Long range transport of radiocaesium derived from global fallout and the Fukushima accident in the ocean interior of the Pacific Ocean since 1960s through 2017

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EGU2020-3175

8 May 2020, EGU2020 online

Presentation outline

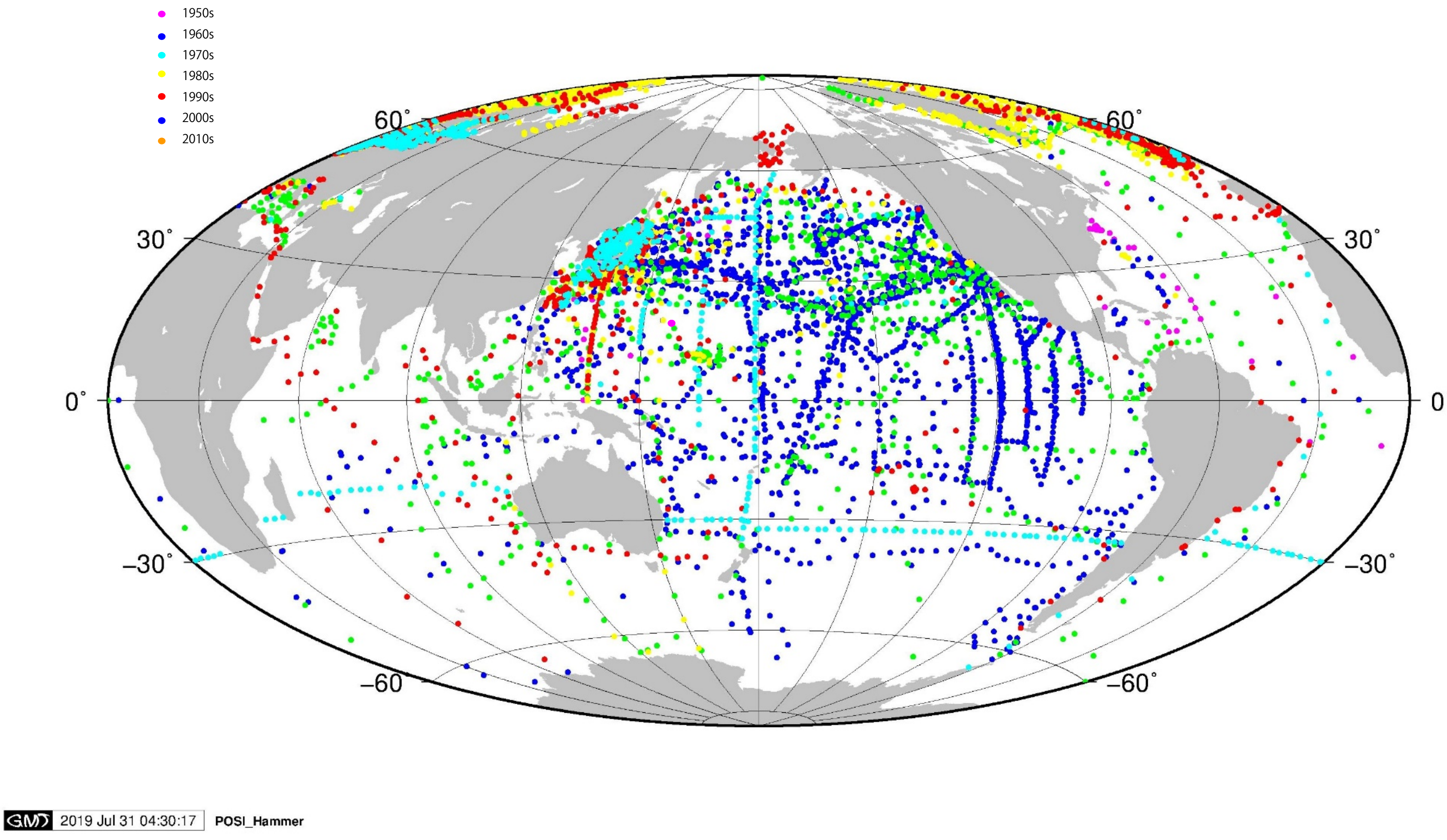
- HAM global 2018 database used in this study.
- Source term, monthly deposition of 137Cs in Japan
- Five sections along 165 deg. E since 1960s
- Temporal change of vertical profiles in the North Pacific Ocean
- Conclusions

HAM Database and reconstruction of 165 deg. E section in 1960s and 1970s

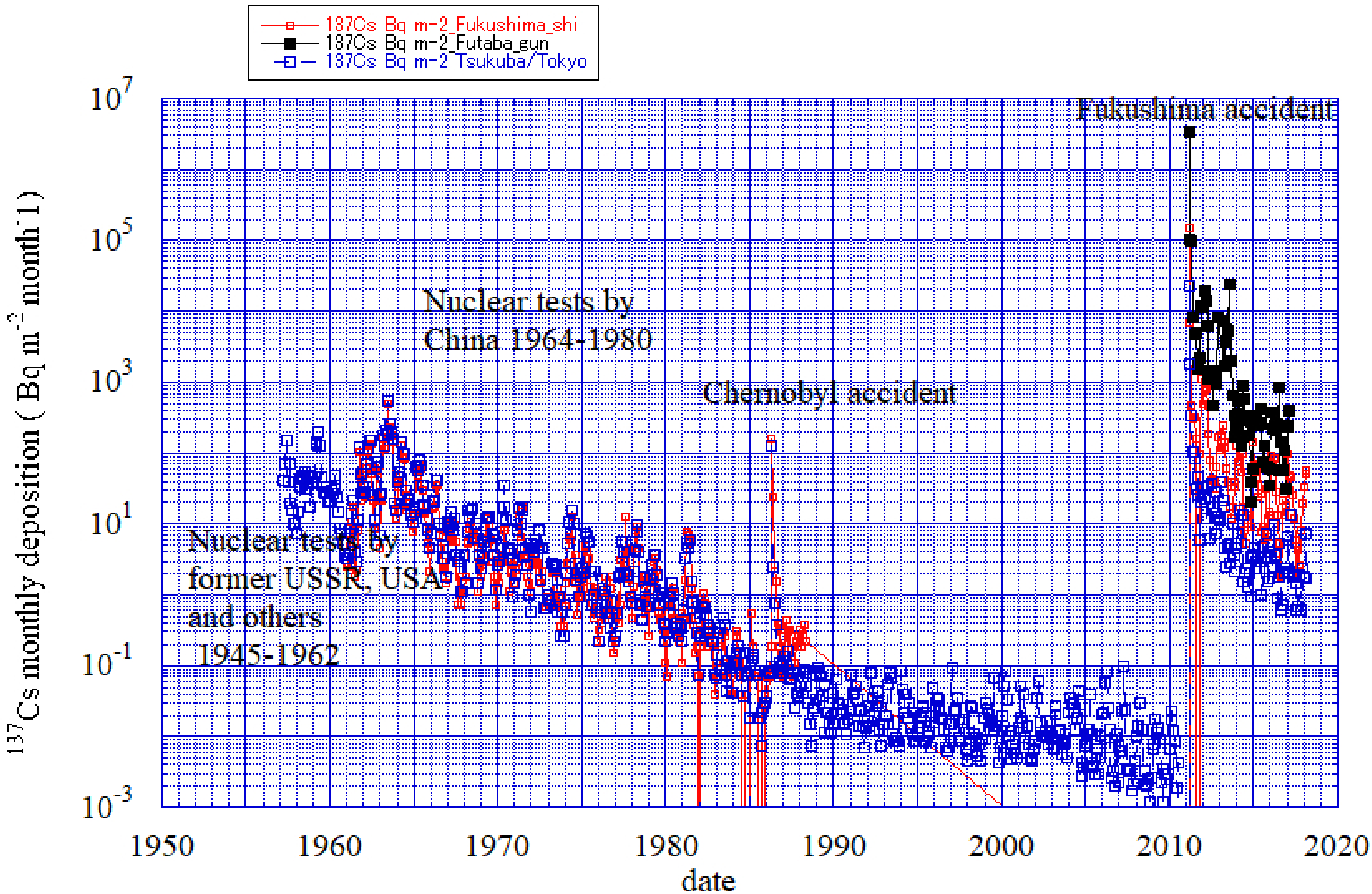
- To establish a database for artificial Radionuclides in the marine environment is important to understand the impact of artificial radionuclides to human. The details of the HAM database and its update was described in part 1 of this article. In this study, we reconstruct ^{137}Cs activity concentration sections for 1965-1968 and 1970-1973 to understand initial conditions of ^{137}Cs activity concentration in ocean interior just after large atmospheric fallout in the early 1960s and ca. 10 years after injection.

