperature profile measurements.
- ±0.1°C and 65 cm of resolution.
- High Density mode → 10-30 km deployments → resolving mesoscale structures.
- Most cost-effective solution to accomplish frequent measurements in short time.
- Spatial and temporal resolution can't be reproduced by other platforms, but improved in combination.
- Operations are inexpensive and without direct CO_2 emissions (SOOP).

XBT deployments per year

No. of XBT deployments per year (NOAA/AOML XBT Network internal reports)

Region	2015	2016	2017	2018	2019	Average
Atlantic	7,986	7,910	7,345	7,766	6,296	7,461
Gulf of Mexico and Caribbean	68	21	85	120	68	72
Indian	2,645	2,402	2,091	1,966	1,869	2,195
Mediterranean	663	321	244	319	105	330
Pacific	6,469	7,675	6,956	5,812	5,377	6,458
Total	**17,831**	**18,329**	**16,721**	**15,983**	**13,715**	**16,516**



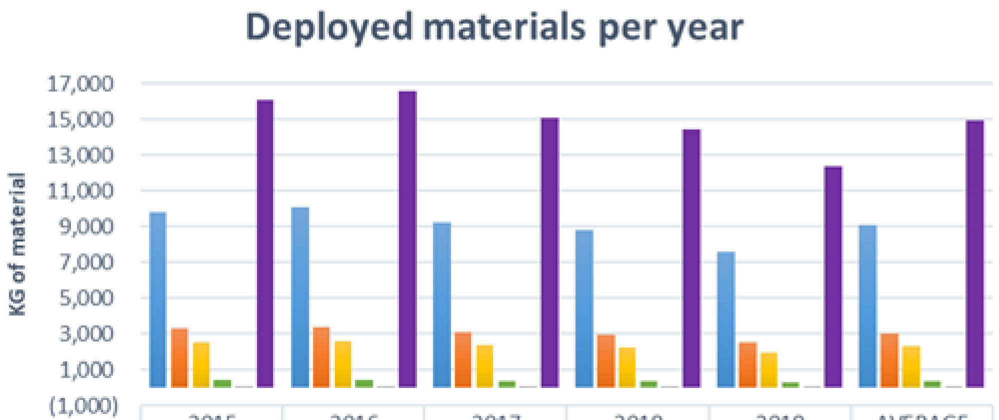
XBT components (each probe) (Lockheed Martin Sippican)

Component	Mass [g]	Materials
Nose / tip	575.16	Zinc die cast alloy - Zamak 3: 95.8% Zn, 4.1% Al, 0.1% Cu
Wire	275	Copper and plastic coating
Body (hollow tail)	33.4	ABS plastic
Spool and thermistor	19.59	75% ABS - 25% metal
TOTAL	**903.15**	-

XBT elemental material mass (each probe)

Material	Mass [g]	Percentage [%]
Zinc	551	61
Copper[a]	183.16	20.3
Aluminum	23.58	2.6
Metal oxide	4.9	0.5 → thermistor
Plastic[a]	140.51	15.6
TOTAL	**903.15**	**100**

XBT materials deployed per year



	2015	2016	2017	2018	2019	AVERAGE
Zinc	9,825	10,099	9,213	8,807	7,557	9,100
Copper	3,266	3,357	3,063	2,927	2,512	3,025
Plastic	2,505	2,575	2,349	2,246	1,927	2,321
Aluminum	420	432	394	377	323	389
Metal oxide	87	90	82	78	67	81
Total	16,104	16,554	15,102	14,435	12,387	14,916

Zinc Copper Plastic Aluminum Metal oxide Total

Minimum natural concentrations
(found in the open ocean):

- Zinc 0.4 ug/L (Chester & Stoner, 1974)
- Copper 0.1 ug/L (Chester & Stoner, 1974)
- Aluminum 0.008 ug/L (U.S. EPA, 2018)

