Revisiting five decades of ^{234}Th data: a comprehensive global oceanic data base

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Introduction

^{234}Th is one of the **most actively used tracers** in oceanography (specially for particle "scavenging") Basic concepts:

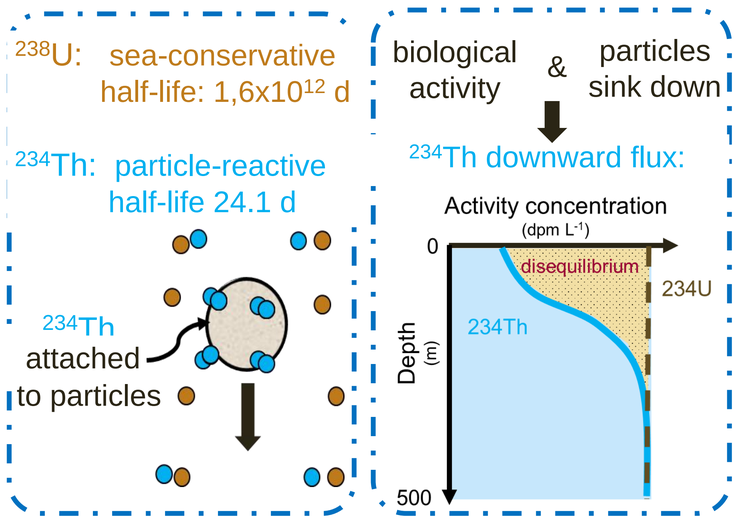


Figure 1. (a) Schematic view of the particle reactive nature of ^{234}Th relative to ^{238}U, and (b) Theoretical ^{238}U-^{234}Th profile in depth.

Data organization

1) **Metadata**

Field name	Field description
Project_Name	E.g., GEOTRACES…
Cruise_ID	Cruise/expedition name
Ship	Research vessel
Chief_Scientist	Cruise Principal Investigator
Region	Ocean of sampling
Period	Cruise initial and final dates
238U	Yes/No
Total_234Th	Yes/No
Particualte_234Th	Yes/No
POC_234Th_ratio	Yes/No
Size_class(es)	number(s) in µm
238U_methods	measured/salinity-derived
Total_234Th_method	brief details
Particualte_234Th	traps/pumps/etc.
234Th_underway	Yes/No
Sediment_traps	Yes/No
210Pb-210Po	Yes/No
CHN	Yes/No
Publication	Yes/No
Journal	Journal of publication
Year	Year of publication
DOI	Digital Object Identifier
Data_localization	Figure/Table/Appendix
Data_resource	url, personal communication…

2) **Data** compiled for each dataset

Field name	Field description
cruise_ID	Cruise/expedition name or number
station_ID	Station name or number
lat_decimal	North latitude in decimal degrees (from - 90 to +90)
lon_decimal	East longitude in decimal degrees (from -180 to +180)
region	*Longhurst* Ocean province of sampling [1]
month	Month of sampling
day	Day of sampling
year	Year of sampling
DOY	Day-Of-Year number
bottom_depth(m)	Bottom depth at station location in meters
depth(m)	Sampling depth in meters
temperature	In situ temperature in degrees centigrade
salinity	Sample salinity in PSU
238U(dpm/L)	Uranium-238 concentration in dpm L^{-1}
total_234Th(dpm/L)	Total Thorium-234 concentration in dpm L^{-1}
diss_234Th(dpm/L)	Dissolved Thorium-234 concentration in dpm L^{-1}
method	Particles sampling method (TRAPS or PUMPS)
depth_real_particle(m)	Particle sampling depth in meters
filter_size(um)	Particle filter size in µm (for two sizes if available)
part_234Th(dpm/L)	Particulate Thorium-234 concentration in dpm L^{-1}
POC(umol/L)	Particulate Organic Carbon concentration in µm L^{-1}
POC:Th(umol/dpm)	POC to ^{234}Th content in sinking particles in µmol dpm^{-1}
PON(umol/L)	Particulate Organic Nitrogen concentration in µm L^{-1}
PON:Th(umol/dpm)	PON to ^{234}Th content in sinking particles in µmol dpm^{-1}

Data availability

Ken Buesseler's lab website: Café Thorium

https://cafethorium.whoi.edu/

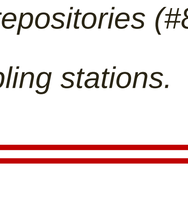
- **Full list** of references
- **Datasets** complied
- Dataset **template**

PANGAEA

❯ Open access: *"Ocean thorium data from around the world"*

Aiming for a collaborative compilation:

Help us to expand the compilation by including new ^{234}Th datasets!



