Modeling drifter trajectories and ensemble dispersion from the Ocean Training Course 2025

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1 Introduction

This project aims to reconstruct the trajectory of drifters deployed during the expedition and to better understand how physical processes govern their motion. We thus need to take into account the satellite measurements of sea surface deformation, wave induced currents and wind speed. We employ a two folded approach: (i) in first approximation a linear combination of the surface currents, Stokes drift and direct wind-force, and (ii) the full equations describing the dynamics of floating intertial particles in the ocean -the Maxey-Riley set. These two methods will allow us to decompose and analyze the individual forces governing the drifter's motion, providing deeper insights into the underlying dynamics.

We focus here on deterministic modellings of the drift. However, given the inherent chaotic nature of the problem and the uncertainties carried by our observations of oceanic and atmospheric variables, stochastic approaches might be relevant to simulate ensemble of probable and realistic trajectories, rather than one *incorrect* estimate. One challenge is to control the dispersion of simulated ensembles to accurately cover the distribution of possible trajectories. To address this question we study the relative dispersion over time of several ensembles of drifters deployed at the same space-time position.

2 Instruments, data and methods

This section describes the two types of drifters deployed during OTC25, as well as the data and trajectory reconstruction methods used in our analysis. We first present the design of the MELODI and SPOT drifters. Next, we introduce the different satellite-derived and drifter datasets (including the preprocessing steps applied when relevant). Finally, we detail the Lagrangian statistics used to characterize the drift dynamics, the trajectory reconstruction methods implemented, and the metrics employed to evaluate them.

2.1 Drifters deployed during the campaign

At the time of writing only eOdyn MELODI and IGE SPOT data are available. We therefore focus on these two types of drifters; however, it should be mentioned that 16 OpenMetBuoy, 4 CLS MARGE-T II, and 1 Sofar Spotter buoys were also deployed during the campaign. Including these additional drifters would help strengthen our analysis, as described in Section 4.