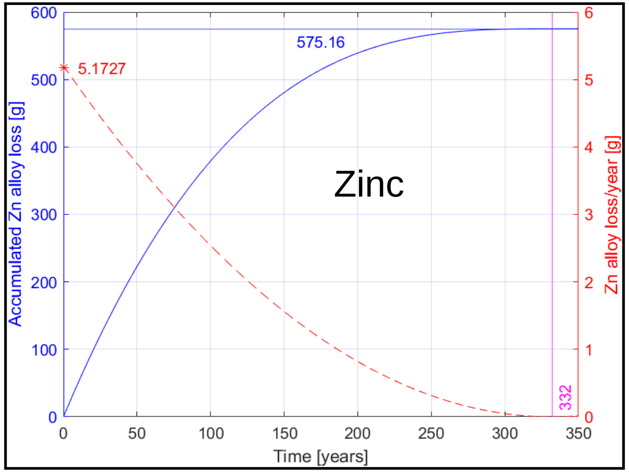
Same mass of material is found naturally in:

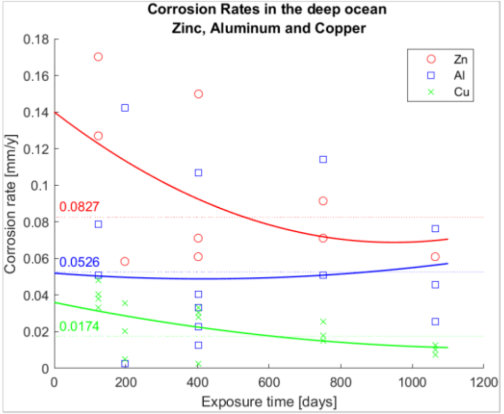
- Zinc → ~ 6 km^2 of ocean water
- Copper → ~ 8 km^2 of ocean water
- Aluminum → ~ 13 km^2 of ocean water

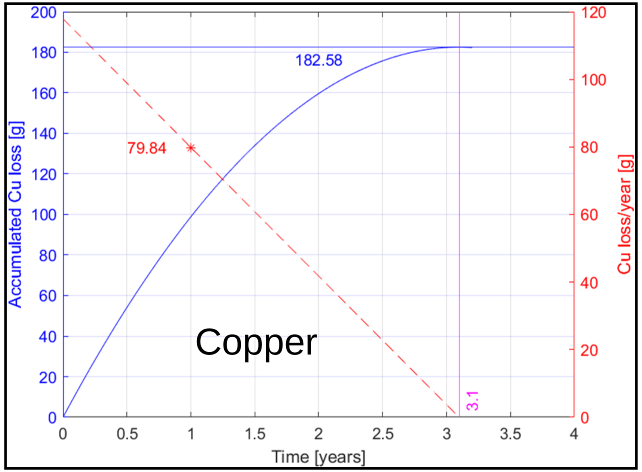
Considering minimum natural concentrations and an average depth of ~ 3.7 km (ngdc.noaa.gov)

Longevity of materials

- **Metal corrosion factors**: exposed surface, presence of other metals, oxygen, temperature, salinity, pH, salinity, sulfates, pressure, flow, marine biota.
- **Plastic breakdown factors**: UV energy (sun exposure), heat, mechanical stress (abrasion and pressure), chemicals, marine biota.
- **Estimated longevity**:
    - Zinc nose (+330 years) and Copper wire (+3 years) - Corrosion rates for deep ocean (Reinhart, 1976 ; Heiser, 1995)
    - ABS plastic 100 to 1,300 years years - (Turner et al., 2020)







Materials toxicity

National Recommended Water Quality Criteria

Aquatic Life Criteria Table (U.S. EPA, 2018 ; see also ANZECC & ARMCANZ, 2000)

- Zinc 90 µg/L (acute) - 81 µg/L (chronic)
- Copper 4.8 µg/L (acute) - 3.1 µg/L (chronic)
- Aluminum: No recommended values

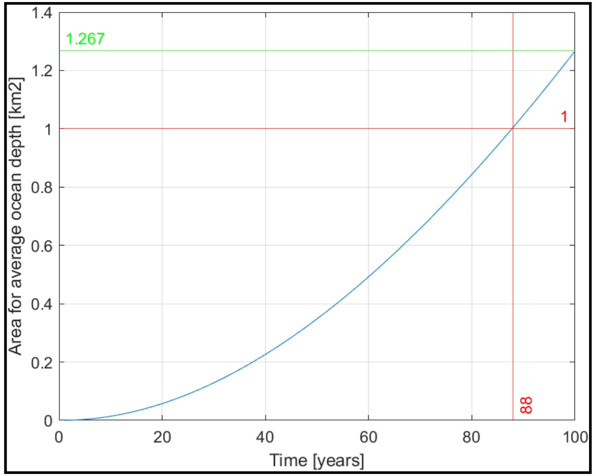
Concentrations not expected to pose a significant risk to the majority of species