^{234}Th timeline

Era 1

1969 — Initial measurement of total ^{234}Th [2]

Two methods for ^{234}Th extraction
- co-precipitated with $Fe(OH)_3$ from 20-30L sea-water samples and beta-counted [3]
- adsorbed on MnO_2 cartridges from 1000–4000 L samples and gamma-counted [4]

1984 ❯ initial analysis of particualte and disolved ^{234}Th [3]

1985 ❯ link between biological processes and ^{234}Th deficits clearly demonstrated [5,6,7]

JGOFS Era (*U.S. Joint Global Ocean Flux Study*)

1987

1988 — 2 long-term time-series projects: *BATS*, Atlantic (Bermuda) & *HOT*, Pacific (Station ALOHA)

1989 ❯ ^{234}Th proposed to trace export production [8]

Era 2

1992 — Empirical method to estimate carbon flux [9]: $POC_{flux}(z) = 234Th_{flux}(z) \times POC:234Th\ (z)$

1996 ❯ beginning of the expansion of the Th-approach to other elemental fluxes [10]

1999 ❯ MnO_2 co-precipitation technique for ^{234}Th from 20L of sewater [11]

2001 — Introduction of the small-volume (2-4L) technique [12,13]

Era 3

2003

2004 — *VERTIGO* study (*Vertical Transport In the Global Ocean*)

2005 ❯ introduction of double spike approach [14]

Era 4

2010 — *GEOTRACES* international research programme

2012 ❯ ^{234}Th intercalibration and standard studies (derived from *GEOTRACES*) [15]

2014 — 1st GEOTARCES Intermediate Data Product (IDP)

2017 — 2nd GEOTARCES IDP

Era

2018 — Dedicated large-scale collaborative projects
- EXPORTS (US, 2017-2022): NP& NA
- COMICS (UK, 2017-2021): NA & SO

More details, data analyses and data use perspectives in an incoming article!

Ceballos, E.; Buesseler, K.; Villa, M. Revisiting five decades of ^{234}Th data. Earth System Science Data. In review.

Scope and nature of the compilation

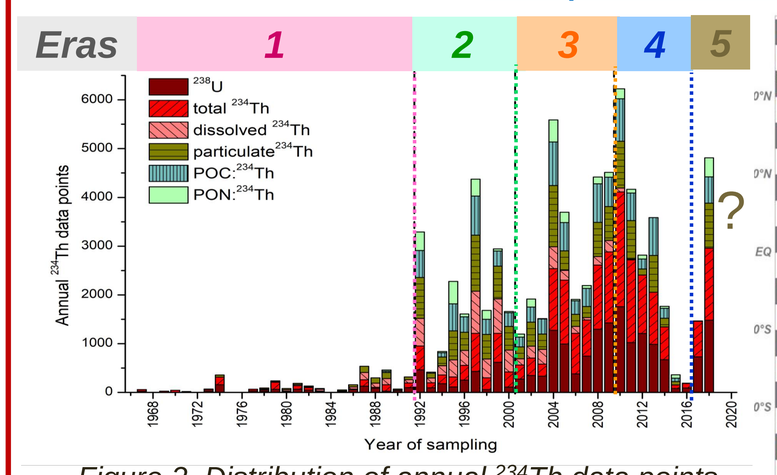


Figure 2. Distribution of annual ^{234}Th data points.

