Progresses of ANTROPIC project

(WP1: Hindcast simulation)

1. Methodology

1.1. Main tasks of WP1:

1. Validate NorESM by the observations of radiotracers and chemical tracers;
2. Investigate historical hydrodynamics with validated modeling results

1.2. Model setup

- **NorESM:** Ocean-ice configuration
- **Time period:** 1945 - near present

1.3. Tracer Setup

1.3.1. Radiotracers:

- **Reprocessing plants:** liquid discharges from two European nuclear reprocessing plants and Sellafield and La Hague

  1. **Tc-99, I-129 & Cs-137:** documented discharge data for Sellafield since 1952 and for La Hague since 1966 (HELCOM, OSPAR, and RADD databases)
  2. **U-236:** a) documented discharge data for La Hague since 1966 (HELCOM databases);b) reconstructed discharges data for Sellafield and La Hague since 1971 (Castrillejo et al., 2020)

- **Global fallout:** atmospheric depostion from nuclear weapon testing

  - **Cs-137 & U-236:** resolved spatiotemporal deposition pattern (UNSCEAR 2000)

1.3.2. Vitual traers:

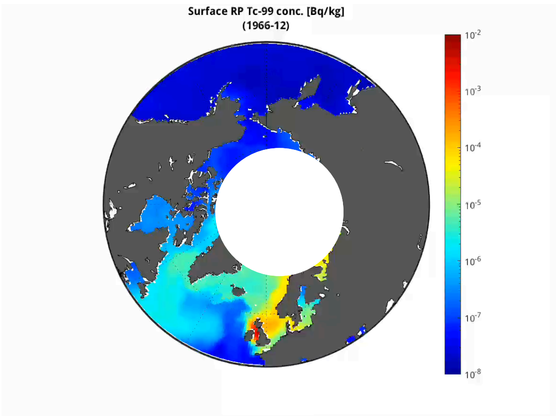
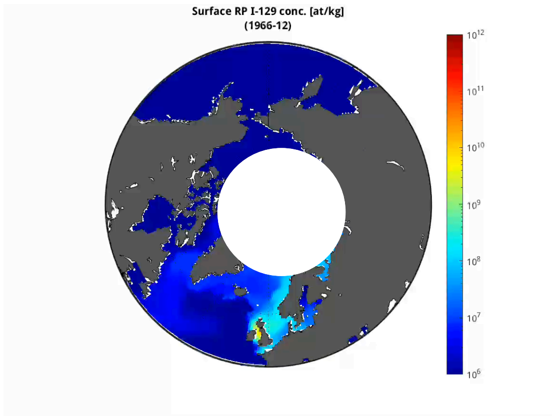
- **Water masses in AO:** constent concentrations in entering water

- Pacific water:
  - Atlantic water (via Fram Strait & Barent Sea)
  - Fresh water

- **Point sources:** constent discharges
  - Sellafield
  - La Hague
  - Fukushima

