Circulation and mixing of Technetium-99 in the Arctic Ocean from 1970 to 2002

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Technetium-99 (^{99}Tc), a highly soluble anthropogenic radionuclide, has been released to the ocean through controlled discharges from the nuclear reprocessing facilities at Sellafield (UK) and Cap la Hague (France). Two periods of heightened discharge in the 1970's and the 1990's have taken place. Leaving the radiological consequences of the release aside, the well known history and localized nature of the ^{99}Tc releases offer an opportunity to use ^{99}Tc as a tracer for marine flows.

After passing the North Sea and the Nordic Seas, ^{99}Tc intrudes into the Arctic Ocean where it is subject to advection in the surface layer below the ice. Additionally, the ^{99}Tc signal subducts via dense water formation in the Barents Sea into the Eurasian Basin, subsequently circulating in the deep Arctic basins.

We investigate advection and mixing of the ^{99}Tc in the circulation systems of Arctic Ocean at different depths. For this purpose the hydrodynamic coupled ice-ocean model NAOSIM, forced with realistic atmospheric data is used, simulating the dispersion of the radionuclide from 1970 to 2002.

The influence of the inter-annual variability of the Ocean circulation on the tracer dispersion and implications for box assessment modelling of radionuclides in the Arctic is discussed.

AWI - NAOSIM model setup

- MOM 2 based ocean module
- 0.25° resolution on rotated spherical grid
- 33 depth levels
- Open boundary at 50°N
- FCT advection scheme
- VP sea ice model, Semtner thermodynamics, snow layer
- ^{99}Tc sources from Sellafield and La Hague
- Initial condition: PHC climatology (Steele et al., 2001)
- SSS restoring (timescale 180 d)
- NCEP forcing 1948-2004

NRPA box model setup

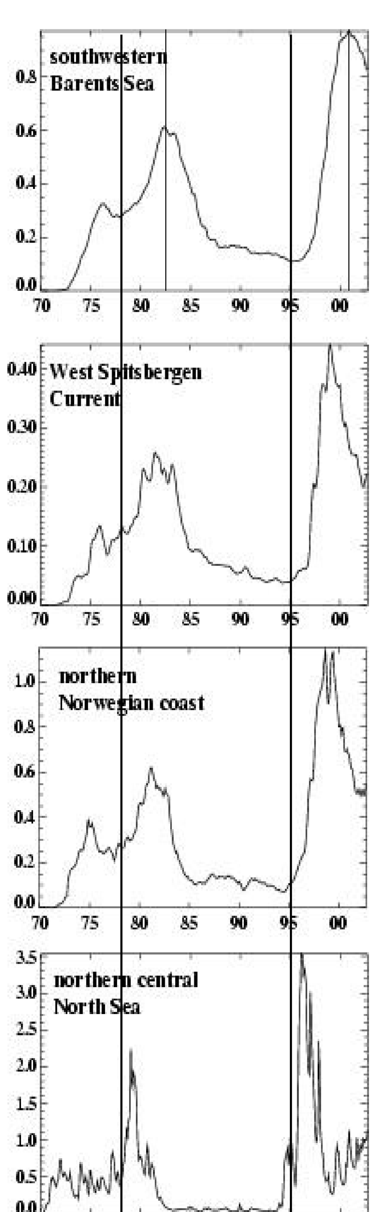
- ARCTIMAR 2
- Improved box scheme and prescribed fluxes
- Non-instantaneous mixing
- advection, sedimentation, diffusion through pore water, resuspension and a burial process of radionuclides in deep sediment
- Improved water-sediment module

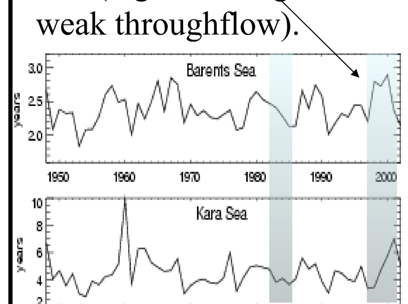
Northward propagation of two Tc-99 peaks