HAM global 2018 database

This dataset is already published at doi: 10.34355/CRiED.U.Tsukuba.00001 (Aoyama, 2019)



Temporal change of monthly deposition of ^{137}Cs at Tokyo/Tsukuba, Fukushima-Shi and Futaba-Gun

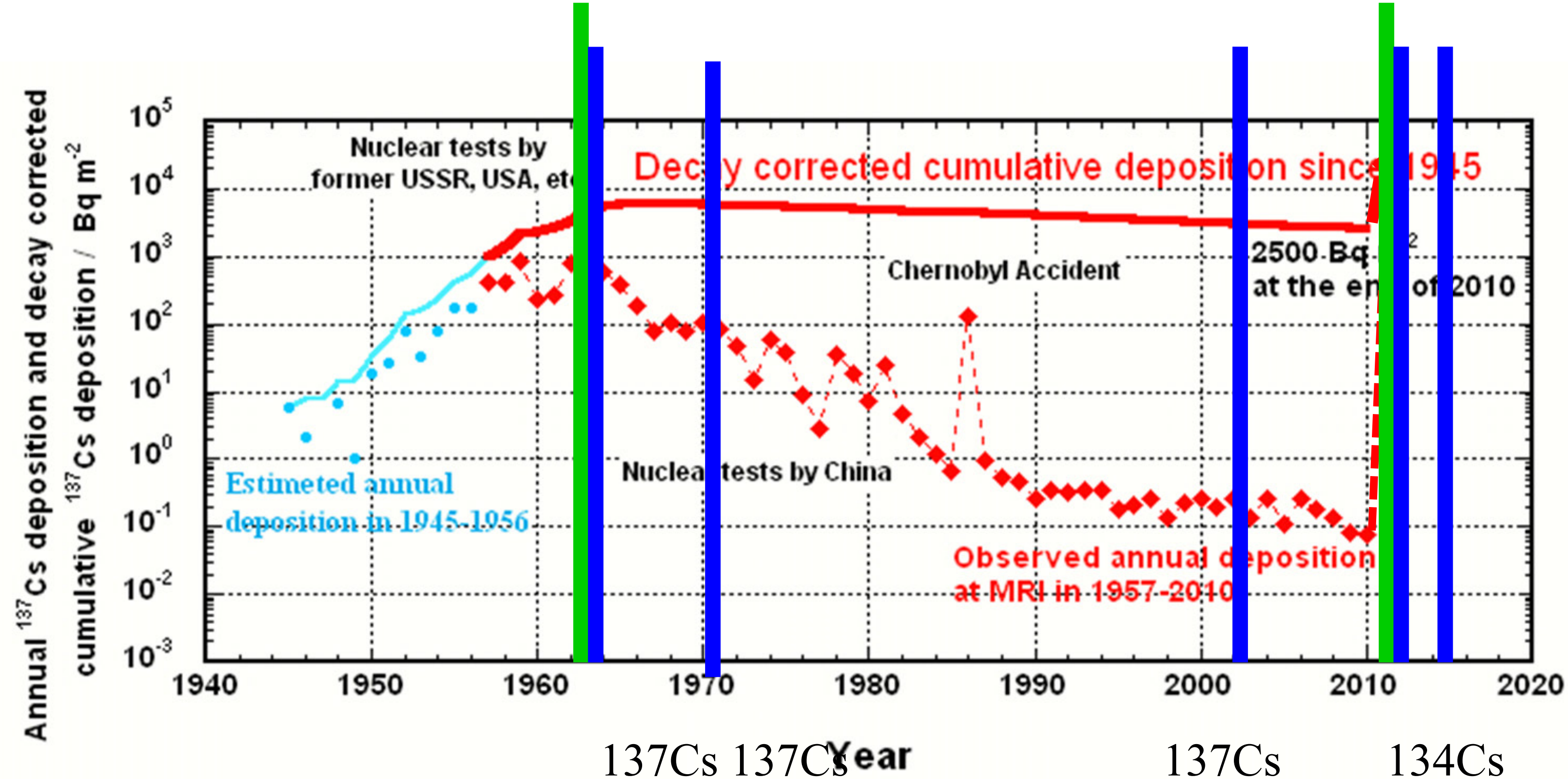


Aoyama, 2019, Kagaku July 2019, Iwanami, in Japanese

Major injections occurred in 1963 and 2011