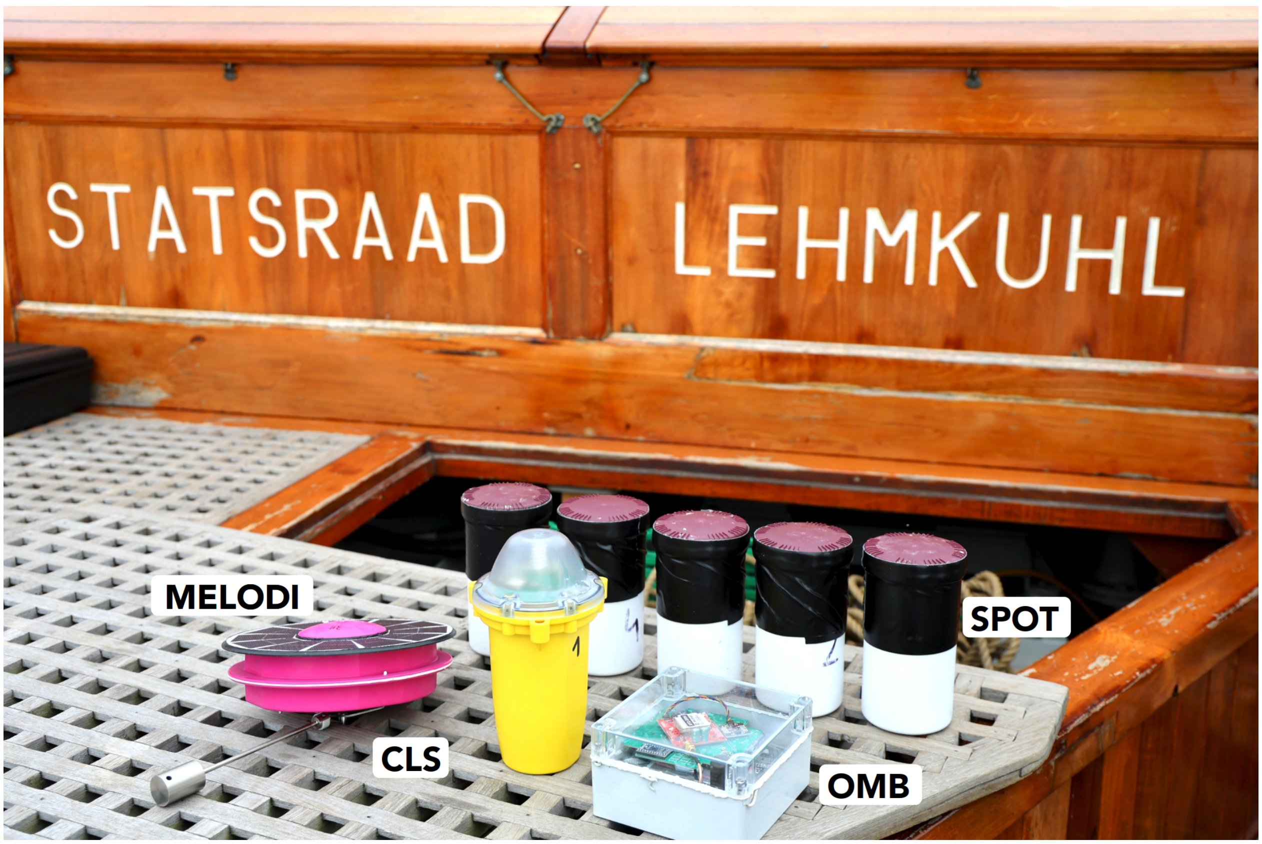


Figure 1: Types of drifters deployed during the OTC25 campaign between Tromsø and Nice. There was also a Sofar drifter not shown in the picture. Photo taken by Joël Marc.

2.1.1 MELODI

The MELODI ("MELODI" 2024) is a surface drifter developed by the company eOdyn. Although we are only interested in the drifter's position, it also measures surface currents, surface temperature and wave parameters. The position is determined using several satellite constellations, with a sampling frequency of 1 hour. The drifter uses the Iridium satellite network to transmit its data. It is powered by four Li-ion 3500 mAh, 3.7 V batteries and a 6 W solar panel, which allows it to operate for at least several months. Thanks to its low-profile, see Figure 2, the MELODI drifter is expected to be only weakly affected by wind drift.

From Tromsø to Nice, 18 MELODI drifters were deployed in various locations: in the North Sea and its

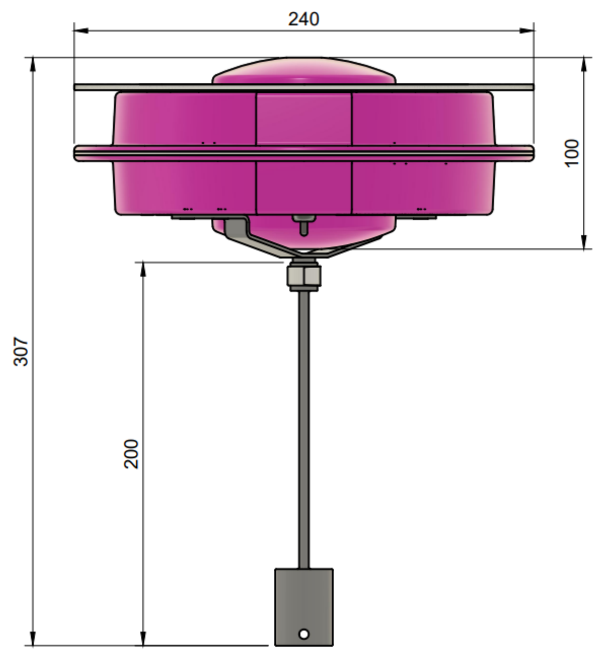


Figure 2: Design of the MELODI drifter

Lofoten eddy, in the North Atlantic (including during a storm event), before and after the Strait of Gibraltar (within the Alboran eddy), and in the western Mediterranean Sea. This can be seen in Figure 3.

