Modelling of Dispersion of Nuclear Device Explosion Debris in the Ocean

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INTRODUCTION AND MAIN RESULTS

Tracers are inserted into surface waters at various sites in March and September 2023 in high-resolution simulations of the global ocean state over the last 50 years. They track over a 4-month period the pool of contaminated water left behind after a nuclear explosion. Dispersion and dilution are generally rapid, but very different at different release sites and times, implying large variation in detectability at different sites and at different times of the year.

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Introduction

Passive tracers representing the near-surface warm pools of mixed radioactive nuclides left by nuclear detonations are inserted at specified locations (blue dots in Figure 1) and times (March 1st, 2023 and September 1st, 2023) into a high-resolution (1/4°) simulation of the global ocean state over the last 50 yrs using the NEMO ocean model. This simulation is forced by surface fluxes representing actual ocean conditions and provides ocean estimates expected to be near reality at the given times. Concentrations of the various radionuclides will then be determined by the UK MOD/ Atomic Weapons Establishment (AWE) in the diagnostic phase from their initial fractions and half-lives.

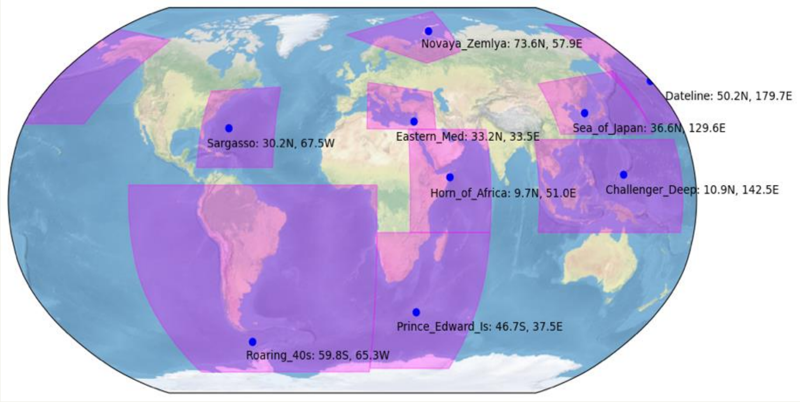

Figure 1: Release sites are denoted by blue dots. Magenta overlays denote diagnosis regions for each tracer release site.

Results

Dissolved and sinking tracers were initially set to 1 in the upper 50m where the dissolved tracer followed the fluid and the "sinking tracer" had an additional sinking velocity of 0.2 mm/s (17m/day) to model radioactive nuclides that were adsorbed onto fine bottom sediment in the explosion.

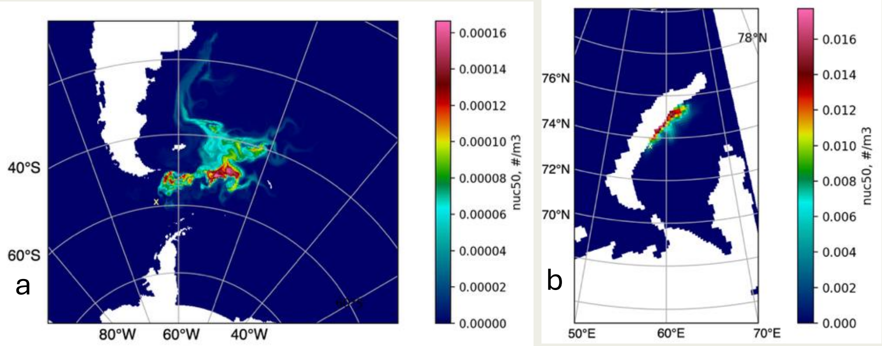

Figure 2: Surface dissolved tracer concentrations 4 months after insertion on Mar 1 2023 at yellow x. a: Drake Passage; b: Novaya Zemlya

Dispersion and dilution were very different at different sites; e.g. 4 months after release on Mar 1 2023 vigorous dispersion in the Roaring 40s (Drake Passage) contrasts with limited dispersion off Novaya Zemlya (Fig. 2a, b). Vertical spread also differed (Fig. 3a, b) with deepening upper-ocean mixing through the southern fall (March–May) over the Roaring 40s, and seasonally varying topographically driven upward motions near Novaya Zemlya.

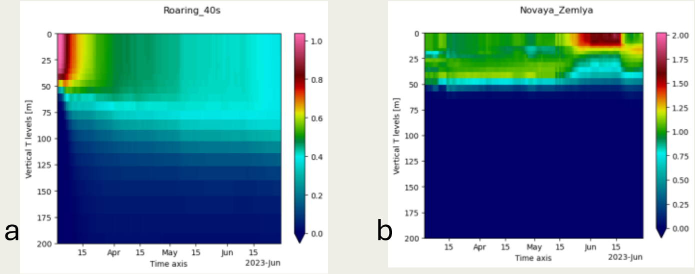

Figure 3: March 2023 release—dissolved tracer as a function of time (x-axis) and depth (y-axis) area-integrated over the diagnosis regions associated with the Roaring 40s (a) and Novaya Zemlya (b) release sites, scaled by the area of the initial grid box at the release site.