Observations were done in 2002, 2012 and 2015

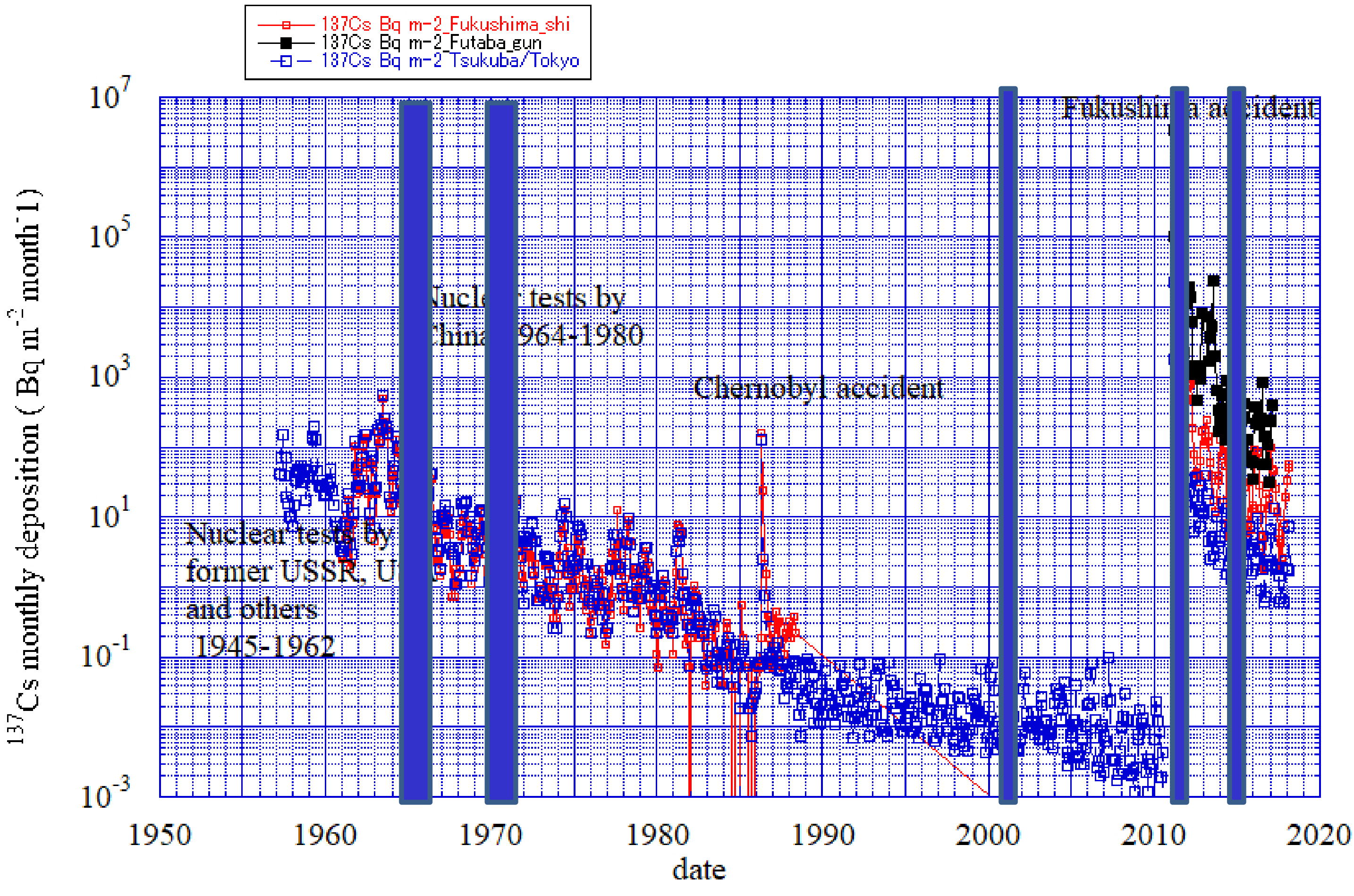
We reconstructed two sections for 1965-1968 and 1970-1973 using HAM databse global 2018.



137Cs 137Cs 137Cs 134Cs

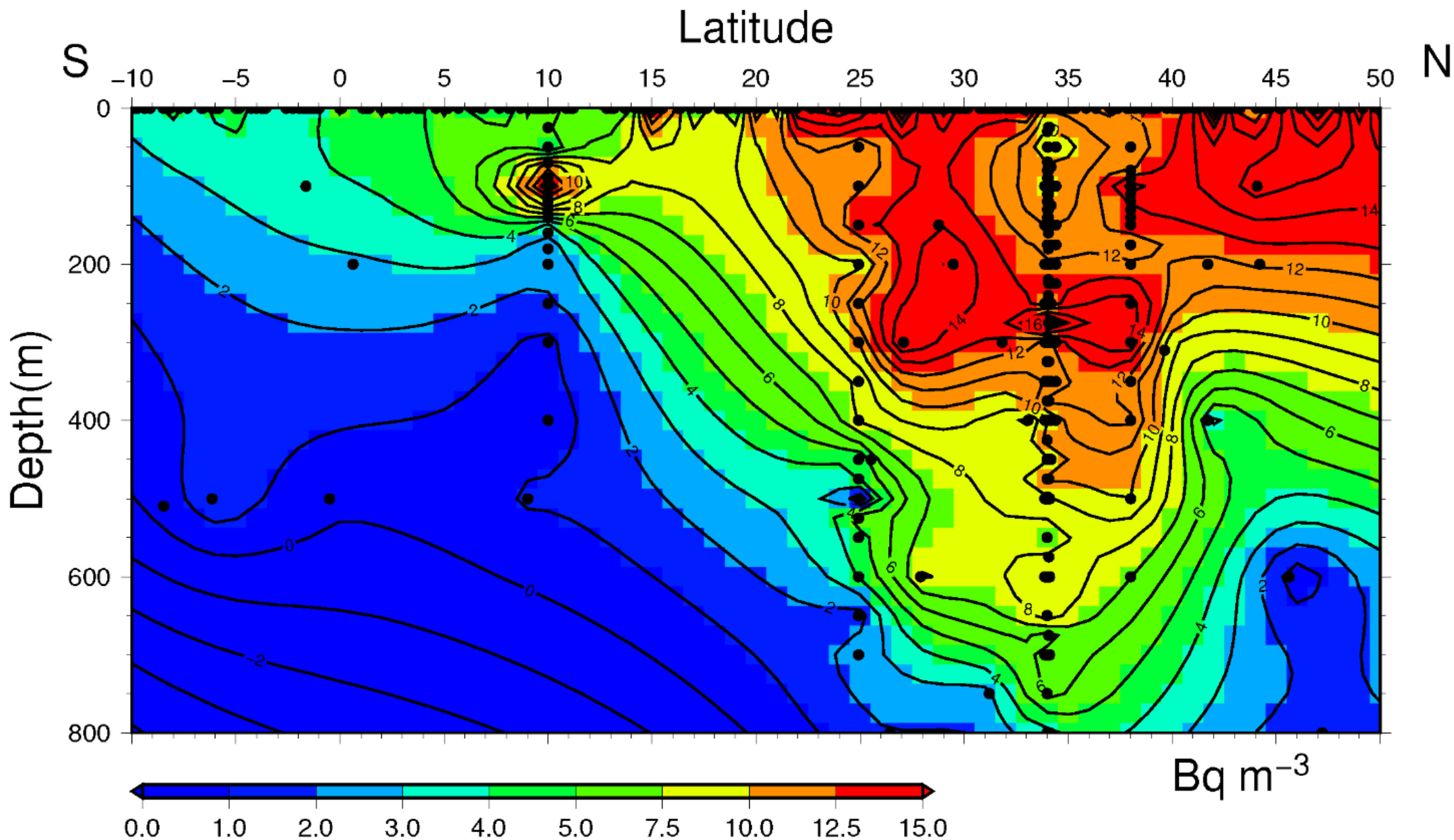
4.5 years 8.5 years 39 years 1 & 4 years

So, we show five sections, 1965-1968, 1970-1973, 2002, 2012 and 2015 along 165 deg. E.