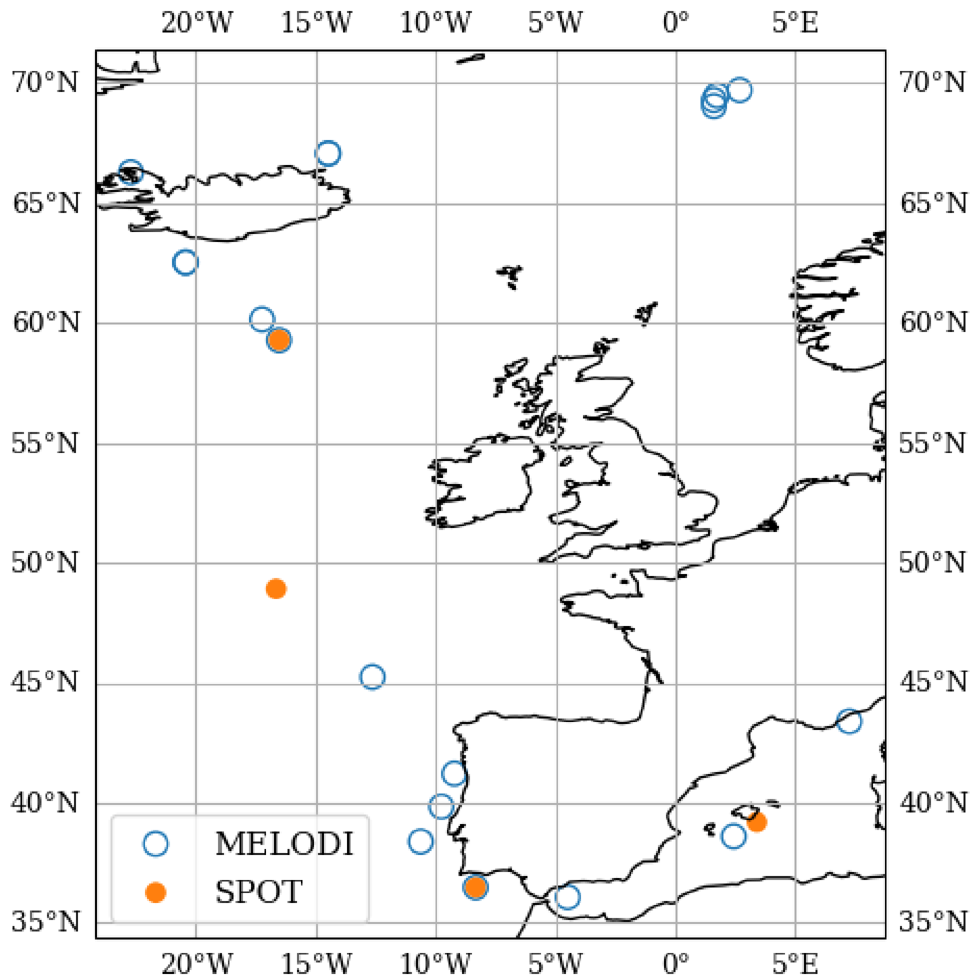


Figure 3: MELODI and SPOT drifter deployments during the OTC25 campaign.

2.1.2 SPOT

The SPOT ("SPOT" 2024) is a home-made surface drifter designed and developed at Institut des Géosciences de l'Environnement (IGE). Its design is very simple, see Figure 4: a weighted waterproof jar containing a GPS tracer powered by external batteries. The GPS tracer is a SPOT Trace, which uses the Globalstar satellite network to transmit its position every 30 minutes. External batteries (4 LR20 alkaline 1.5V 13Ah) allow the drifter to operate for up to 6 months and counting at the time of writing.

During the first deployments we noticed that the SPOT drifters exhibited an orbital motion around their vertical axis and we suspected that it was the cause for the observed effective sampling frequency being larger than the nominal 30 minutes (see Figure 6). To mitigate this motion we designed a dynamic anchor attached to the bottom of the drifter. Being at sea we had to reuse material available aboard the ship: old sails and steel wire ropes, as visible in Figure 5.

The last 5 drifters deployed in the Mediterranean Sea were equipped with this anchor. Using the drifter data presented in Section 2.2.2 it seems that the anchor was effective in improving the effective sampling frequency, as shown in Figure 6. Further analysis would be required to confirm this is due to the dynamic anchor and not because of an overall quieter sea state in the Mediterranean Sea.

