Estimation of $^{137}$Cs inventory by an ocean general circulation model for the global database interpolation

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Background

- Artificial radionuclide $^{137}\text{Cs}$ has been supplied into the ocean
  - global fallout due to atmospheric nuclear weapons tests since 1945
  - releases from reprocessing plants since 1952
  - fallout and discharge due to the Fukushima Dai-ichi Nuclear Power Plant (1F NPP) accident since 2011
- $^{137}\text{Cs}$ activities measured for scientific purposes as well as environmental health and safety monitoring have been summarized in a historical database by IAEA MARIS.
- It is difficult to estimate the inventory in each basin by the database because the spatio-temporal density of the observations varies widely, therefore
The object of this study is to investigate the temporal change of the inventory in each basin from the results of OGCM (CESM2, POP2; 1 degree), which is validated by comparison with the database (IAEA MARIS).
Model

- Parallel Ocean Program version 2 (POP2) of the Community Earth System Model version 2 (CESM2) (Danabasoglu et al., 2020).
- The horizontal resolution is 1.125 degrees in longitude and 0.28 to 0.54 degrees in latitude.
- The simulation period was from 1945 to 2030, and the atmospheric conditions were forced to cycle through repeating normal years.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Global fallout</th>
<th>Re-processing Plant</th>
<th>Fukushima input</th>
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</thead>
<tbody>
<tr>
<td>Case1</td>
<td>0</td>
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<td>Case2</td>
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<td>Case3</td>
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</tbody>
</table>
Input due to global fallout

Cumulative $^{137}$Cs deposition by 1970 (Bq/m$^2$) with optimization of integrated cumulative $^{137}$Cs deposition

$$F(\lambda, \phi, t) = F_0(t) \frac{P(\lambda, \phi)}{P_0(t)} \varepsilon(\phi),$$

$F(\lambda, \phi, t)$ : the estimated annual deposition (Bq/m$^2$/yr)
$\lambda, \phi$ : longitude, latitude  $t$ : time
$F_0(t)$ : Observed annual deposition (Bq/m$^2$/yr) on a reference site of MRI at 36° latitude
$P(\lambda, \phi)$ : Annual precipitation (mm/yr) by the GPCP climatological data (Adler et al., 2018)
$P_0(t)$ : Observed precipitation (mm/yr) on a reference site
$\varepsilon(\phi)$ : Empirical function of the meridional distribution to fit the meridional distribution of zonal cumulative $^{137}$Cs deposition in 1970 constructed by observed data (Aoyama et al., 2006).

Temporal change of $^{137}$Cs deposition (Bq/m$^2$/year) is proportional to the one at the site of MRI, Japan
Input from reprocessing plants

Sellafield (54.4205N, 3.4975W)
La Hague (49.7128N, 1.92083W)

Discharge rate

Aarkrog, 2003

Maximum, 5.2 PBq/year in 1975
41 PBq in total
14 TBq/day
Input due to 1F NPP accident

Cumulative $^{137}\text{Cs}$ deposition (Bq/m²) from 2011/3/11 – 5/1 (Aoyama et al., 2016)

Direct release rate of $^{137}\text{Cs}$ (Bq/day) (Tsumune et al., 2020)
$^{137}$Cs activity in the North Pacific

Global fallout
$^{137}\text{Cs}$ activity in the North Atlantic

Global fallout + Reprocessing plants
$^{137}\text{Cs}$ activity in the North Pacific

Global fallout + 1F NPP accident
Inventory

Cs-137 Inventory 1963

Cs-137 Inventory 1973

Cs-137 Inventory 1983

Cs-137 Inventory 1993

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$^{137}\text{Cs}$ inventory

Global and major 4 basins
$^{137}\text{Cs}$ inventory

137Cs inventory in the South Atlantic increased by 2015 and then did not decrease.

Other basins
$^{137}Cs$ inventory in the North Atlantic

Inventory in each basin (Case 2)

Release rate from Reprocessing plants (Total)

Inventory by reprocessing plants (Case 2-Case 1)
137Cs inventory in the North Atlantic

- Releases from reprocessing plants peak in 1975 and are large from 1970 to 1980.
- The inventory in the North Atlantic increases until 1965 and does not decrease until 1985.
- The inventory in the Greenland Sea reaches its maximum after 1980, after the peak of releases, and then decreases.
- The impact of reprocessing plants alone has a complex shape.
- The peak in the North Atlantic is seen in 1995.
- The Greenland Sea inventory reaches its maximum after 1980, after the peak of the release, and then decreases.
- The peaks in the Arctic Ocean and the Labrador Sea are also late.
- The South Atlantic also shows a slight increase.
- It is possible that the 137Cs released from the reprocessing plant had migrated to the Greenland Sea and then returned to the North Atlantic.
- In 2030, the inventory due of the reprocessing plant is 8 PBq.
- However, it is difficult to detect the impact of the reprocessing plants because the inventory due to the global fallout is 50 PBq.
After the 1F NPP accident, the decrease rate of inventory in the North Pacific is greater than the one due to nuclide decay.

The inventory in the South Pacific and Indian Ocean increased due to the 1F NPP accident, but not significantly enough to be detectable as a concentration.

In 2030, the inventory due of 1F NPP accident is 10 PBq.

However, it is difficult to detect the impact of the reprocessing plant because the inventory due to the global fallout is 40 PBq.
The impact of the release from reprocessing plant and input due to the 1F NPP accident on the inventory by global fallout was investigated in more detail until 2030.

Even after 2030, it is still possible to detect $^{137}\text{Cs}$ activity by global fallout in the global ocean. Model simulations are useful for future observations to fill gaps in the database.