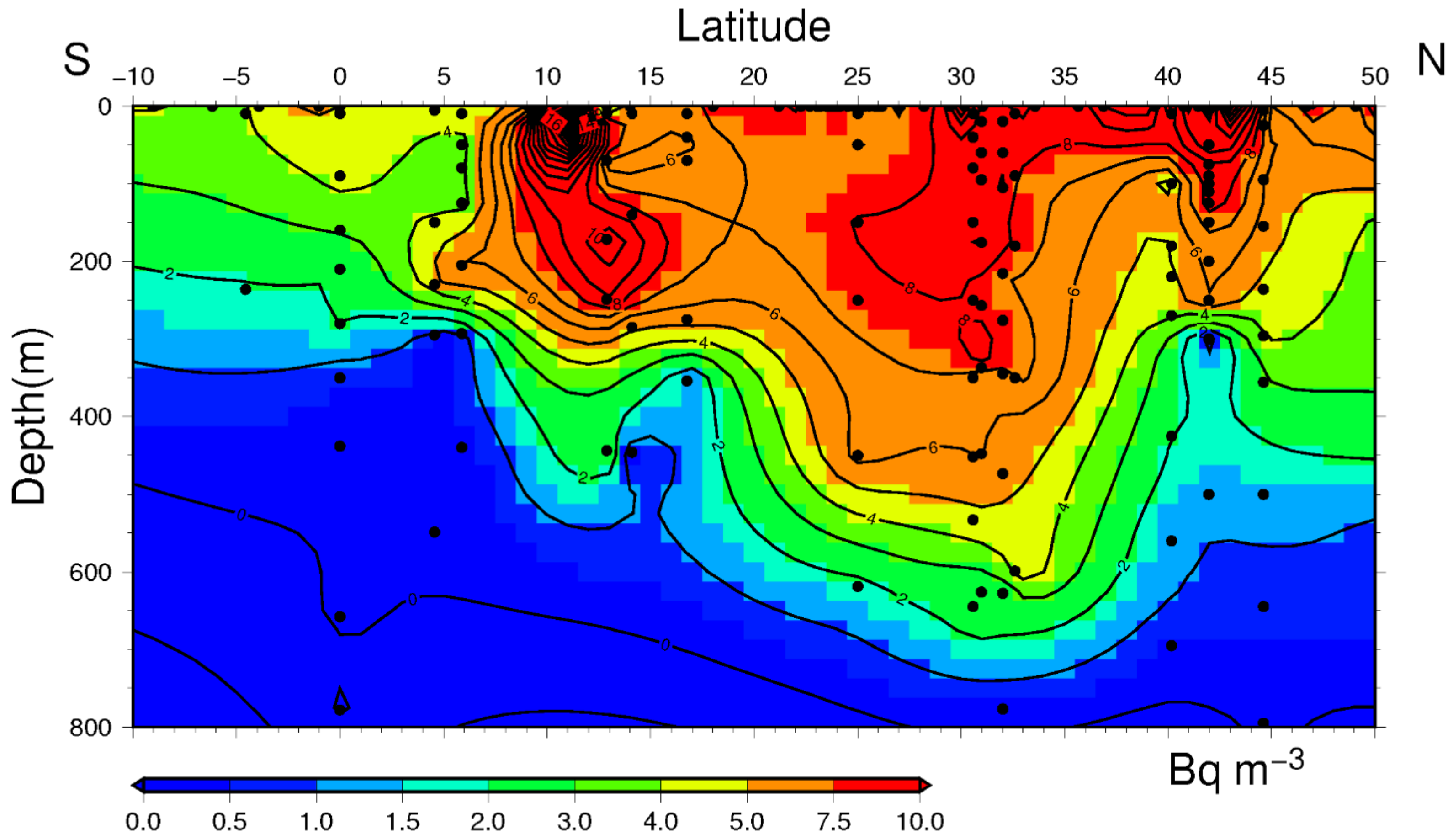
Aoyama, 2019, Kagaku July 2019, Iwanami, in Japanese

Figure 1. Reconstructed section of fallout 137Cs activity in seawater along 165 deg. E (between 160 deg. E and 163 deg. W) in 1965-1968 as depth coordinate.



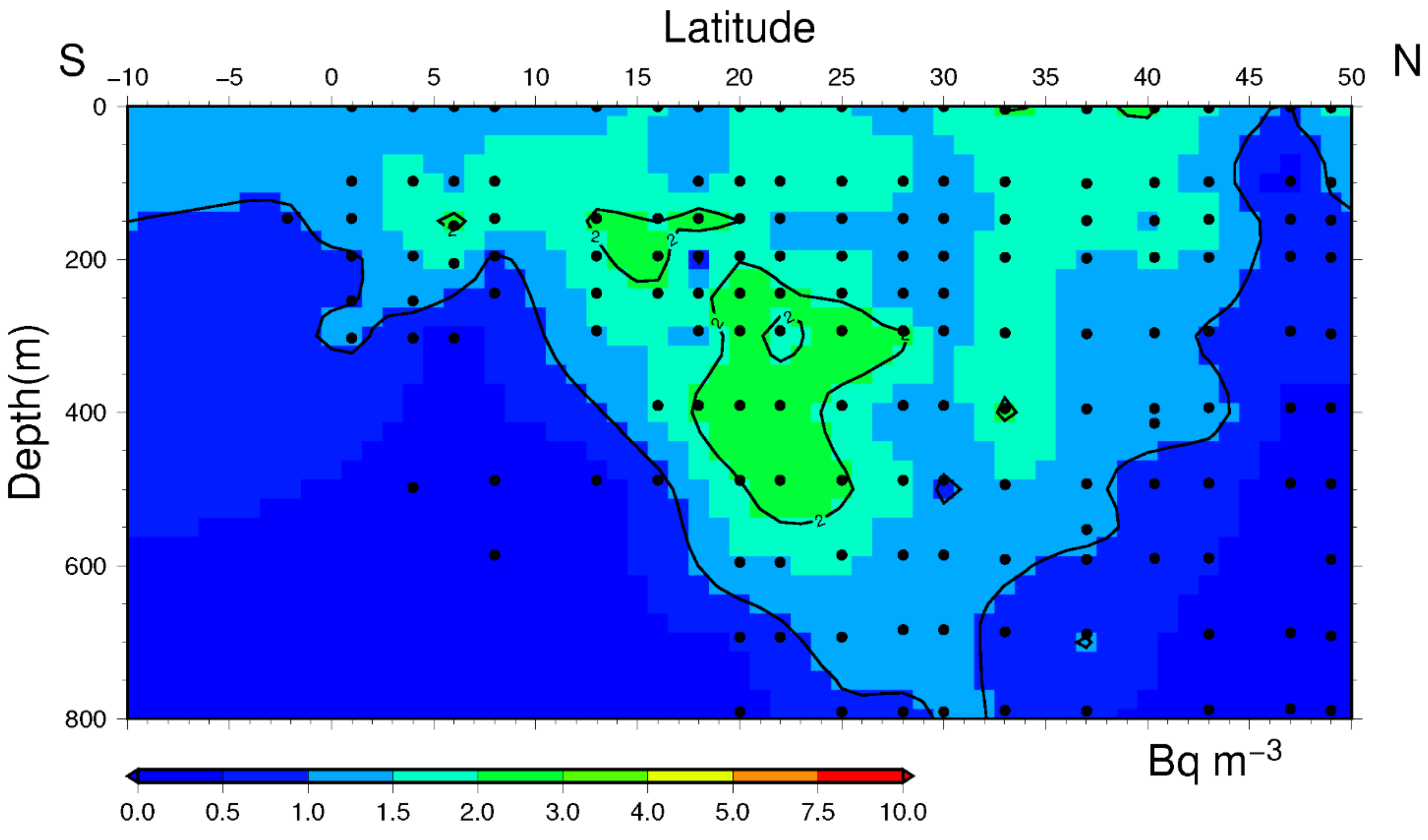
- Basic feature of radiocaesium distribution along 165 deg. E section in 1965-1968 was dome shape distribution of which deepest places were around 30-40 deg. N and of which maximum depth were around 600-800 meters depths. The penetration of ^{137}Cs is found less than 800 m depth, associated with the bowl shape of isopycnals in the mid-latitude region. In general, the ^{137}Cs activity concentrations in the subsurface and intermediate water of the mid-latitude region of the western North Pacific were higher than those in surface waters of the subtropical and equatorial Pacific. On the other hand, ^{137}Cs activity concentrations in surface waters of the subarctic Pacific were higher than in the subsurface and intermediate waters.
- At around 34-38 deg. N, we observed ^{137}Cs activity concentration maxima, at 250- 300 m depth, CMW region, in 1965-1968 of which 137Cs activity concentration was around 16 Bq m^{-3}, highest among this section (Figure 1). At around 38-45 deg. N, we observed 137Cs activity concentration was uniform from the surface to 100 meters depth by vertical mixing and ^{137}Cs activity concentration was around 10-14 Bq m^{-3} which is lower than CMW region maximum of 16 Bq m-3. At around 25-30 deg. N, we observed ^{137}Cs activity concentration maxima, at 200- 300 m depth, STMW region, of which ^{137}Cs activity concentration was around 14 Bq m^{-3}, also which is lower than CMW region maximum of 16 Bq m^{-3}. (This study)

Figure 2. Reconstructed section of fallout 137Cs activity in seawater along 165 deg. E (between 160 deg. E and 165 deg. W) in 1970-1973 as depth coordinate.



