

# Predicting Oil Spill Drift in the Laptev/Kara Sea

## Context, assumptions and simulation framework

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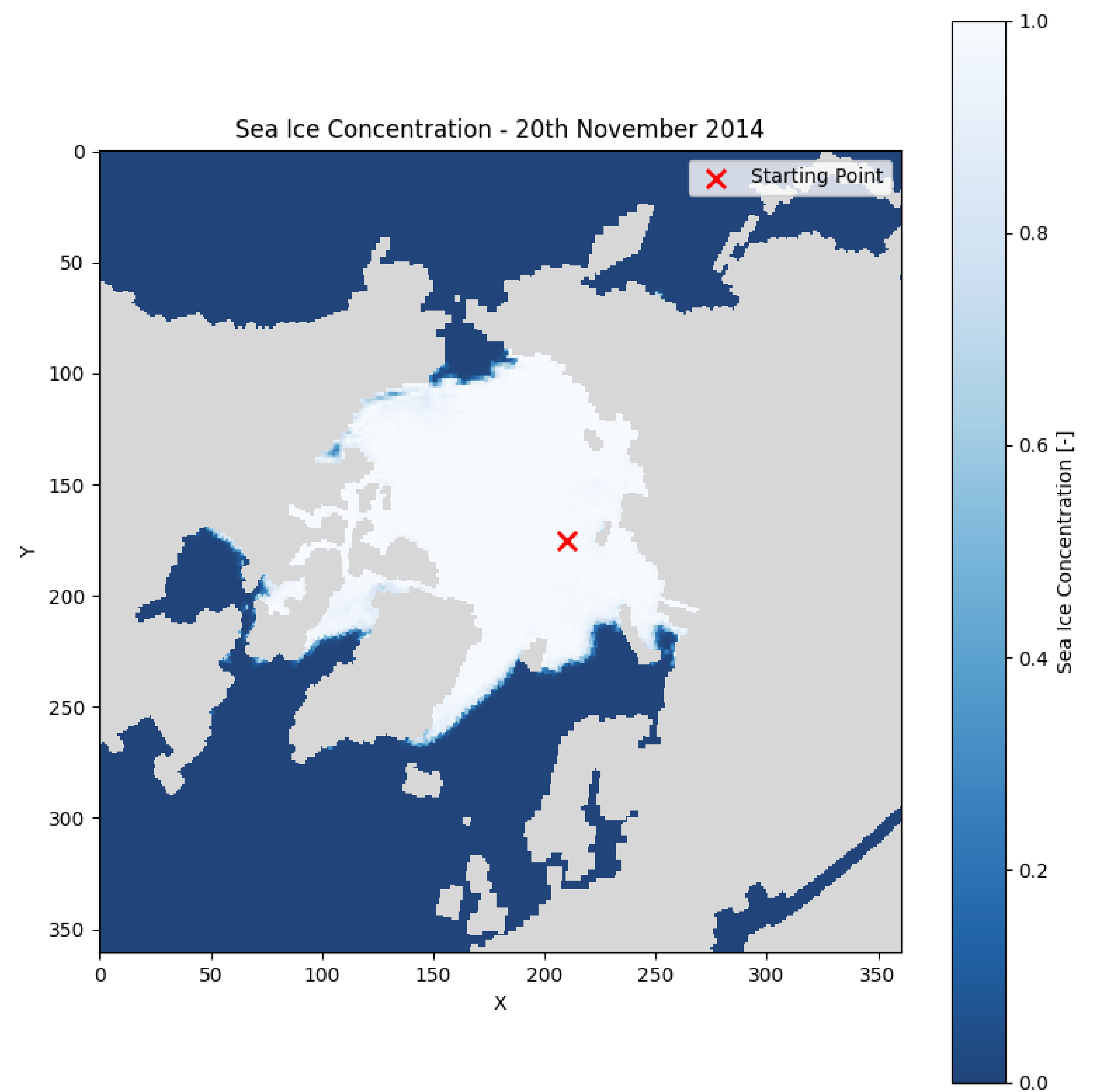
### Context

Arctic sea-ice decline is transforming the Laptev/Kara Sea region into a more accessible area for shipping, resource exploration and industrial activity. These changes increase the probability of accidents in a remote environment where emergency response is logistically difficult.