2. Results

2.1. Radiotracer transport

<table>
<tr><th>RP-derived Tc-99</th><th>RP-derived I-129</th></tr>
<tr><td>
</td><td>
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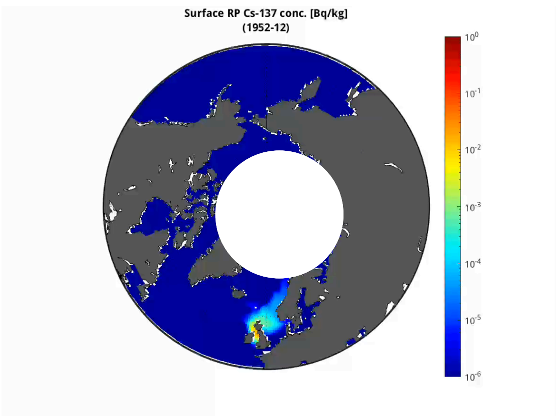
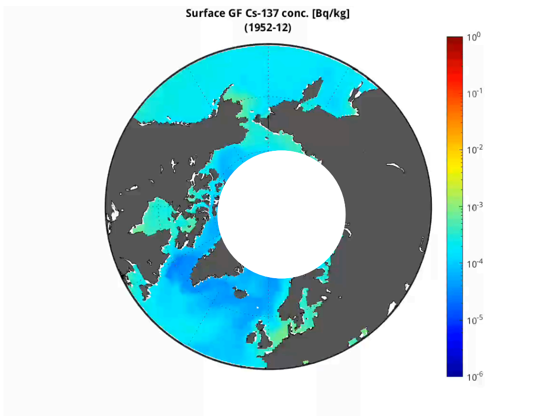
<tr><th>RP-derived Cs-137</th><th>GF-derived Cs-137</th></tr>
<tr><td>
</td><td>
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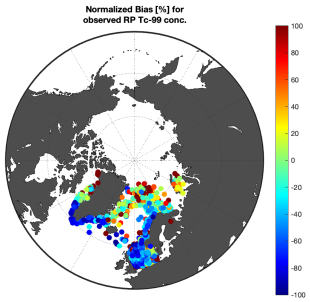
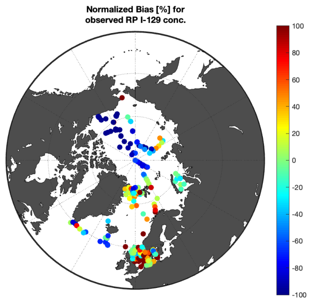
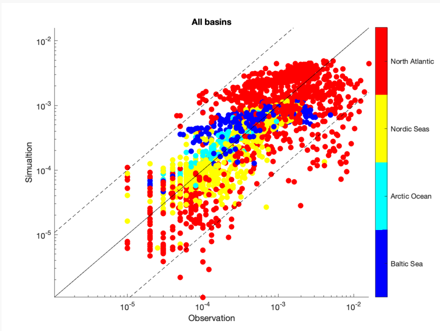
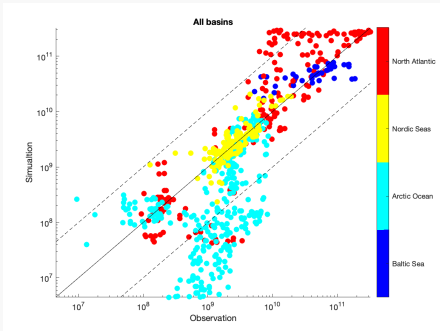
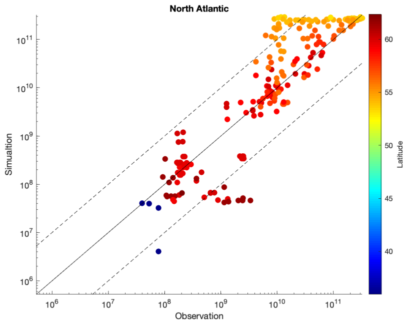
2.2. Model validation

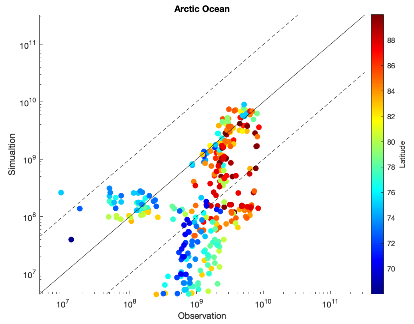
2.2.1 Spatial distribution

	Tc-99 (all basins)	I-129 (all basins)
Spatial distribution		
Observation vs. simulation		
Mean normalized bias	**Overall (n=2238): 33.8%** • Baltic Sea (n=480): 63.2% • Arctic Ocean (n=134, outliers excluded): 43.3% • **Nordic Seas (n=612): 3.4%** • North Atlantic (n=1011, outliers excluded): 39.1%	**Overall (n=852): 11.2%** • Baltic Sea (n=92): 45.3% • Arctic Ocean (n=323, outliers excluded): -38.8% • **Nordic Seas (n=179): 23.9%** • North Atlantic (n=225, outliers excluded): 73.6%
Correlation coefficient	**Overall (n=2238): 0.427** • Baltic Sea (n=480): 0.427 • Arctic Ocean (n=134, outliers excluded): 0.906 • **Nordic Seas (n=612): 0.812** • North Atlantic (n=1011, outliers excluded): 0.292	**Overall (n=852): 0.795** • Baltic Sea (n=92): 0.531 • Arctic Ocean (n=323, outliers excluded): 0.529 • **Nordic Seas (n=179): 0.830** • North Atlantic (n=225, outliers excluded): 0.757