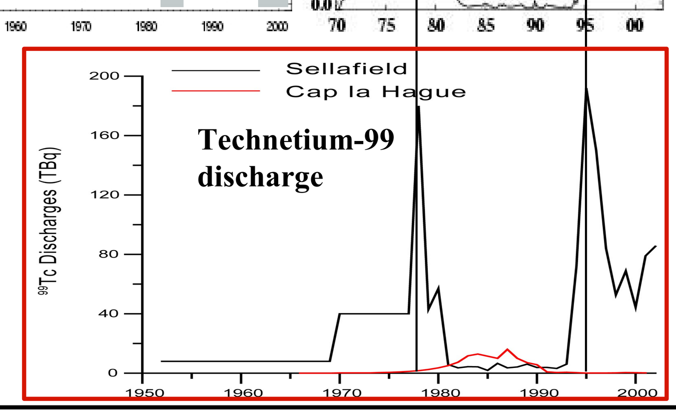
The displacement of the two release peaks from 1978 and 1995 can be followed in upper ocean concentrations via the North Sea into the West Spitsbergen Current and the Barents Sea.

The 1995-peak when reaching the Barents Sea travels slower than the previous 1978-peak. This is partly due to anomalously low flow through the Siberian Shelves in the late 1990s (Harms and Karcher, 2005).

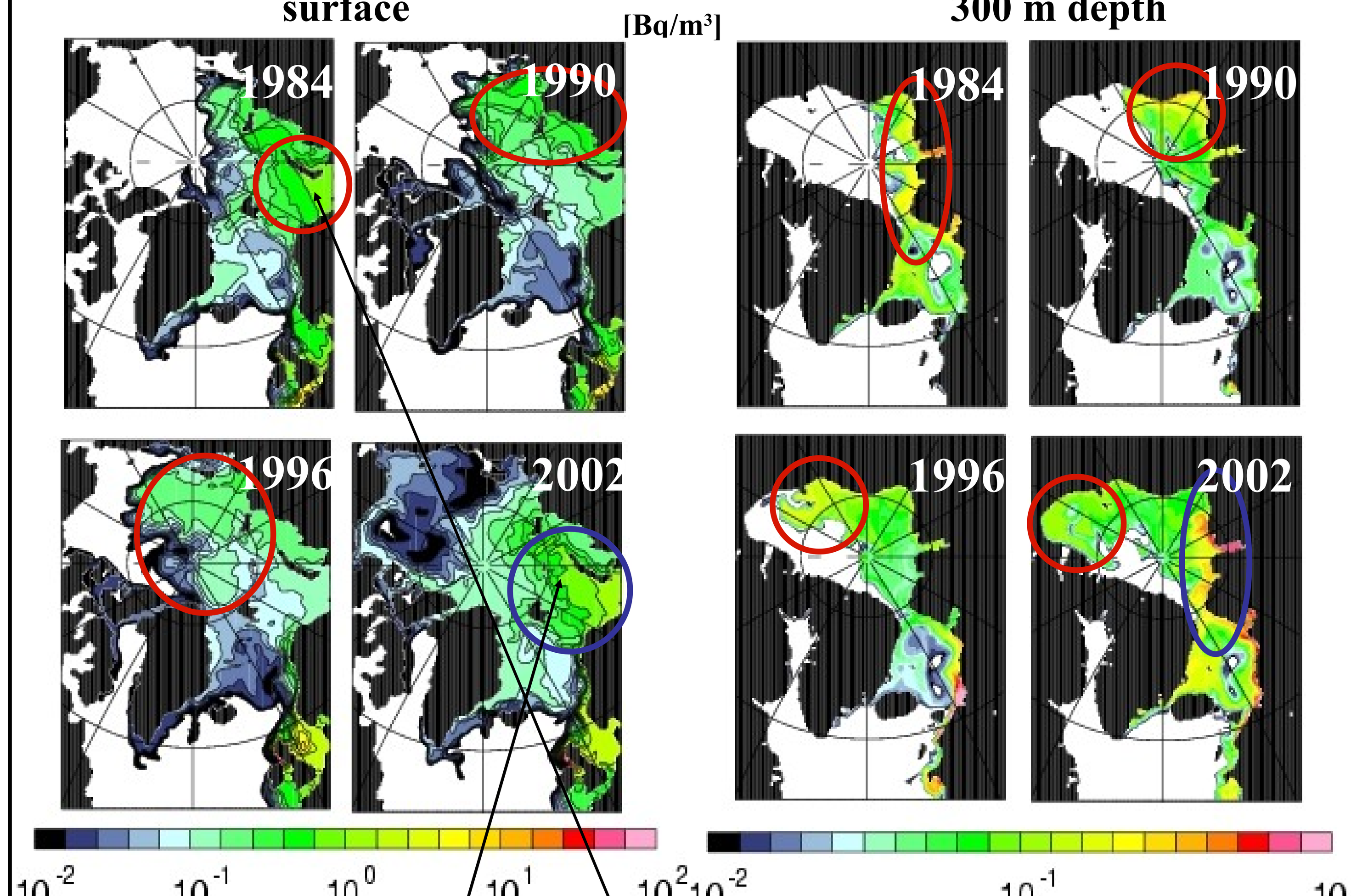
This is also evident from **flushing time** calculations for the Barents and Kara Sea (high flushing time = weak throughflow).