- Typical feature of a section in 1970-1973 along 165 deg. E was a southward movement of ^{137}Cs which make wider dome shape distribution of which deepest places were around 30-35 deg. N and of which maximum depth were around 600- 700 meters depths. It should be noticed that the ^{137}Cs activity concentrations in the subsurface and intermediate water of the subtropical region around 10-15 deg. N in the western North Pacific, where ^{137}Cs activity concentration was up to 16 Bq m^{-3}. This higher activity concentration was highest along 165 deg. E. This indicated that the southward movement of ^{137}Cs together with STMW might be the main cause of this phenomenon. (This study)

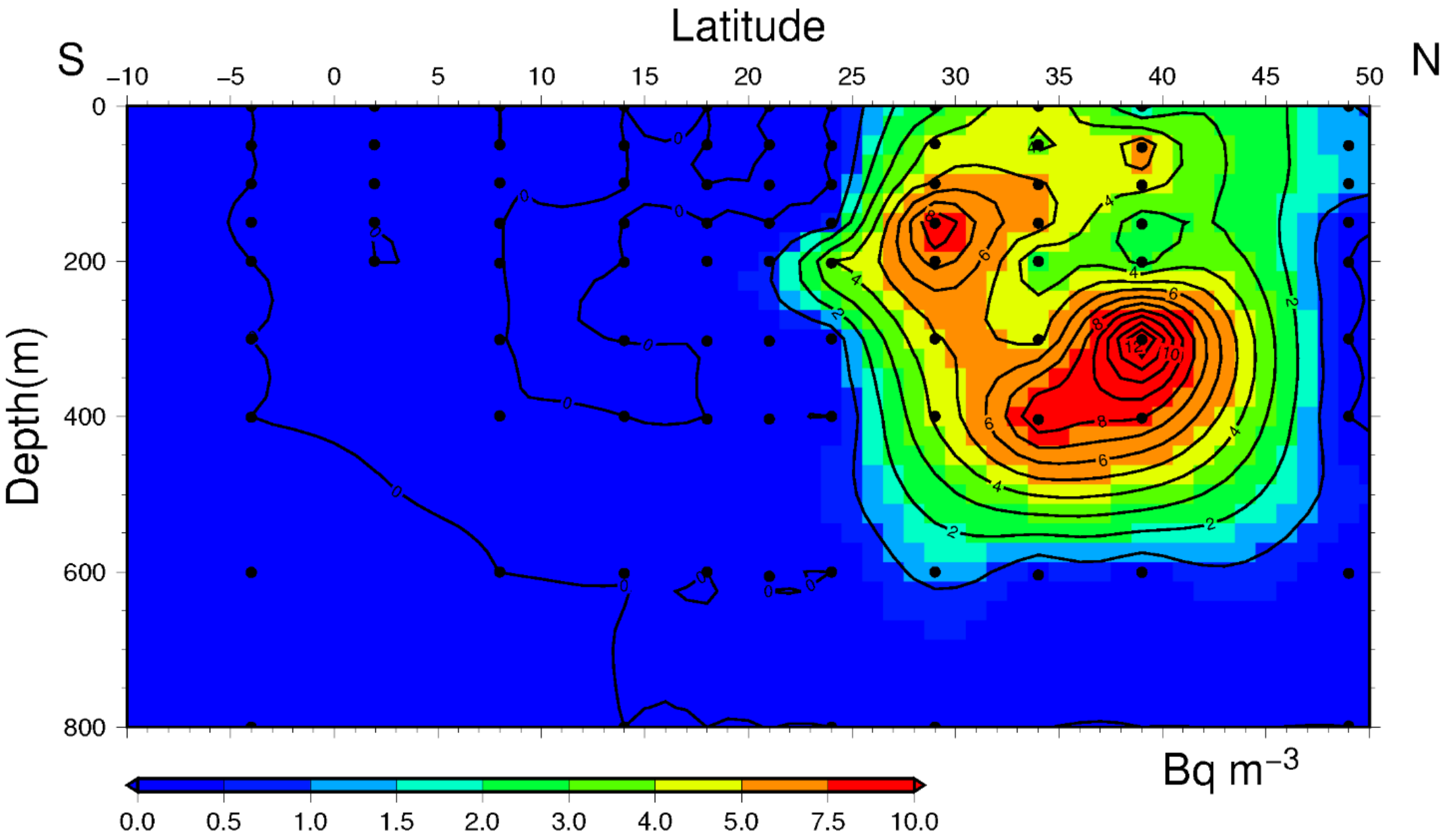
Figure 3. Section of fallout ^{137}Cs activity in seawater along 165 deg. E in 2002 as depth coordinate.



In 2002, at around 200N, we observed two ^{137}Cs activity concentration maxima, at 250 m and 400 to 500 m depth . A third maximum occurred at around 200-m depth from 60N to 160N in the subtropical and equatorial Pacific, and a fourth relatively lower maximum occurred at 400-m depth in the midlatitude region (35 deg. N). A third maximum occurred at around 200-m depth from 60N to 160N in the subtropical and equatorial Pacific (Figures 3), and a fourth relatively lower maximum occurred at 400-m depth in the midlatitude region (35deg. N). We consider the most pronounced core of high ^{137}Cs, at 400- to 500-m depth at around 20 deg. N, to be the water mass labeled with ^{137}Cs from global fallout in the early 1960s. The ^{137}Cs activity concentration at this core in 2002 was around 2 – 3 Bq m^{-3} and the start of moving in 1963-1965 was 16 Bq m^{-3} which indicates only one third of dilution occurred during about 40 years travel in the ocean interior as CMW.

(Aoyama M, Hirose K, Nemoto K, Takatsuki Y, Tsumune D. Water masses labeled with global fallout137Cs formed by subduction in the North Pacific. Geophysical Research Letters. 2008;35(1):L01604.)