As Arctic sea ice declines, shipping routes remain open for longer periods each year, increasing both maritime traffic and the potential risk of oil spills. In the Arctic, oil can interact with sea ice instead of spreading only at the ocean surface. It may become trapped, transported over long distances by sea-ice motion, and released later when the ice concentration decreases.

This project investigates how oil particles released in the Laptev/Kara region could drift with sea ice before melting out, in order to support oil-spill monitoring and containment planning.

### Study area



The release point is located in the **Laptev/Kara Sea region**, at grid cell [210,175]. Oil beads are released on the **20<sup>th</sup> of November** and then transported by sea-ice motion.

## Simulation framework

<p><b>1</b> Oil representation</p> <p>Oil is represented by <b>100</b> discrete Lagrangian beads released from grid cell [210, 175].</p>	<p><b>2</b> Sea-ice transport</p> <p>Beads are transported by the simulated sea-ice velocity field.</p>	<p><b>3</b> IDW interpolation</p> <p>Sea-ice velocity and concentration are interpolated at beads locations using Inverse Distance Weighting (IDW).</p>	<p><b>4</b> Daily advection</p> <p>Each bead is moved forward using a one-day time step.</p>	<p><b>5</b> Melt-out threshold</p> <p>If local sea-ice concentration drops below <b>15%</b>, the bead is removed from the simulation.</p>	<p><b>6</b> Ensemble design</p> <p>The experiment is repeated for <b>10</b> forcing years, from <b>2014 to 2023</b>.</p>
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## Objective



The objective is to estimate where and when oil particles transported by Arctic sea ice are likely to be released.

The results aim to identify main drift pathways, melt-out timing, high-probability impact zones, and containment needs for Arctic oil-spill response planning.