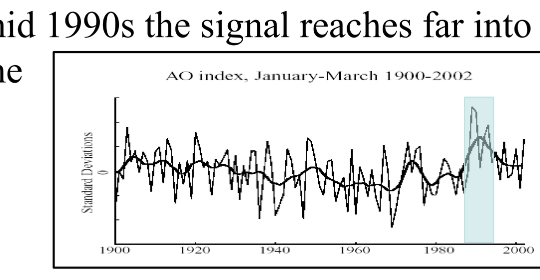




Spreading of Tc-99 in the Arctic Ocean I (NAOSIM)



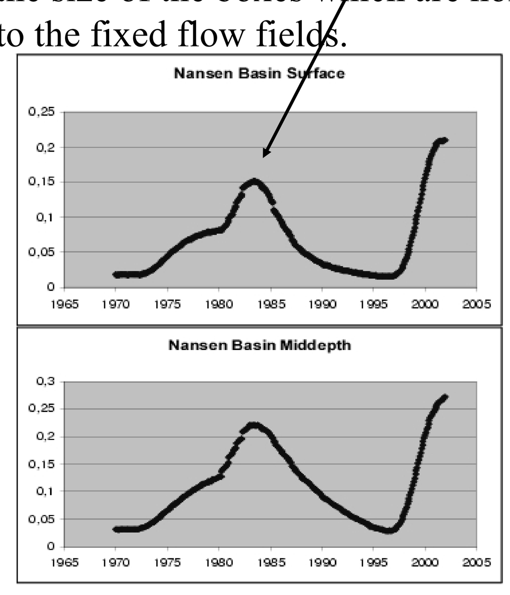
The displacement of the 1978-peak (red circles) can be followed to enter the central Arctic. Due to the strong AO regime in the early/mid 1990s the signal reaches far into the Makarov and Canadian Basins. In the late 1990s the 1978-peak has left the Arctic surface waters, while the 1995-peak (blue circles) has reached the Siberian shelves.