	I-129 (North Atlantic)	I-129 (Arctic Ocean)

Latitude





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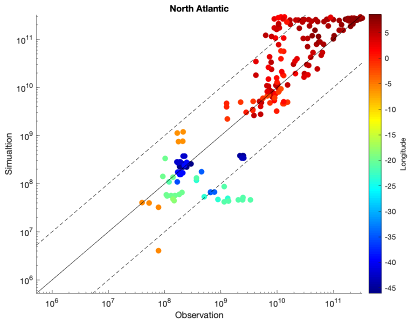

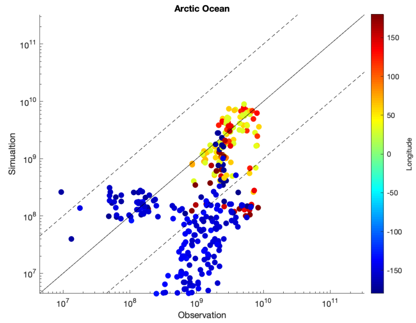

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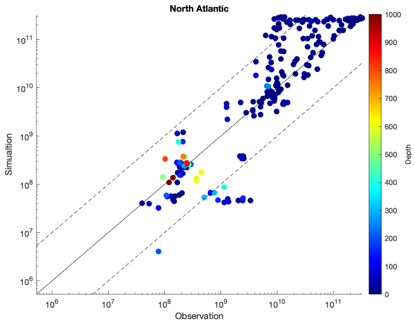
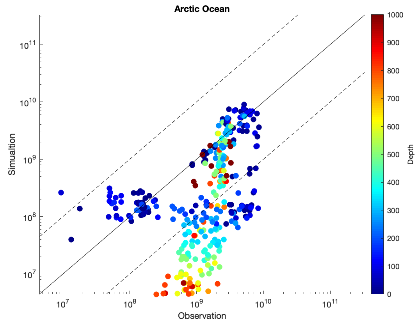
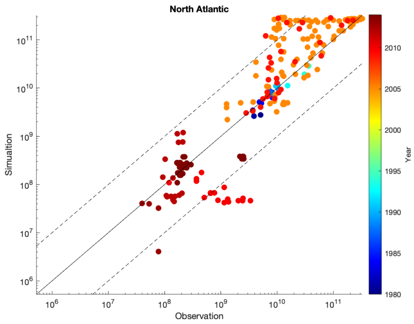
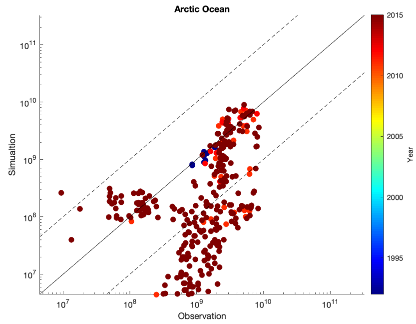