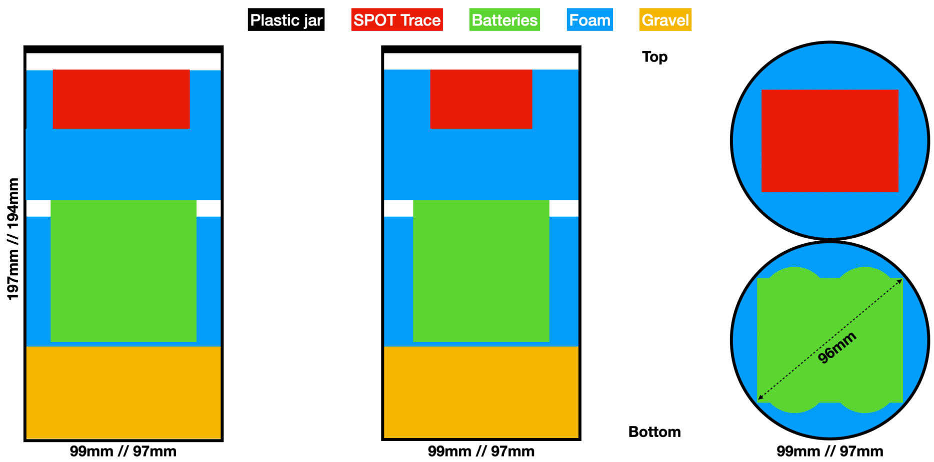


Figure 4: Design of the SPOT drifter

Figure 5: SPOT drifter with a dynamic anchor

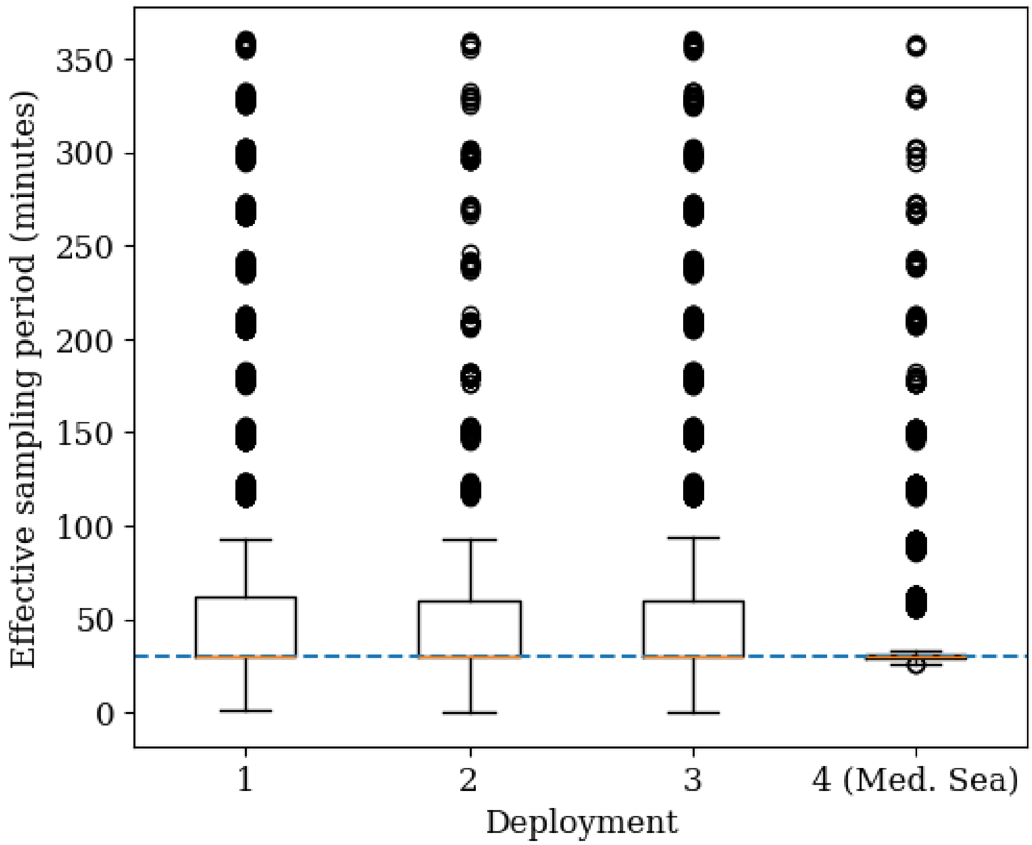


Figure 6: SPOT drifters effective sampling period. The dashed blue line indicates the nominal sampling period of 30 minutes.