Ocean	Volume [km3]	Average depth [m]	Average XBT/year	Time Zn [years]	Time Cu [years]
Atlantic	306,000,000	3,646	7,533	5.97E+09	6.88E+08
Indian	264,000,000	3,741	2,195	1.77E+10	2.04E+09
Mediterranean	4,390,000	1,480	330	**1.96E+09**	**2.25E+08**
Pacific	660,000,000	4,080	6,458	1.50E+10	1.73E+09

Earliest time: 225 Million years to reach dangerous concentrations (chronic)

At the current deployment rate (+16k XBT/year), all probes should be deployed inside a 1 km^2 section of the ocean, for 88 years, to reach dangerous concentrations of Zinc (XBT main material)

Area vs Time
(to reach dangerous concentrations)



XBT vs natural and anthropogenic flux

- **Zinc:** 17 to 66 Million metric tons enters the ocean each year (Neff, 2002)

- **Copper**: 2 Billion metric tons enters the ocean each year (Rauch & Graedel, 2007)

- **Aluminum**: 270 Billion metric tons enters the ocean each year (Van Hulten et al., 2013)

- **Plastic**: 4.8 to 12.7 million metric tons of plastic enters the ocean each year (Jambeck et al., 2015) and 10% is fishing gear, greatly harmful for marine species (Li et al., 2016). 80% comes from land – 20% from marine sources.

XBT vs Total input of materials into the ocean

Material	XBT mass [kg/year]	Total Earth cycle fluxes [kg/year]	Contribution of XBTs to the Total	Equivalent time of XBT operations [years]
Zinc	9,100	4.15E+07	2.19E-04	4,560
Copper	3,025	2.04E+09	1.48E-06	674,383
Aluminum	389	2.68E+11	1.45E-09	688,117,570
Metal oxide	81	N/A	N/A	N/A
Plastic	2,321	8.75E+09	2.65E-07	3,770,505
TOTAL	**14,916**	**2.79E+11**	**5.35E-08**	

Worst case: +4500 years of operations to input same amount than total Earth cycle

CO2 emissions reference

44 tn CO_2 eq for +16,500 XBT probes produced per year

=

Emissions of 9 passenger cars per year (US EPA)

=

Emissions of ~ 40 km traveled by an average container merchant vessel

=

~ 6.6 x10 $^{-7}$ % of the U.S. emissions in 2018 (6.7x10^{9} CO_2 eq tn) (US EPA)

In High Density mode ~ 20 km/XBT → 2 XBT deployed in 40 km
→ M/V underway produced same emissions than the annual production of +16k XBT materials

CO_2 eq XBT material production Cradle-to-Gate (Hammond & Jones, 2011)

Material	Mass per XBT [g]	Deployed mass [tn/year]	Emissions [tn CO_2e]
Aluminum	23.6	0.4	5.1
Copper	183.2	3.0	8.2
Zinc	551.0	9.1	28.1
ABS plastic	48.1	0.8	3.0
Total			**44.4**

M/V CO_2 eq emissions (International Maritime Organization, 2009)

Vessel type	Total efficiency [g CO_2 / tn-km]	DWT [tn]	Emission [tn CO_2 / km]
Container	12.5	94,600	1.2
Vehicle carrier	60.3	12,600	0.8

Observational platform comparison

- **Argo floats:** global array of temperature/salinity profiles up to 2 km of depth.
  - A complement to XBTs but can't reproduce the same data features (Riser et al., 2016; Goes et al., 2020)
  - 900 deployed per year inputs 28% more materials into the ocean (Riser & Wijffels, 2020) .
  - 0.1 kg/profile Argo vs 0.9 kg/profile XBT (but introducing lead, TBTO and lithium).
  - CO_2 production emissions are 5 times greater than for XBTs.