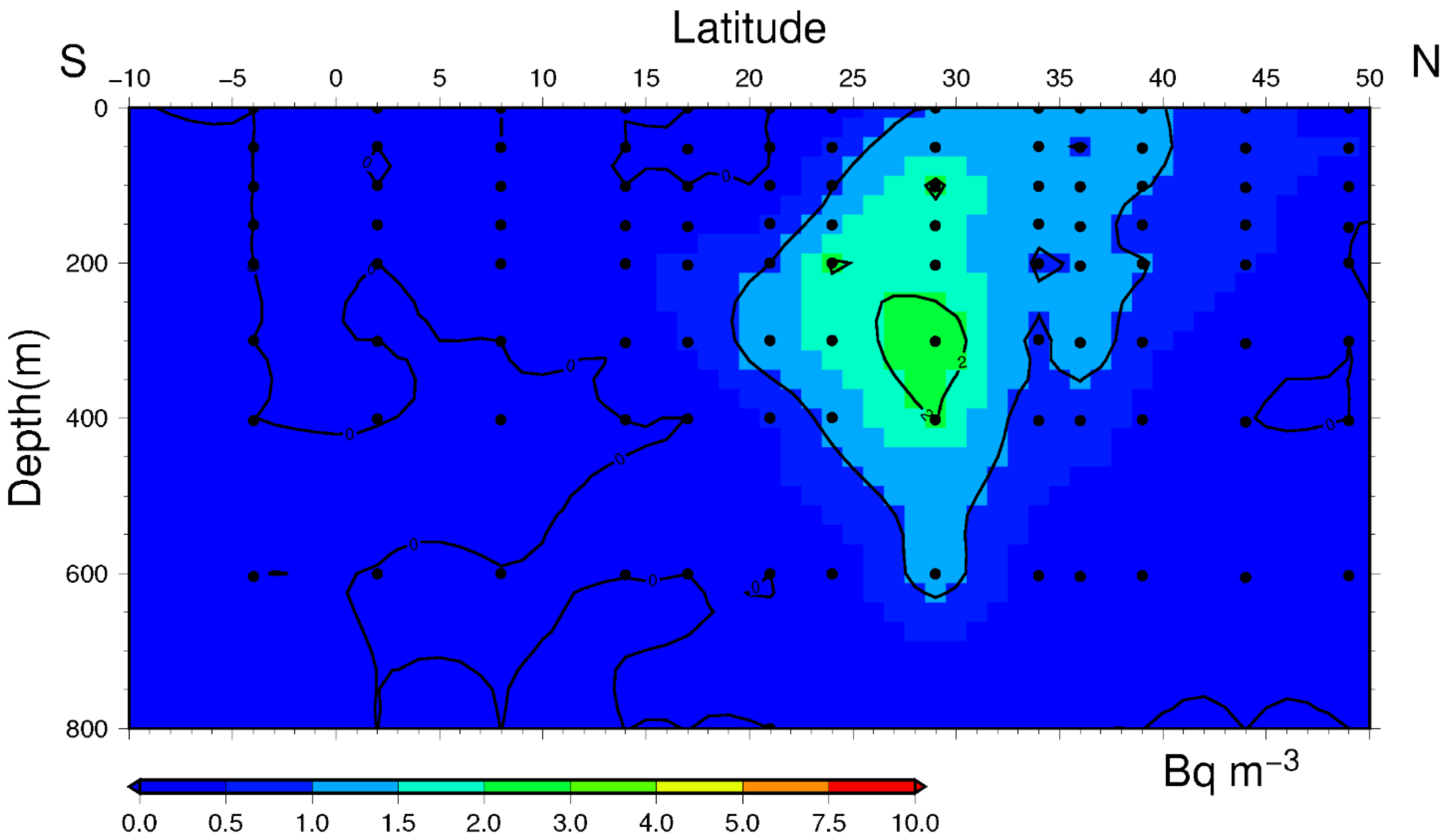
Figure 6. Section of Fukushima accident derived ^{137}Cs (same as ^{134}Cs) activity in seawater along 165 deg. E in 2012 as depth coordinate.



- We observed two cores in the 137Cs section which corresponded to STMW and CMW. In June 2012 at 29°N, 165°E, maximum ^{134}Cs activity (6.12 ± 0.50 Bq m^{-3}) was observed at 151 m depth (σ_ϑ = 25.3) corresponding with STMW. After the Fukushima accident in March 2011, radiocaesium released from the accident site was subducted and transported to southward during 15 months.
- At 34°N, 165°E and 39°N, 165°E, ^{134}Cs activity concentration reached a maximum in June 2012 at around σ_ϑ = 26.3 corresponding with CMW. ^{134}Cs activity concentration at 301 m depth at 39°N, 165°E was 9.18 ± 0.71 Bq m^{-3} and that at 404 m depth at 34°N, 165°E was 6.20 ± 0.44 Bq m^{-3}, respectively. Therefore maximum activity concentration along 165 deg. E was observed at 301 m depth at 39°N, 165°E.

(Aoyama M, Hamajima Y, Hult M, Uematsu M, Oka E, Tsumune D, et al. 134Cs and 137Cs in the North Pacific Ocean derived from the March 2011 TEPCO Fukushima Dai-ichi Nuclear Power Plant accident, Japan. Part one: surface pathway and vertical distributions. Journal of Oceanography. 2016;72(1):53-65.)

Figure 7. Section of Fukushima accident derived ^{137}Cs (same as ^{134}Cs) activity in seawater along 165 deg. E in 2015 as depth coordinate.