2.2 Satellite and drifter data

Our analysis requires both maps of geophysical quantities (surface currents, waves, winds) and lagrangian drifter trajectories.

2.2.1 Satellite-derived gridded products

Geophysical quantities of interest are derived from satellite observations, assimilated in physical models of varying complexity.

2.2.1.1 Sea Surface Height

VarDyn is a variational mapping method jointly reconstructing Sea Surface Height (SSH) and Sea Surface Temperature (SST) (Le Guillou, Chapron, and Rio 2025). The version used in our analysis assimilates both SWOT KaRin and Nadir altimeters data and produces daily $0.05° \times 0.05°$ maps. This dataset provides both SSH and sea surface currents, derived from the SSH field using the cyclogeostrophic inversion method proposed by Bertrand, Le Sommer, et al. (2025) and implemented in the Python package `jaxparrow` (Bertrand, Vianna Zaia De Almeida, et al. 2025).

2.2.1.2 Sea Surface Wind

Wind acts both directly on the drifter (the leeway) and indirectly through its effect on waves and currents. We use the wind velocity at 10 meters above the surface from the $0.125° \times 0.125°$ hourly ECMWF bias corrected product (WIND_GLO_PHY_L4_NRT_012_004 2024) developed by the Royal Netherlands Meteorological Institute.

2.2.1.3 Sea State

Waves also affect drifter trajectories through the Stokes drift. We employ the Stokes drift obtained by assimilating significant wave height in the wave model MFWAM, available in the 0.083° × 0.083° hourly Global Ocean Waves Analysis and Forecast product (GLOBAL_ANALYSISFORECAST_WAV_001_027 2023) developed by Mercator Ocean International.

2.2.2 Drifter data

Starting from the raw GPS positions transmitted by the drifters, we perform several preprocessing steps before using them in our analysis.

2.2.2.1 L0 version

The L0 version of the data consists of datasets containing the original timestamps and positions (latitude and longitude) for each drifter, complemented by its deployment date and time. Each record also includes the time interval between successive measurements.

2.2.2.2 L1 version

The L1 version of the data is produced by applying the following Quality Control (QC) steps to the L0 dataset:

1. Spurious GPS locations were removed following the procedure described by Elipot et al. (2016),
2. Curated trajectories were divided into segments whenever the time gap between two consecutive timestamps exceeded 6 hours,
3. Segments shorter than 1 day are discarded.

As shown in Table 1, these QC steps result in only a small reduction in the number of MELODI drifter observations. In contrast, about 20% of the SPOT observations were discarded, primarily due to transmission issues that caused large gaps in the original trajectories and consequently led to many short segments being removed.

Table 1: Number of observations and segments in L0 and L1 versions for SPOT and MELODI datasets.

Dataset	# Observations		# Segments	
	L0	L1	L0	L1
SPOT	24503	19846	20	189
MELODI	47399	46837	19	39

2.2.2.3 L2 version

Trajectories are resampled at a regular time interval of 1 hour using a linear interpolation for the positions and the velocities are then computed using central differences.

An example of L0, L1 and L2 trajectories for a SPOT drifter is shown in Figure 7. It can be seen that the L0 trajectory contains some spurious points, which are removed in the L1 and L2 versions. Holes in the L1 and L2 trajectories correspond to gaps larger than 6 hours in the original data. Holes are not filled by interpolation in the L2 version as those trajectories are then considered as distinct segments.