Argo float materials

Material	Mass per float [kg]	Mass per year [kg]
Copper	0.1	90
Zinc	0.1	45
Plastic	2.0	1,800
Lithium	0.2	180
Lead	0.8	720
TBTO	0.0	4
Metal oxide	-	-
Aluminum	18.0	16,200
Total	**21.15**	**19,039**

Highly toxic (Lead, TBTO)

14,916 kg for XBTs (78%)

CO_2 eq Argo material production
Cradle-to-Gate (Hammond & Jones, 2011)

Material	Mass per float [kg]	Mass per year [tn]	Emissions [tn CO_2e]
Copper	0.10	0.09	0.20
Zinc	0.05	0.05	0.10
Plastic	2.00	1.80	6.00
Lithium	0.20	0.18	1.00
Lead	0.80	0.72	1.20
TBTO	<0.01	<0.01	N/A
Aluminum	18.00	16.20	212.20
Total			**220.7**

44.4 tn for XBTs

Other sources of pollution

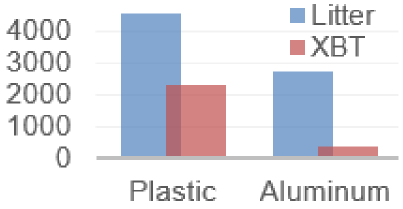
✓ The scientific value of instrumentation deployed outweighs the fact that its materials are lost.

✗ Materials that have no other purpose than the mere disposal thereof ("dumping" →UNCLOS, 1994).

Litter: cigarette filters are the most common plastic found on beaches worldwide (US Ocean Conservancy) and are extremely toxic due to chemical contents (Slaughter et al., 2011).

Main collected items in the US coast Sept 2019 – Sept 2020 (TIDES program - coastalcleanupdata.org, 2020):

- Cigarette filters → +1M items (~ 170 kg) / year
- Aluminum cans → +160k items (~ 2,720 kg) / year
- Plastic bottles and caps → +230k items (~ 4,730 kg) / year



Shipwrecks: +3M globally potentially releasing 2.5 to 20.4 million tonnes of oil (UNESCO; Whittington et al., 2017)

Irma Hurricane (2017) → +1,800 shipwrecks in Florida Keys (Guertin, 2019) → ~ 41,000 kg of debris (vs 15,000 kg XBT)

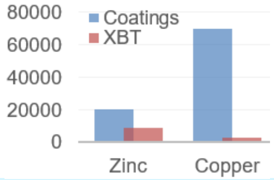
Coatings: great source of microplastics concentrated in shipyards and marinas → 0.5kg/m^2 hull cleaning waste (IMO)

Case study (Daehne et al., 2017) → ship coating waste from +200k leisure boats in Germany

→ Release 70 tn copper, 20 tn zinc, 10 tn biocides per year (Germany).

→ 11M leisure boats registered per year in the US (US Coast Guard report, 2017)

x55



Conclusion

- XBTs provides an invaluable dataset of +50 years.
- Simple system and inexpensive way of collecting data with spatial and time scales not possible to accomplish with other platforms.
- Takes advantage of M/V routes → operations do not generate extra CO_2 emissions.
- Materials don't represent any significant hazard to marine environment, remaining on the seabed with minimum interaction with surface marine life.
- Worst case scenario → dangerous concentrations of metals would be reached in 225 million years of operations.
- Dangerous metal concentrations would be reached over 88 years of operations if deploying ALL in 1km^2 of ocean.
- XBT mass deployed is so small in comparison to natural fluxes that more than 4,500 years of operations are needed generate same amount of waste (than in a year of natural fluxes).
- Plastic input represents only 2.7×10^{-7} compared to total plastic that enters the ocean annually, and microplastics are an issue at the surface whereas XBT plastics remain buried at the seabed.
- A single year of plastic bottles and caps collected along the US coast doubles the plastic deployed with XBTs.
- CO_2 emissions of material production → small fraction and equivalent to the annual emissions of 9 passenger cars.
- Compared to other platforms such as Argo floats → XBTs currently inputs 78% of mass and 25% CO2 material production emissions, and do not release lead, lithium or antifouling materials (TBTO).
- XBTs do not represent any hazard to the marine environment, and relative to other sources its impact is far too small to be considered a risk or a greater issue than other human activities in the ocean.