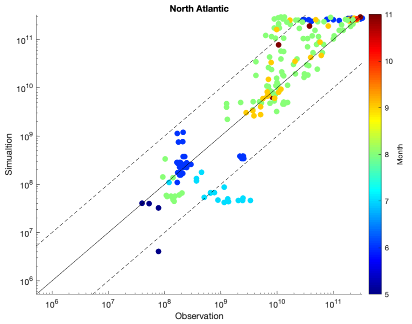


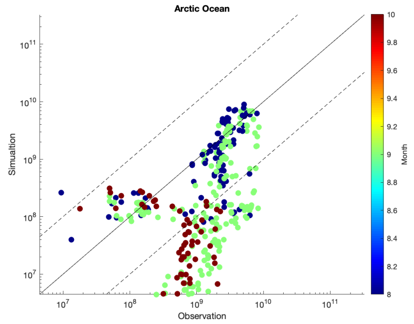
Year





Month

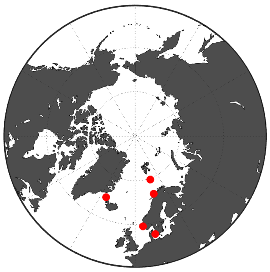
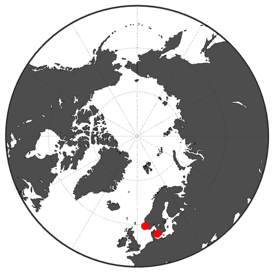
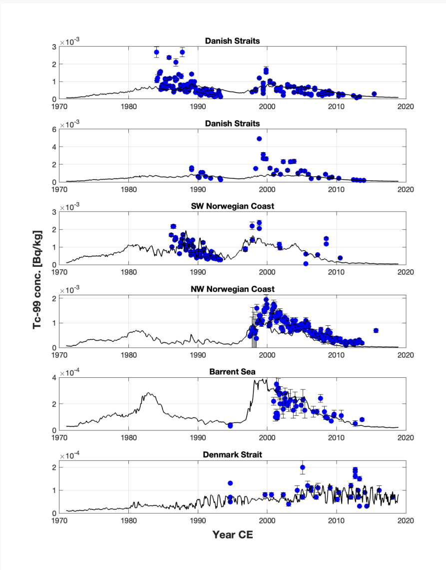
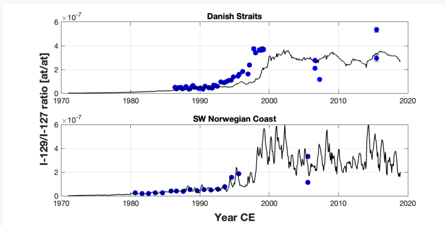




Summary:

1. NorESM has the best performance in the Nordic Seas (low MNB and high r);
2. High NBs and low r are observed in the European marginal seas, such as the Danish Straits and the British coast
3. Low NBs are observed in the deep water of the Canada Basin (advection or ventilation issue?).

3.2.2 Temporal evolution

	Tc-99	I-129
Station location		
Temporal evolution		