Seasonally varying flow can give different tracer distributions after releases at different times of the year. E.g. the tracer distribution 4 months after release on Sep 1 2023 at Novaya Zemlya (Fig. 4) goes southward instead of northward (Fig. 2b).

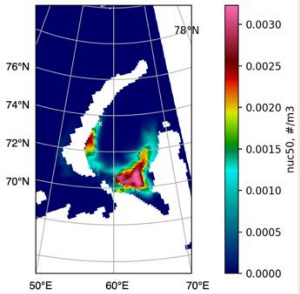

Figure 4: Surface dissolved tracer concentrations 4 months after insertion on Sept 1 2023 at Novaya Zemlya

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Sinking

Even a relatively slow sinking rate of 0.02 cm/s, i.e. ~17m/day, has a major effect on the tracers. After 4 months they sink down to depths of ~2000m (Fig. 6) where the ocean bottom is sufficiently deep, as it mostly is near to sites like Roaring 40s. Only a small fraction (16%) settles onto the limited topography in this region < 2000 m deep (Fig. 5a). Where the bottom is quite shallow such as near Novaya Zemlya (Fig. 5b) and the Horn of Africa, 100% of the sinking tracer settles to the bottom within a few weeks. Surface concentrations of these sinking tracers are correspondingly also very low.

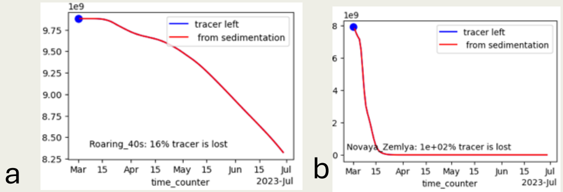

Figure 5: Percentage of initial sinking tracer remaining suspended in the ocean 4 months after insertion on Mar 1 2023. a: Drake Passage (Roaring 40s); b: Novaya Zemlya

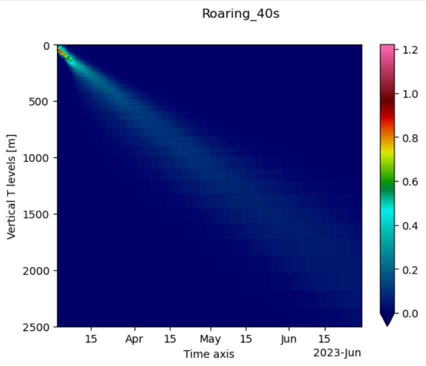

Figure 6: Scaled area-integrated (as in Fig. 3) sinking tracer over the Roaring 40s diagnosis region

Dilution rates

Maximum values of the dissolved tracer fall rapidly over 4 months (see Fig. 7a). Over subtropical sites like the Sargasso and Challenger Deep (and also Novaya Zemlya) dilution is relatively weak (typically a factor of 50 after 4 months) but (Fig. 7a and 7b) dilution is more than an order of magnitude stronger (an extra factor of ~10–80) at the Antarctic Circumpolar sites (Roaring 40s, and Prince Edward Island) where the initial tracer region is dispersed very rapidly and to very low concentrations by rapid, strongly sheared currents.

Dilution is sensitive to seasonal variation in flow, particularly striking at Novaya Zemlya and the Sargasso Sea (Fig. 7b).

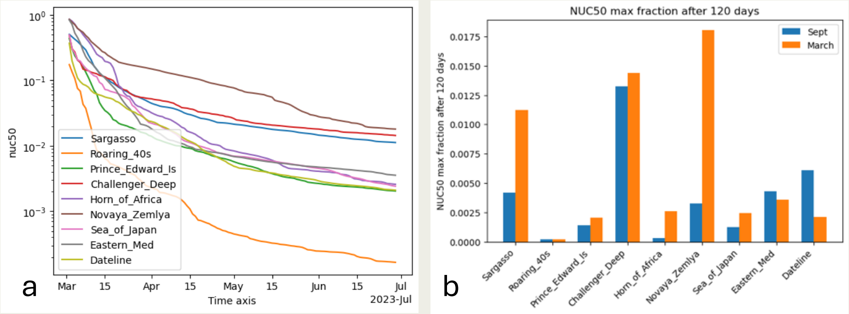

Figure 7: a. Time variation of maximum tracer concentrations for the 9 release sites over 4 months after insertion of tracer on 1 Mar 2023. b: Maximum tracer concentrations at end of 4-month period for September (blue) and March (orange) releases.

Conclusions

The radionuclide distribution is very sensitive to the flow regime near the detonation site. At some coastal sites, like Novaya Zemlya (and subtropical sites like the Sargasso and Challenger Deep sites), the tracer remains relatively confined and less dilute, but at the Antarctic Circumpolar sites (Roaring 40s and Prince Edward Island), the initial tracer region is diluted and dispersed very rapidly. Even a relatively slow sinking rate of 0.02 cm/s, i.e. ~17m/day, has a major effect on the tracers, which then have very low surface concentrations after only a few days.

Recommendations

1. Rapid deployment of any monitoring activity or On-Site Inspection (OSI) is important, as the near-surface concentrations decrease rapidly. This is particularly so in the case of additional sinking (from explosions which interact with the seabed), with even the smallest particles quickly sinking away from the surface.

2. It is important to deploy the monitoring capability in the main direction of tracer travel; this can vary widely between sites, and even at different times of year.

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