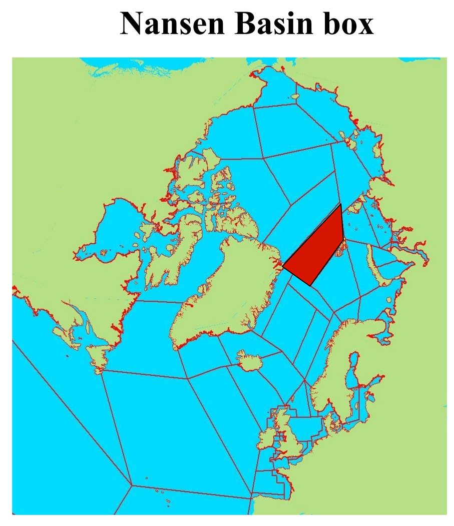
At 300 m depth inside the Atlantic Water layer the 1978-peak is passing the Beaufort Sea in the early 2000s after crossing the Lomonosov Ridge in the early 1990s with the strong AO cyclonic regime. It outlines the current structure as derived from observations by Rudels et al. (1994). The tracer indicates that the signal which recirculates along the mid-Arctic Lomonosov Ridge is rather diffusive while the part following the continental slope into the Makarov and Canadian Basins keeps a more pronounced shape.

Tc-99 in the Arctic Ocean III (NRPA box model)

The figures show the dispersion of the Tc-99 peaks into the Arctic Ocean's Nansen basin in the NRPA box model. Timing and concentration of the 1978-peak in this area are comparable to NAOSIM though some years too early. This is more pronounced for the 1995-peak. The differences are partly due the size of the boxes which are homogeneous inside, partly due to the fixed flow fields.

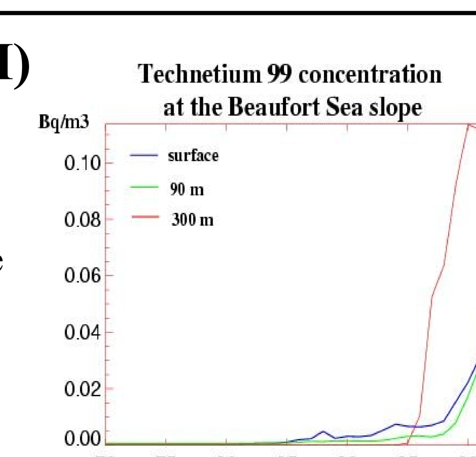


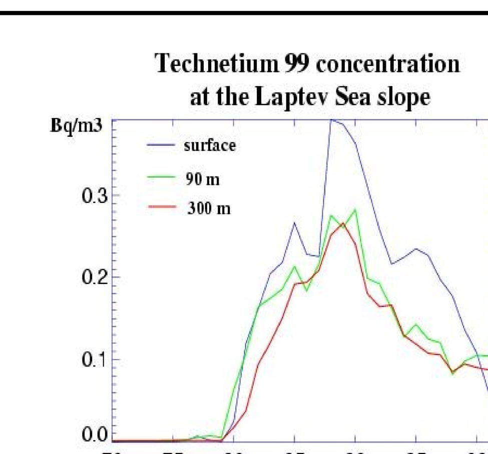
Nansen Basin box

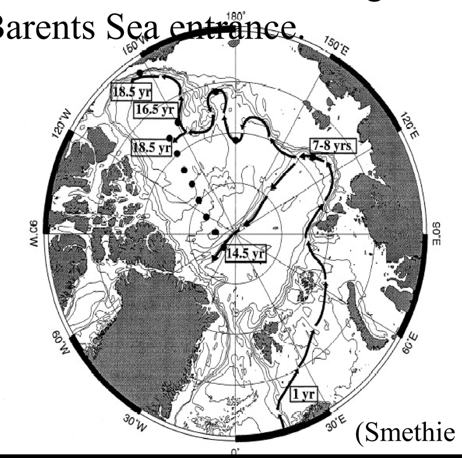


Spreading of Tc-99 in the Arctic Ocean II (NAOSIM)