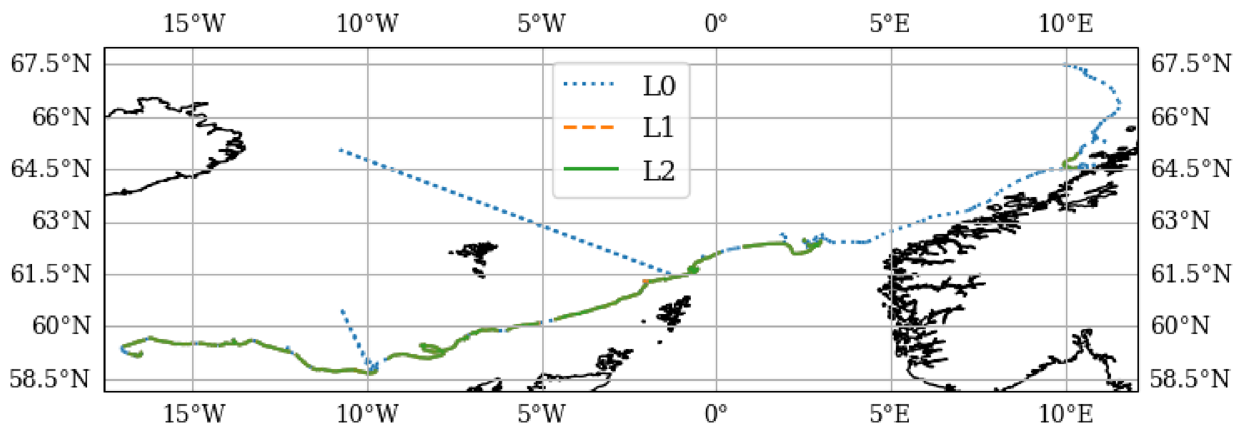


Figure 7: SPOT drifter 0-4498291 data (2025-05-12 – 2025-09-16) at different pre-processing levels.

Figure 8 presents the L2 trajectories of both SPOT and MELODI drifters deployed between Tromsø and Nice during OTC25.

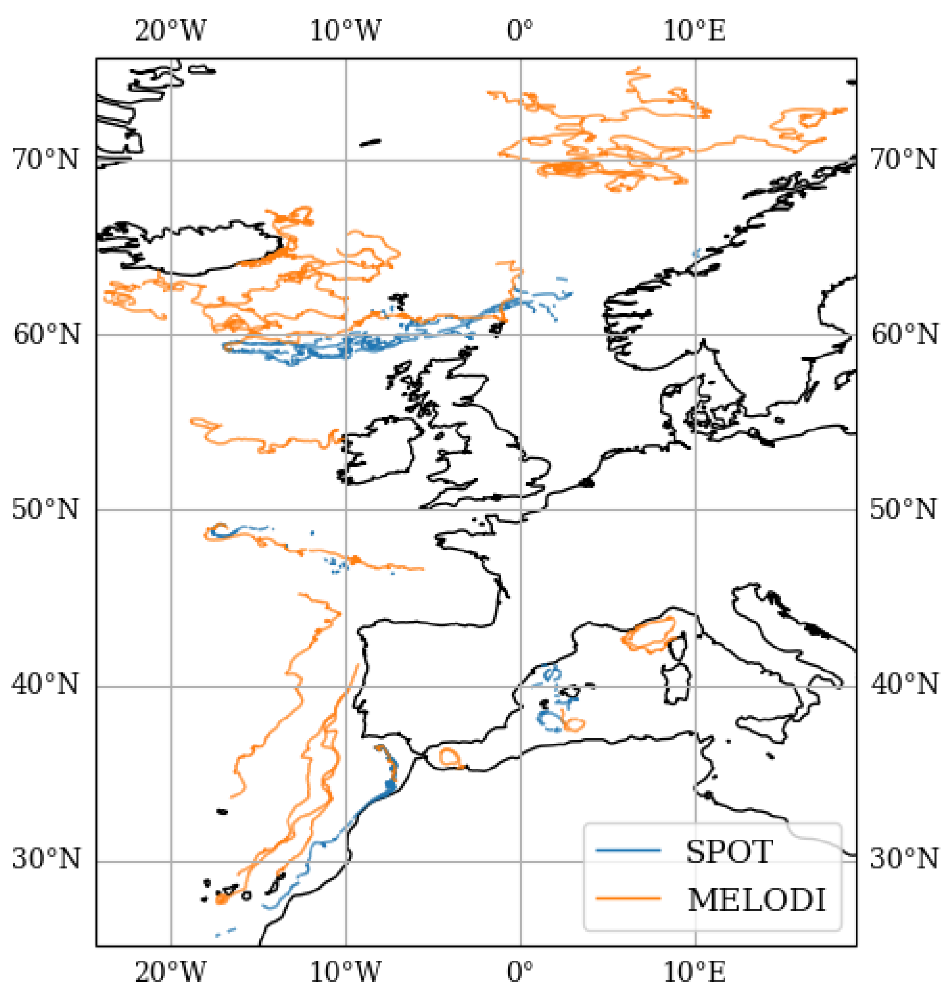


Figure 8: L2 drifters data from the OTC 25 (2025-04-25 – 2025-09-16).