Drift pathways



Melt-out timing

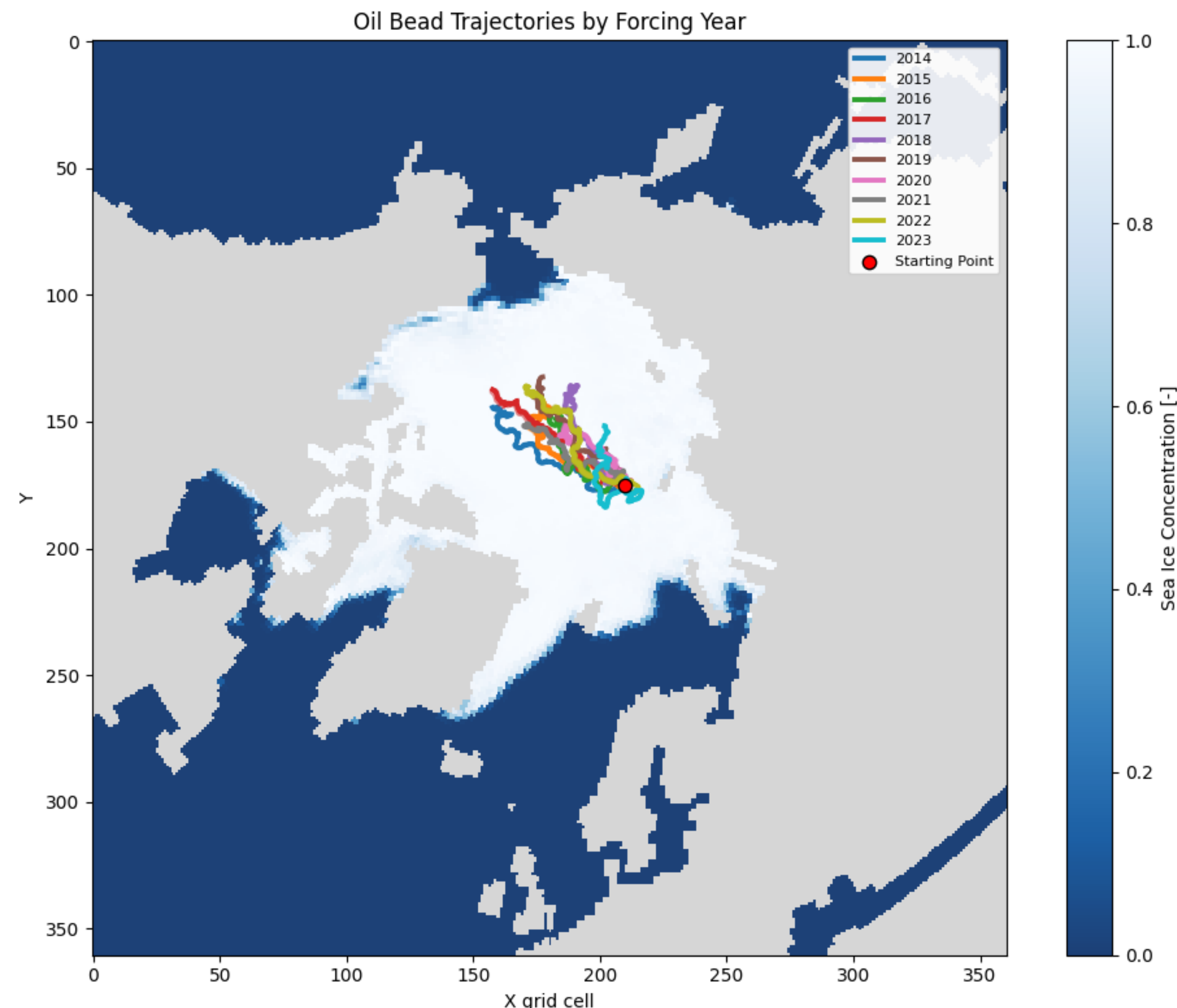


Containment needs

# Results and operational implications

## Predicting oil-bead drift from the Laptev/Kara Sea

### 1 Ensemble drift pathways



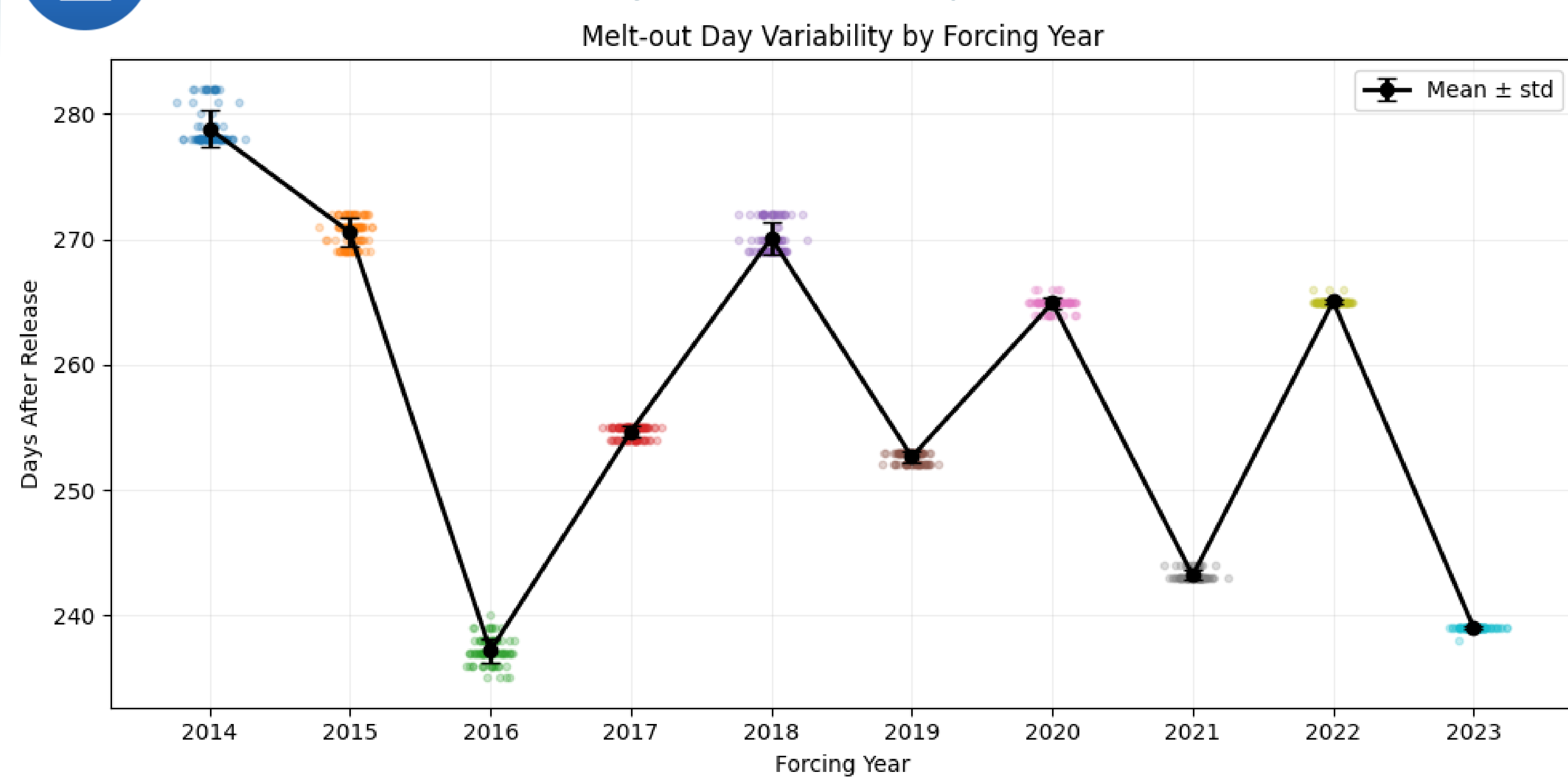
Oil beads follow a coherent drift pathway from the Laptev/Kara release point rather than dispersing randomly across the Arctic. Within each forcing year, trajectories remain relatively grouped, indicating low intra-annual variability in transport.