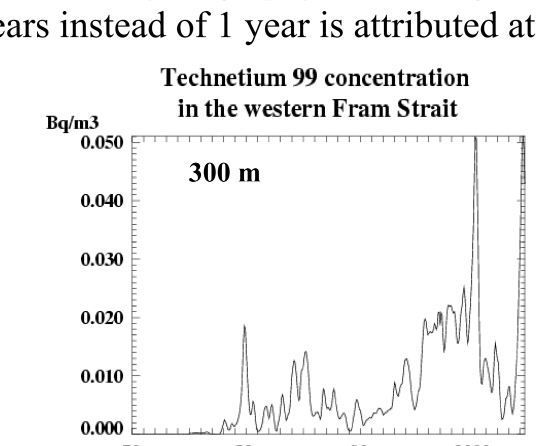
The displacement of the earlier 1978-peak in the Arctic can be timed as 7 years to St.Anna Trough and 11 years to the Laptev Sea slope at all depths, surface, halocline and Atlantic layer. After 22 years the peak reaches the Beaufort Sea in the Atlantic Layer boundary current, while at the surface the signal is approaching even slower from the west with the Beaufort Gyre. Along the Atlantic layer shortcut loop along the Lomonosov Ridge in the Eurasian Basin the 1978-peak reaches Fram Strait after 20(18-23) years. These results compare well with tracer and hydrography derived ages of Atlantic Water when an age of 4 years instead of 1 year is attributed at the Barents Sea entrance.

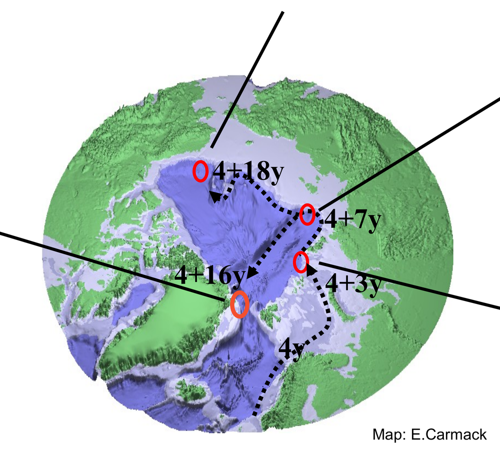


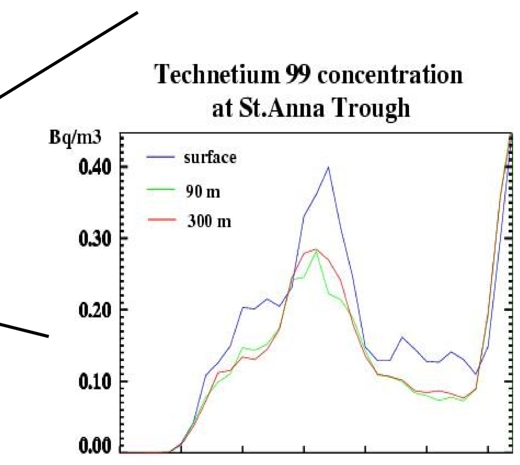




(Smethie et al., 2000)







RESULTS:

•Tc-99 is suggested as an excellent tracer for Atlantic derived water masses in the Arctic Ocean. The comparison of the early 1978-peak and the recent mid 1990s peak occurred during different atmospheric and oceanic states of circulation. The inflence of these different states ob dispersion and mixing of watermasses can be studied, and complement studies based on hydrography and other tracers.

•We find a clear imprint of the changes of atmospheric conditions during the early 1990s high Arctic Oscillation period in the patterns of tracer dispersion in our model simulation, namely fast and widespread penetration of Atlantic Water into the Canadian and Makarov Basins.

•The spreading of the two Tc-99 signal can be used for model validation not only in circulation models, but also in box assessment models used for assessment of radiological consequences of radionuclide releases to biota and man.

•As part of RADNOR, box model simulatuions based on circulation fields from different climatic periods are in preparation

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• **Karcher, M., R. Gerdes, F. Kauker and J. P. Gwynn**, Tracing Atlantic derived water in the Arctic Ocean and the Nordic Seas with ^{99}Tc, in prep.

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