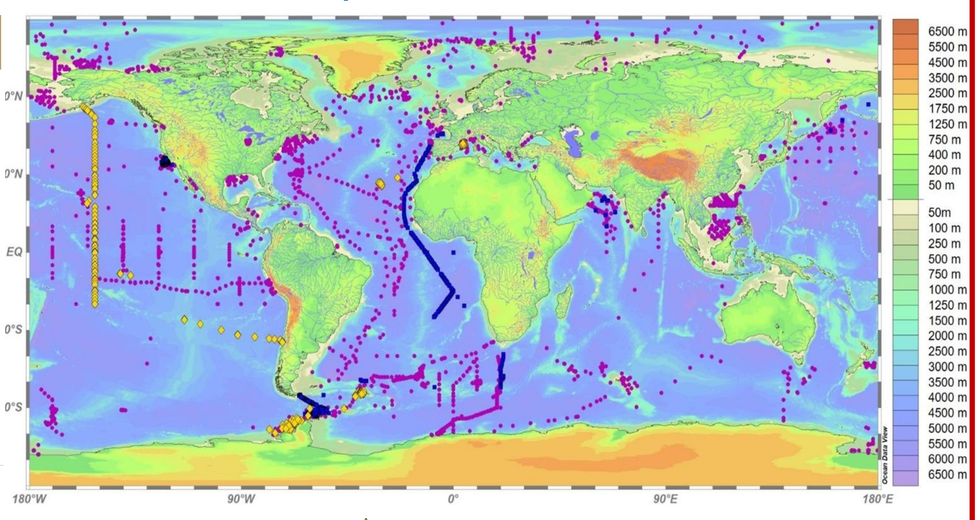


Figure 3. Map showing the distribution of sampling stations.

cruises: 379

locations: 5134

total ^{234}Th: 2,1458
dissolved: 6,591
particulate: 13,955

Towards a better understanding of oceanic carbon uptake: data use perspectives

This treasure of data opens many future studies:

- ➢ better evaluation of global parameters: e.g., fluxes (POC, PIC, BSi), or particle export efficiency (POC exported relative to Primary Production),
- ➢ analysis of steady (SS) versus non-steady states (NSS) conditions,
- ➢ re-evaluation of ^{234}Th-derived POC fluxes,
- ➢ seasonal comparison of export estimates,
- ➢ regional studies of the temporal evolution of the strength of the BCP…

[16] The *SS* predicts the export during specific time frames, while the *NSS* along the entire season (for the correct re-occupation time)

⬇

concept of *WOS* (*Windows Of Success*)

affected by:
- temporal variability of the bloom
- methodological uncertainties

⬇

The accuracy of the available ^{234}Th-SS-derived export estimates need to be assessed

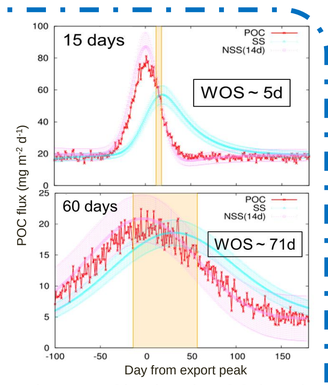


Figure 4. Simulated WOS length for blooms of 15 and 60 days duration.

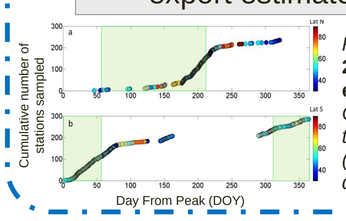


Figure 5. **Qualitative hint of the proportion of the 234Th-SS-derived export estimates currently employed that might be biased.** *Compilation of stations sampled with ^{234}Th from temperate and polar latitudes by hemisphere (North (a) and South (b). Shaded areas indicate time frames during which bloom conditions are found in [17].*

References

[1] Longhurst, 2006. *Elsevier Inc*.; [2] Bhat et al., 1969. *Earth Planet. Sci. Lett*. 5, 483–491; [3] Mann et al., 1984. *Nucl. Instrum. Methods Phys. Res*. 223, 235–238; [4] McKee, et al., 1984. *Earth Planet. Sci. Lett.*, 68(3), 431-442; [5] Coale and Bruland 1985. *Limnol. Oceanogr*. 30, 22-33; [6] Bruland and Coale 1986. *Springer US*, Boston, MA; [7] Coale and Bruland 1987. *Limnol. Oceanogr*. 32, 189-200; [8] Eppley et al., 1989. *John Wiley*, New York; [9] Buesseler et al., 1992.. *Deep-Sea Res*. 39, 1115-1137; [10] Bacon et al., 1996. *Deep-Sea Res. II*, 43(4-6); [11] Rugters van der Loeff and Moore 1999. *Verlag Chemie*, Weinheim, pp. 365–397, Ch. 13; [12] Buesseler et al., 2001. *Marine Chem.* 74(1), 15-28; [13] Benitez-Nelson et al., 2001. *J. Radioanal. Nucl. Chem*. 248, 795-799; [14] Pike et al., 2005. *J. Radioanal. Nucl. Chem*. 263, 355-360; [15] Maiti et al., 2012. *Limnol. Oceanogr*.: *Methods*.10(9), 631-644; [16] Ceballos-Romero et al., 2018. *Geophys. Res. Lett.* 45(24), 414-426; [17] Cole et al., 2012. *Journal of Geophys. Res.: Oceans.* 117 (C8).