Mean normalized bias	• Danish Straits surf. (n=164): 39.7% • Danish Straits bo. (n=37): -19.2% • SW Norwegian Coast (n=81): 28.9% • NW Norwegian Coast (n=159): -38.3%	• Danish Straits surf.(n=46): -23.2% • SW Norwegian Coast (n=19): -12.9%

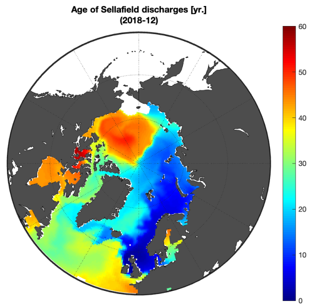
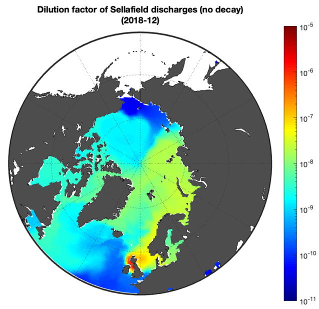
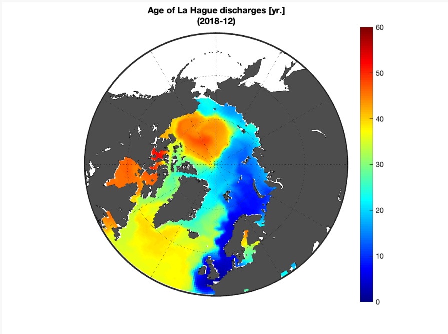
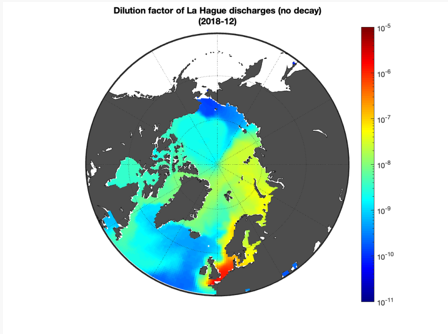
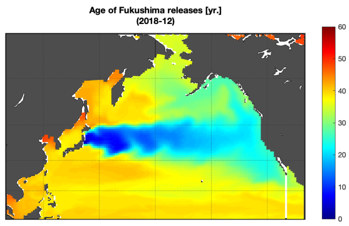
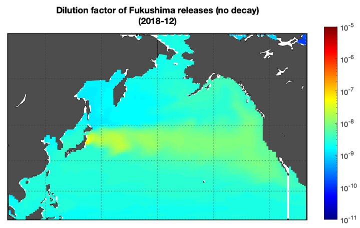
	• Barent Sea (n=42): 35.8% • Denmark Strait (n=33): -11.3%	
Correlation coefficient	• Danish Straits surf. (n=164): 0.166 • Danish Straits bo. (n=37): 0.428 • SW Norwegian Coast (n=81): 0.418 • NW Norwegian Coast (n=159): 0.753 • Barent Sea (n=42): 0.681 • Denmark Strait (n=33): not corr.	• Danish Straits surf.(n=46): 0.753 • SW Norwegian Coast (n=19): 0.923