Across forcing years, however, the position of the annual clusters shifts noticeably, showing that drift pathways are highly sensitive to year-specific sea-ice and atmospheric conditions.

#### Why it matters

Trajectory clustering reveals where oil is likely to travel, while year-to-year shifts quantify uncertainty in pathway location.

### 2 Melt-out timing variability



Melt-out timing shows marked interannual variability. In our simulations, the mean melt-out day ranges from approximately 239 to 279 days after release, depending on the forcing year.

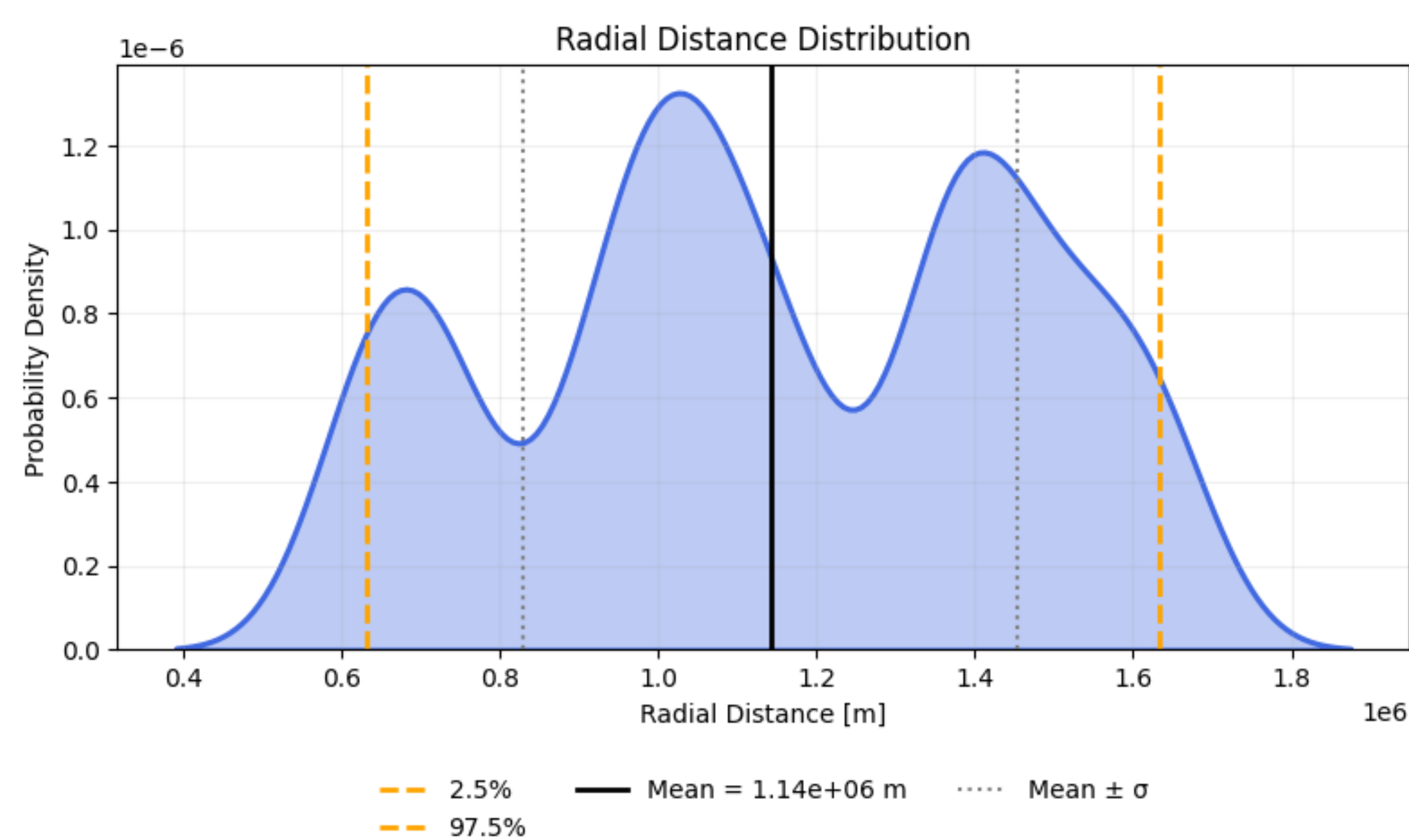
Within a given year, the spread remains limited, meaning that most oil beads are released from the ice within a relatively short seasonal window once conditions are set.

However, the sequence of annual means does not follow a simple increasing or decreasing trend. Instead, it fluctuates substantially from one year to another, highlighting the strong sensitivity of melt-out timing to year-specific sea-ice and atmospheric conditions.

Years with earlier melt-out may correspond to weaker or less persistent sea-ice conditions, allowing oil beads to leave the ice more rapidly.