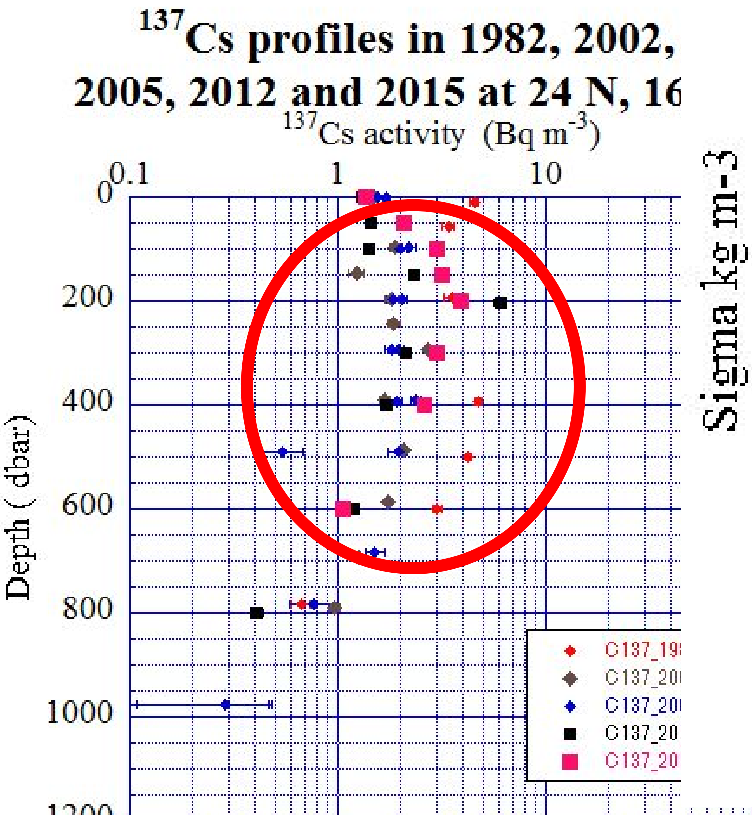


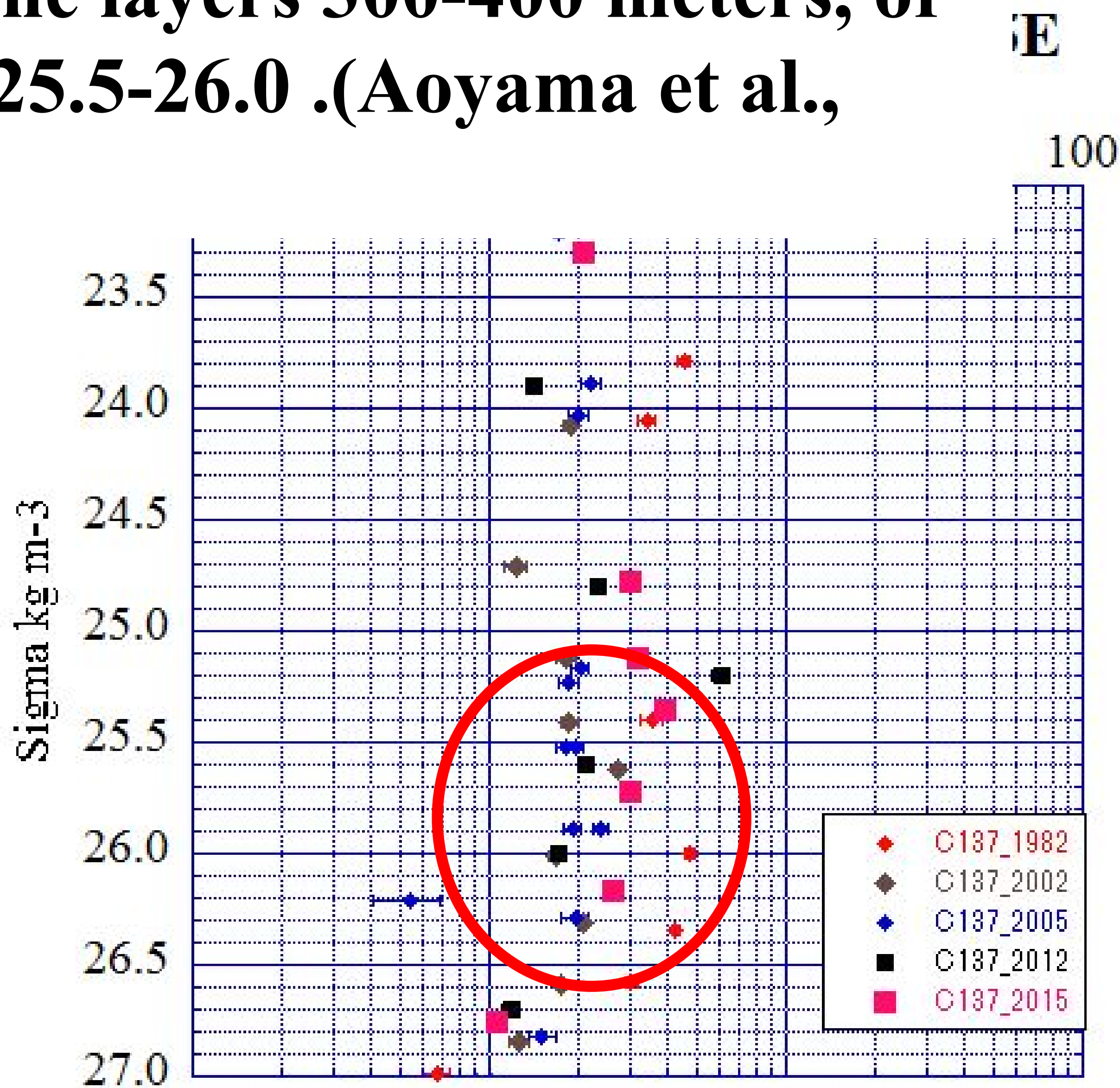
- We observed only a core in the ^{137}Cs section which corresponded to STMW at 29.00 deg. N, 165.00 deg. E at 301 m depth (σ_ϑ =25.54) where ^{134}Cs activity concentration was 0.7±0.09 Bq m-3 and ^{137}Cs activity concentration was 3.67±0.2 Bq m^{-3}, respectively.
- The core corresponded to CWM which was observed in the 2012 section was not observed in the 2015 section because the core corresponding to CWM was transported to the east.

(This study)

Temporal change of vertical profiles in the North Pacific Ocean

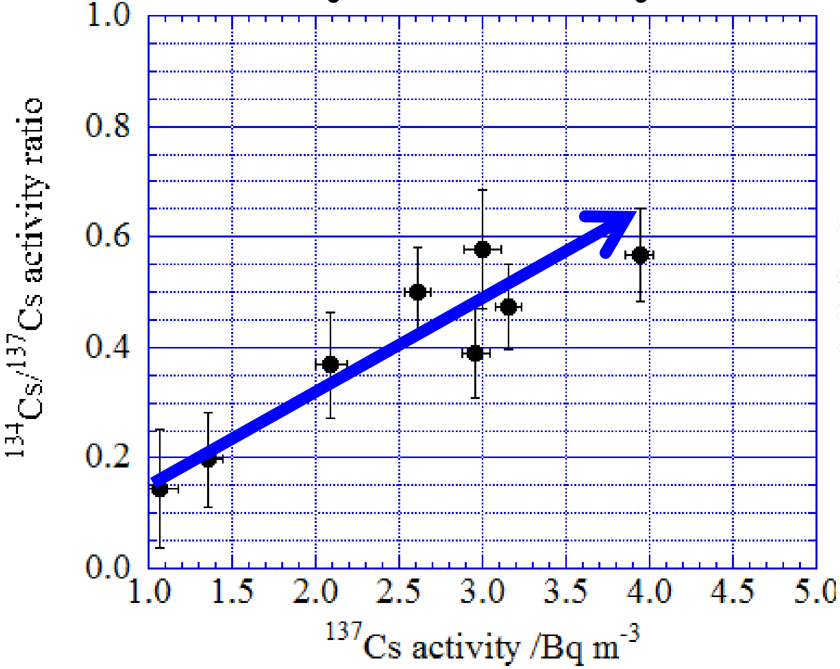
At 24 deg. N, 165 Deg. E, we found increase of ^{137}Cs activity at the layers 300-400 meters, of which density is 25.5-26.0 .(Aoyama et al., EGU2018-2187)