Summary:

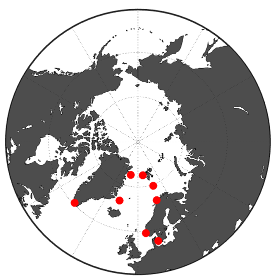
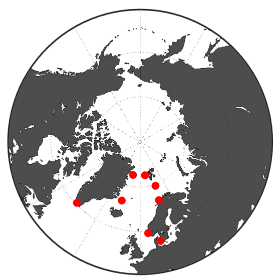
1. Low r are observed at the stations of the European marginal seas.
2. MNBs are acceptable at all stations;

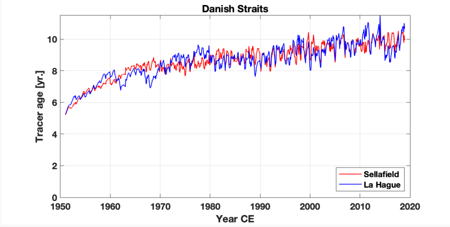
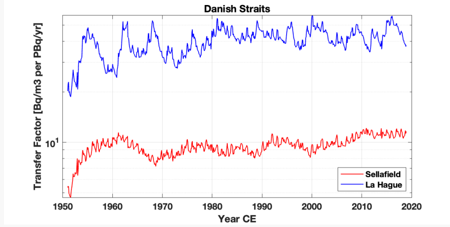
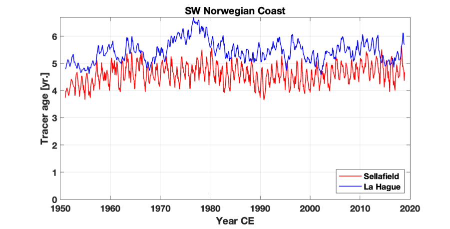
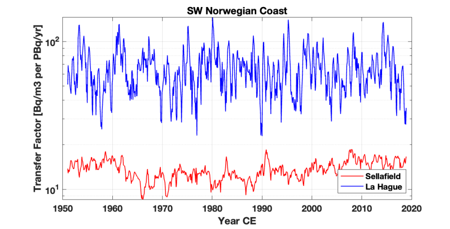
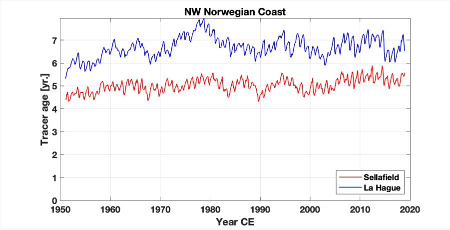
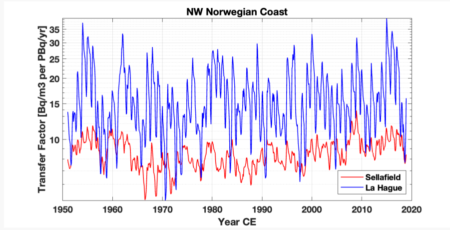
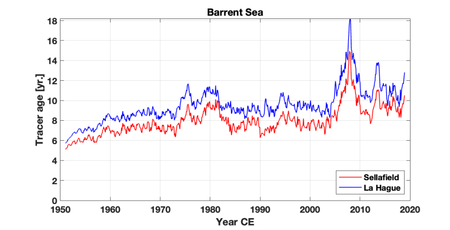
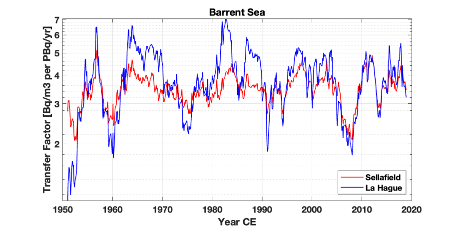
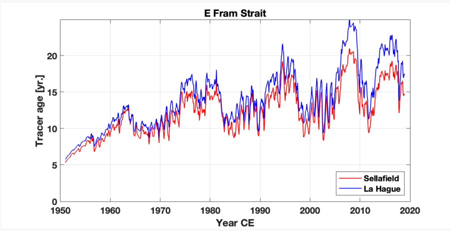
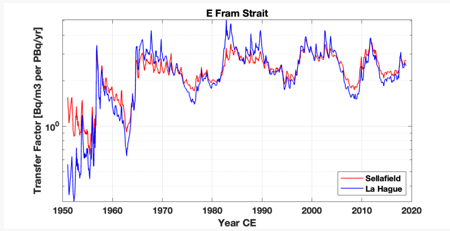
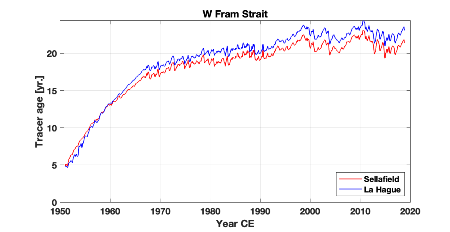
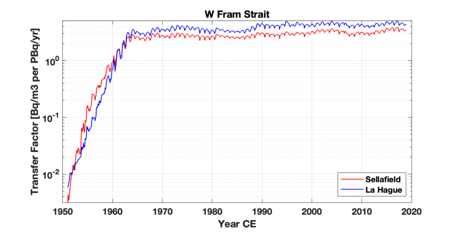
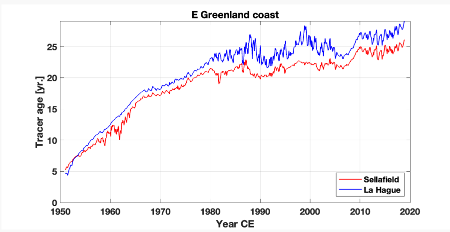
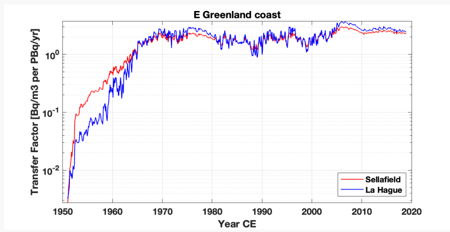
3.3 Point-source releases