**Key message :** *Interannual variability dominates over within-year variability.*

### 3 Transport distance

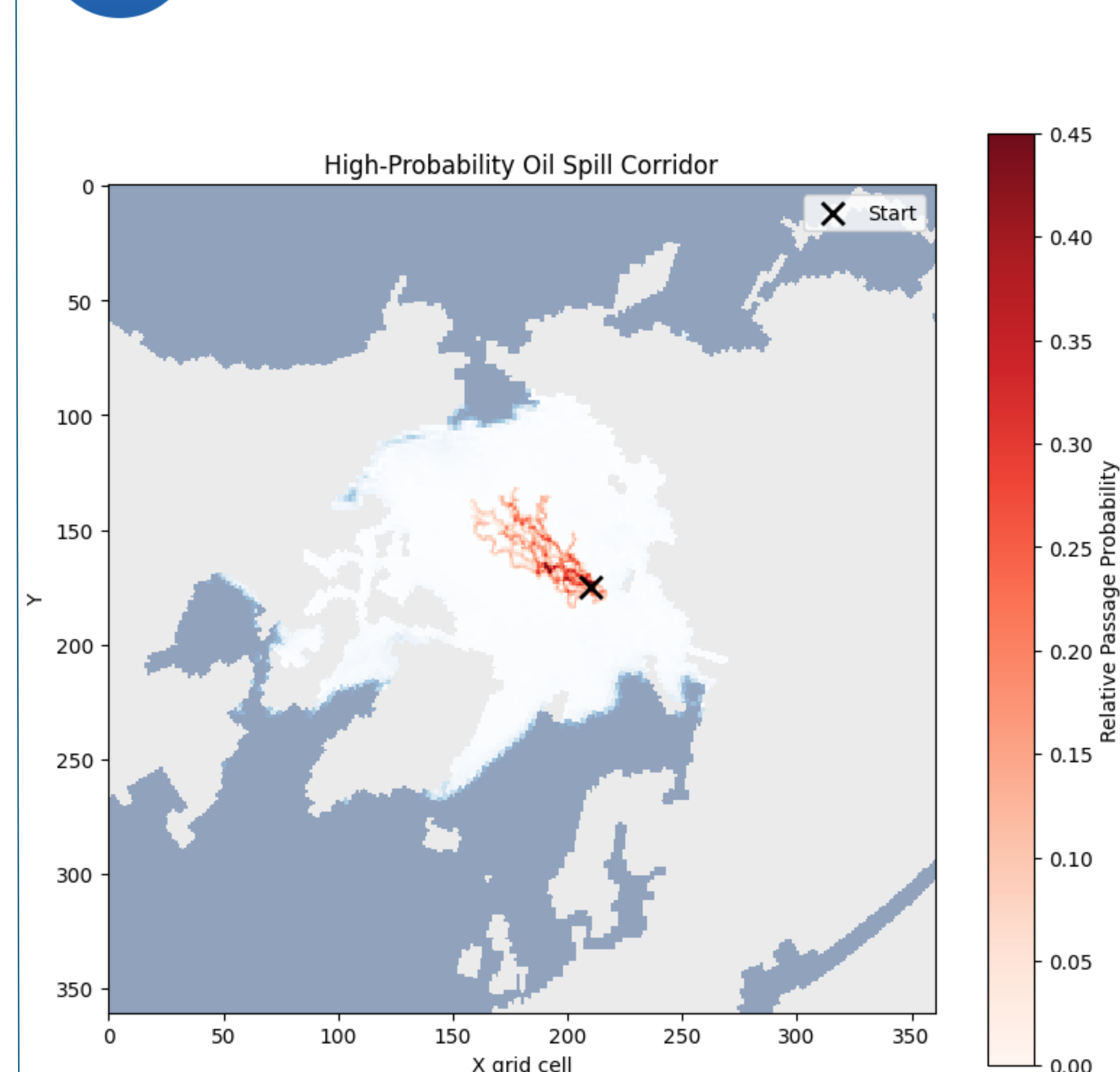


Final bead positions are located on average about 1,142 km from the release point, with a 95% interval of 630km to 1,632km. This confirms that oil trapped in sea ice can be transported over long distances before melt-out.

However, the spread remains bounded, providing a first-order search radius for monitoring and response planning.