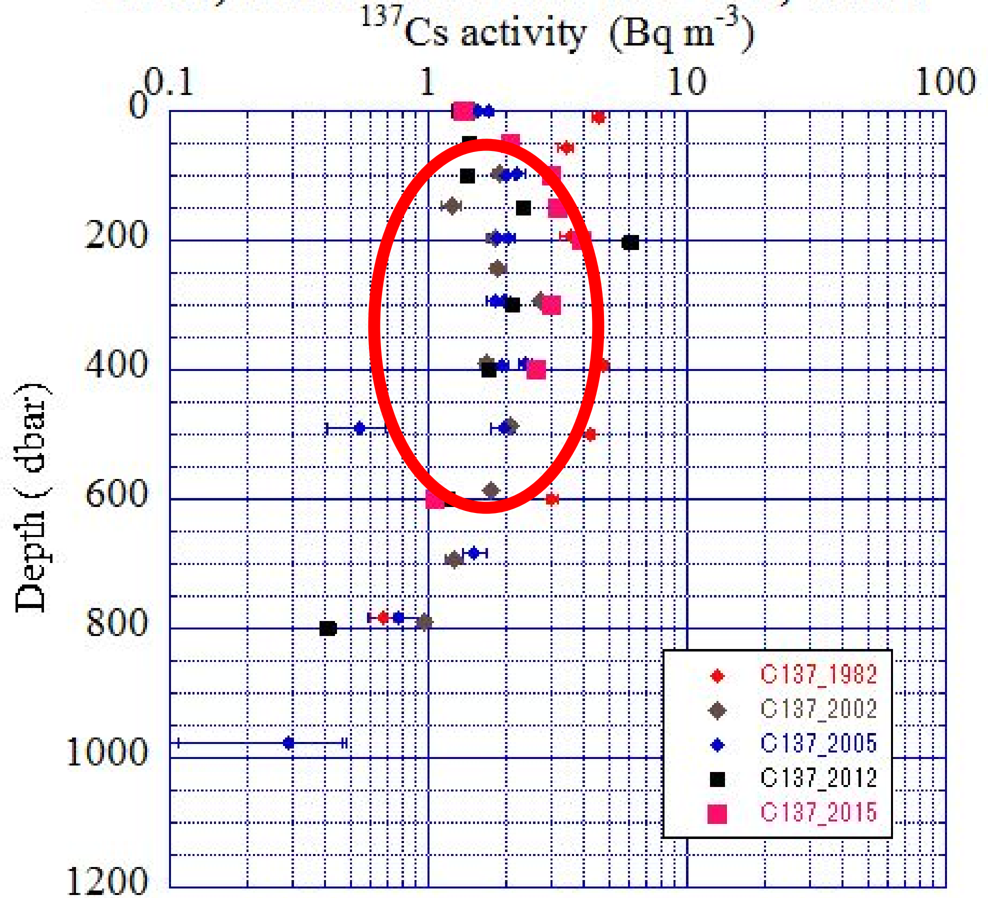


At 24 deg. N, 165 Deg. E, we found increase of ^{137}Cs activity at the layers 50-400 meters, of which density is 25.5-26.0, STMW, and ^{134}Cs/^{137}Cs activity ratio ranged 0.15+-0.10 to 0.58+-0.11 with positive relationship.

^{137}Cs activity vs. activity ratio



^{137}Cs profiles in 1982, 2002, 2005, 2012 and 2015 at 24 N, 165E



Typical features observed in vertical profiles at 24 deg. N, 165 deg. E

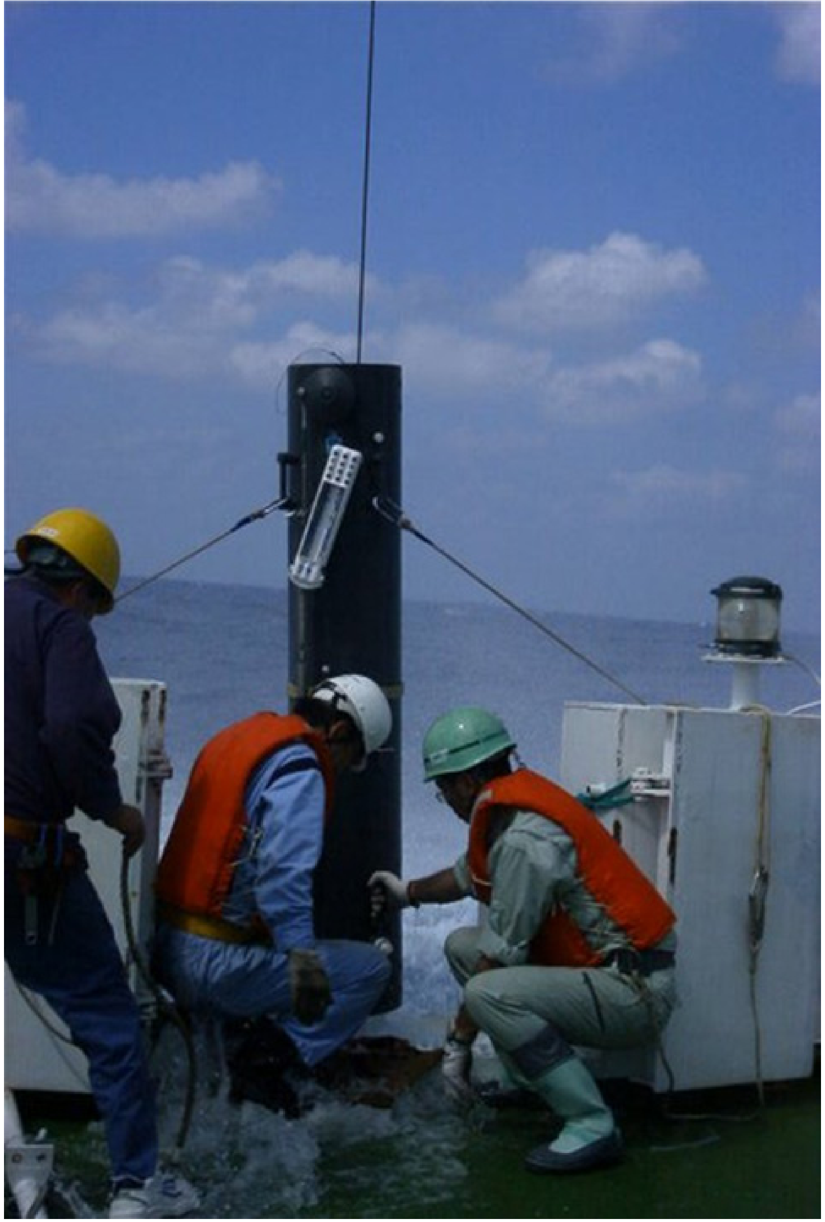
- ^{137}Cs activity concentrations in the STMW in the western North Pacific Ocean of which depths are around 200-400 meters were higher rather than those in the surface layer. ^{137}Cs activity concentrations showed maximum around 3 Bq m^{-3} at around sigma=25.5 g kg-1 while it was around 1-2 Bq m^{-3} in surface water.
- ^{134}Cs/^{137}Cs activity ratios was around 0.5 indicating contribution of Fukushima derived ^{137}Cs and fallout derived 137Cs are similar.
- FNPP1 derived radiocaesium subducted into ocean interior due to STMW formation are already recirculated and becomes homogenous within subtropical gyre after several years after injection to the STMW while Fukushima derived radiocaesium did not reach deeper layer below sigma=26.5 g kg^{-1}. (Aoyama et al., EGU2018-2187)

Concluding remarks

In this presentation, we summarized a long term history of ^{137}Cs in the ocean interior along 165 deg. E section and inventory of ^{137}Cs in the North Pacific Ocean since the 1960s to 2017. We show two reconstructed sections in 1965-1968 and 1970-1973 using HAM database global 2018 and three observed sections in 2002, 2012, and 2015. We also evaluated contributions of Fukushima derived ^{137}Cs to global fallout ^{137}Cs based on ^{134}Cs vs. ^{137}Cs activity ratio. In addition to sections and vertical profiles, we show a long term history of ^{137}Cs inventory in the North Pacific Ocean since the 1960s until 2017.

We observed that key processes of transport of radiocaesium in the ocean interior were the formation of CMW and STMW by subduction. Then, subducted radiocaesium within STMW was transported southward while subducted radiocaesium within CMW was transported east at the beginning. Relatively higher activity concentrations of radiocaesium had been kept a long time as a few decades and not diluted much. Therefore ^{137}Cs activity concentration in the ocean interior at mode water regions of STMW and CMW is higher rather than that in the surface water in wide region of the North Pacific Ocean.

Since Fukushima derived radiocaesium can be assumed as short term injection, in other words as a single injection, we could observe clear southward transport of radiocaesium in STMW and eastward transport of radiocaesium in CMW comparing with two sections obtained in 2012 and 2015. In contrast to the Fukushima accident injection, global fallout was continuous injection for several years or more, we observed a result of integration of transport within STMW.



Thank you for your attention!!