2.3 Modeling of drifter trajectories

2.3.1 Linear combination

2.3.2 Maxey-Riley equation

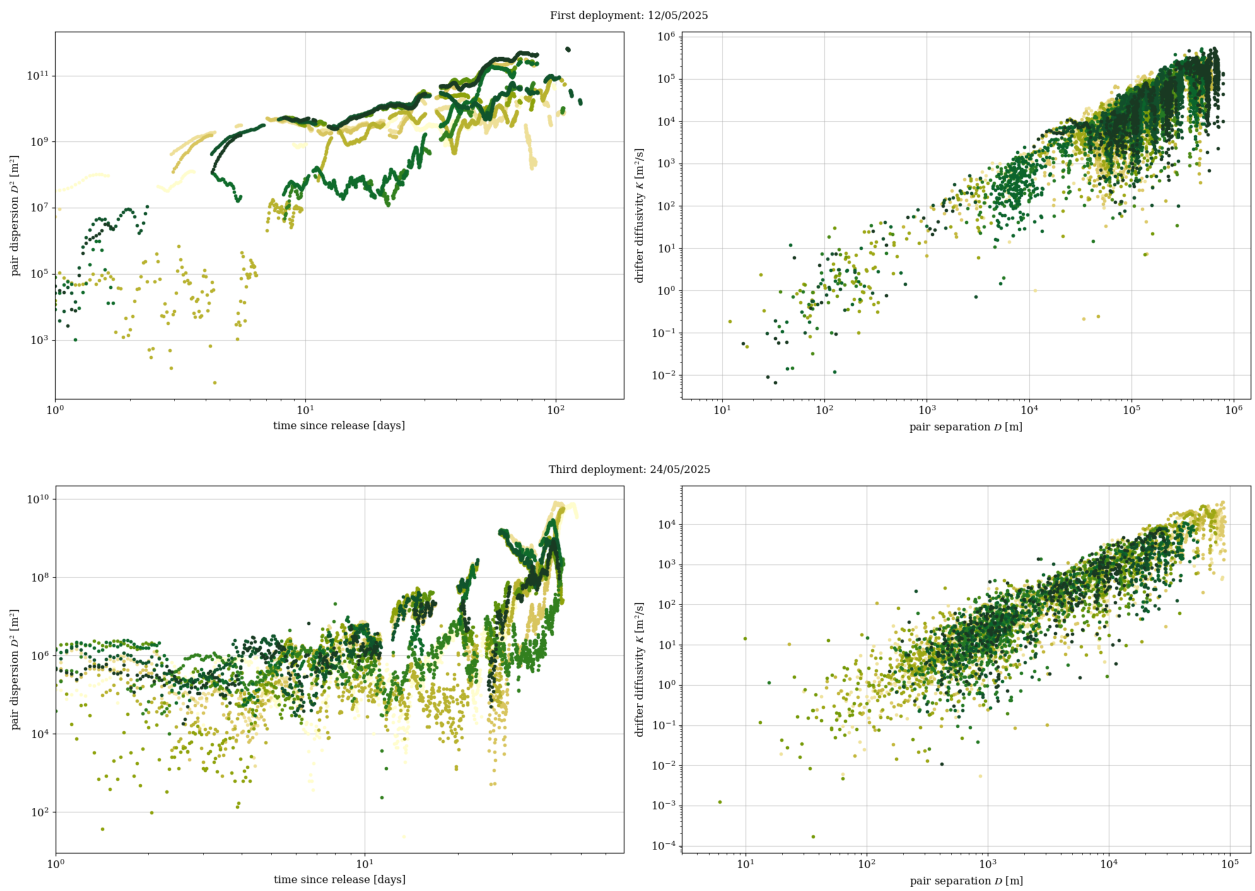
2.4 Pair dispersion

2.5 Drone measurements

Source: Instruments, data and methods

3 Results

3.1 Pair dispersion



Source: Results

4 Discussion

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5 Conclusion

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