**Mean distance  $\approx$  1141.7 km | 95% interval  $\approx$  630.1–1632.3 km**

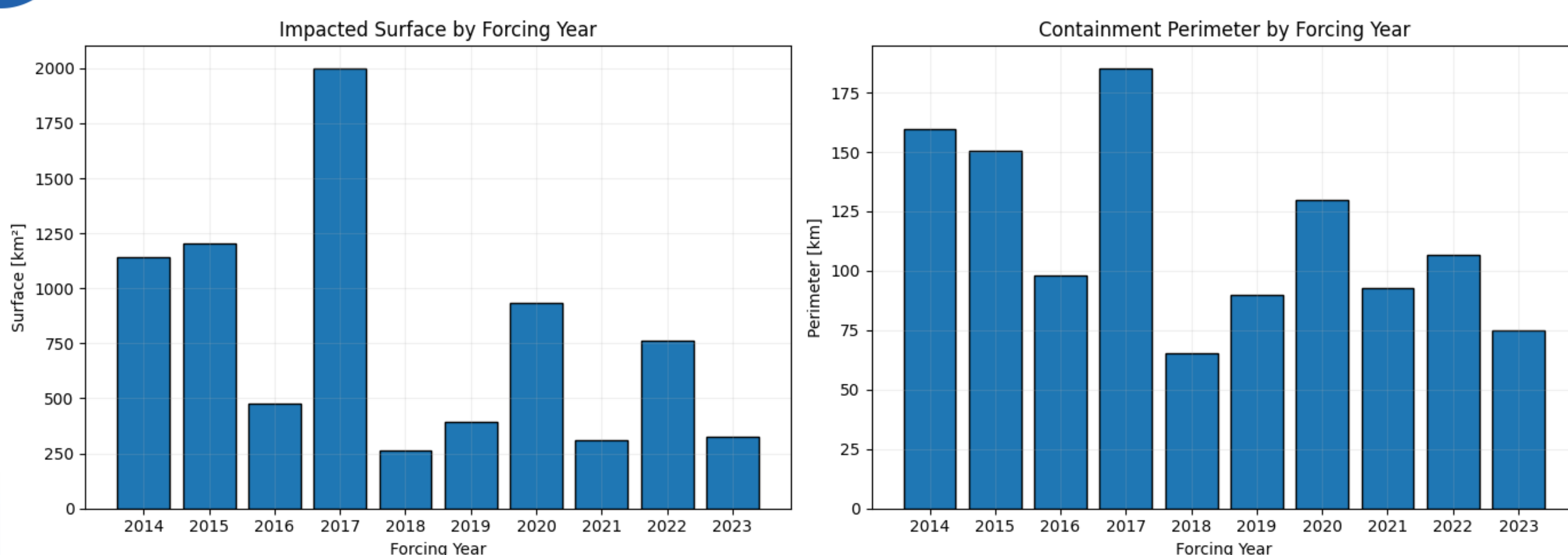
### 4 High-probability spill corridor



The probability map highlights the grid cells most frequently crossed by oil-bead trajectories. Instead of a wide and uniform spread, the model identifies a compact downstream corridor where passage probability is highest.

This probability map identifies the main corridor most frequently crossed by oil beads. It highlights priority areas for surveillance and response planning. It can also support risk zoning and the pre-positioning of emergency assets.

### 5 Containment requirements



Containment requirements vary substantially between forcing years, confirming that response needs depend strongly on annual drift conditions. The largest impacted surface occurs in 2017, while lower values are observed in years such as 2018 and 2021.

Using the convex-hull approach, the mean impacted area is about 781.8 km<sup>2</sup> and the 95% quantile reaches about 1643.3 km<sup>2</sup>. The mean containment perimeter is about 115.3 km, with a 95% quantile near 173.8 km. These values provide first-order estimates of the boom length and operational footprint required under different conditions.

#### Key statistics

- Mean impacted area  $\approx$  **781.8 km<sup>2</sup>**
- 95% quantile  $\approx$  **1643.3 km<sup>2</sup>**
- Mean perimeter  $\approx$  **115.3 km**
- 95% quantile  $\approx$  **173.8 km**

#### Operational implications

- Focus surveillance along the high-probability drift corridor.
- Prepare response operations around a broad melt-out window that varies between years.
- Use the upper-range containment estimate ( $\sim$ 174 km perimeter) for conservative boom-planning scenarios.
- Treat ensemble spread as useful planning information, not as a flaw.

#### Conclusion

Ensemble simulations suggest that oil released in the Laptev/Kara region follows a coherent but year-dependent drift system. The results identify likely pathways, melt-out timing, priority monitoring zones, and first-order containment needs. Together, these outputs provide practical guidance for Arctic spill-response planning while preserving the uncertainty needed for robust decision-making.

#### Limitations

- Only 10 forcing years were used.
- Oil is represented as passive beads.
- Weathering, spreading, waves, beaching, re-mobilization, and oil-ice chemistry are not included.
- Results should be interpreted as guidance, not exact forecasts.

Access to our code simulations :