3.3.1 Spatial distribution

	Surf. tracer age	Surf. transfer factor (no decay)
Sellafield		
La Hague		
Fukushima		

3.3.2 Temporal evolution

	Surf. tracer age	Surf. transfer factor (no decay)
Station location		
Danish		

Straits		
SW Norwegian Coast		
NW Norwegian Coast		
Barent Sea		
E Fram Strait		
W Fram Strait		
E Greenland Coast		
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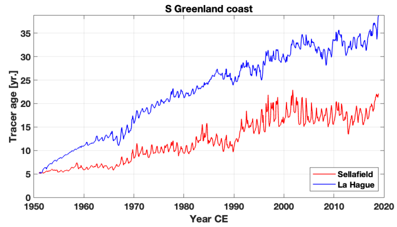
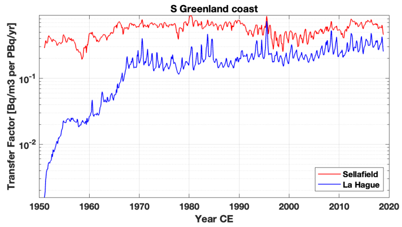
Greenland Coast		

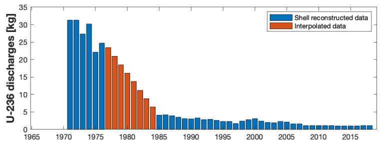
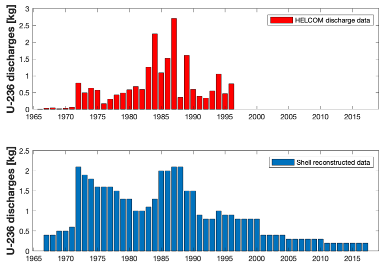
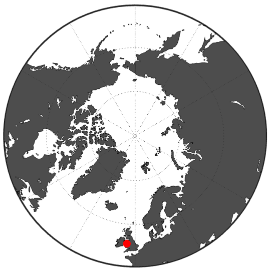
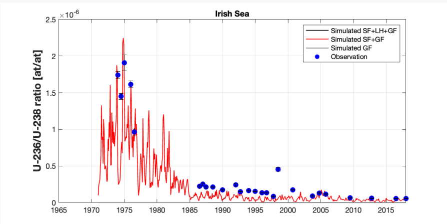
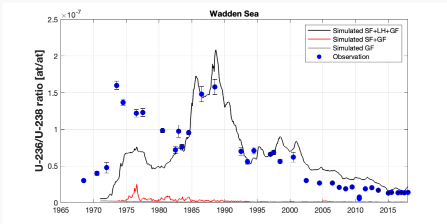
Summary:

1. Dischages from La Hague has 1 year more transit tiem than thoes from Sellafield.
2. A branch of Sellafield discharges transport across the North Atlantic reaching S Greenland directly.

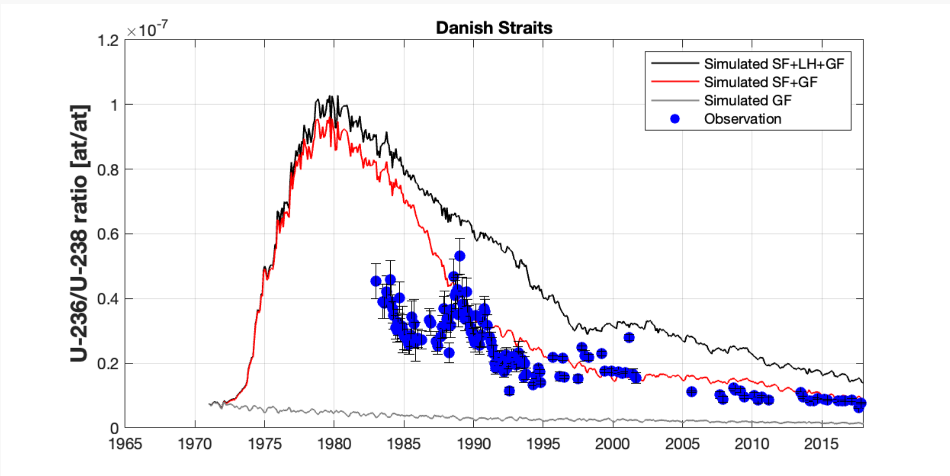
3.5 Water masses in Arctic (to be updated)

3.6 U-236 discharge data

3.6.1 Current discharge data

	Sellafield	La Hague
Discharge data		
Data Source	• 1971-1976: shell data • 1977-1984: interpolation • 1985-2018: shell data	• 1966-1996: HELCOM • 1997-2018: shell data
Sampling station		
Temporal evolution		
Mean normalized bias	• Irish Sea: -48%	• Wadden Sea: 30.9%
Correlation coefficient	• Irish Sea: 0.892	• Wadden Sea: 0.706

3.6.2 Validation with seaweed data

<table>
<tr><th></th><th>U-236</th></tr>
<tr><td>Station location</td><td></td></tr>
<tr><td>Temporal evolution</td><td>
</td></tr>
<tr><td>Mean normalized bias</td><td>• Danish Straits: 125%</td></tr>
<tr><td>Correlation coefficient</td><td>• Danish Straits: 0.829</td></tr>
</table>

Summary:

- La Hague:
    1. Before 1980: the reconstruted discharge data is more reliable than the official discharge data;
    2. After 1980: the reconstruted discharge data and the official discharge data are consistent with each other.

- Sellafield
    1. Years with shell data are trustable;
    2. The interpolated data may not be right;
    3. Combining transit time and transfer factor results from virtual tracers, it is possible to resolve SF discharge with seaweed data.

4. Next Step

1. Re-run WP1 for the vitual tracers of AO water masses;
2. Re-run WP1 for U-236 discharges from RPs;
3. Move on to WP2.