



*Supplement of*

## **Data-driven enhancement of ocean surface forcing for accurate floating debris transport modelling in the East/Japan Sea**

**Hong Thi My Tran et al.**

*Correspondence to:* Jun Myoung Choi (jmchoi@pknu.ac.kr)

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# Supplement

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These Additional Materials provide the analyses cited in Sect. 3.5 of the manuscript. Tables S1-S2 report PTM-DX windage-coefficient sensitivity, Table S3 reports the segment-based PTM-DX evaluation, and Tables S4-S5 compare the original single-particle and 10-realisation ensemble results. MAE values are in kilometres; lower values indicate better agreement. C1-C8 are defined in Table 1 of the manuscript.

## S1. Windage-coefficient sensitivity

For PTM-DX, the geometry-based coefficient  $r = 0.015$  was compared with  $r = 0.005$  and  $r = 0.030$  while all other settings were unchanged. The lowest average MAE was 117.3 km for C8 at  $r = 0.005$ , 42.9 km for C7 at  $r = 0.015$ , and 88.2 km for C4 at  $r = 0.030$ . The geometry-based value therefore produced the lowest overall error.

Table S1. PTM-DX MAE (km) for the windage-sensitivity test with  $r = 0.005$ . Avg. is the mean for days 5, 10, 30, and 75.

| Day  | C1    | C2    | C3    | C4    | C5    | C6    | C7    | C8           |
|------|-------|-------|-------|-------|-------|-------|-------|--------------|
| 5    | 130.2 | 128.2 | 123.1 | 129.8 | 106.3 | 117.1 | 90.0  | <b>29.2</b>  |
| 10   | 252.4 | 243.2 | 223.7 | 237.2 | 207.1 | 220.9 | 166.0 | <b>138.2</b> |
| 30   | 473.4 | 449.3 | 300.2 | 423.5 | 260.2 | 348.0 | 209.0 | <b>161.1</b> |
| 75   | 550.2 | 541.3 | 290.9 | 459.2 | 219.8 | 369.3 | 145.0 | <b>140.7</b> |
| Avg. | 351.6 | 340.5 | 234.5 | 249.9 | 198.4 | 211.1 | 122.0 | <b>117.3</b> |

Table S2. PTM-DX MAE (km) for the windage-sensitivity test with  $r = 0.030$ . Avg. is the mean for days 5, 10, 30, and 75.

| Day  | C1    | C2    | C3    | C4           | C5    | C6    | C7    | C8    |
|------|-------|-------|-------|--------------|-------|-------|-------|-------|
| 5    | 130.2 | 128.2 | 123.1 | <b>25.6</b>  | 106.3 | 31.8  | 48.4  | 58.6  |
| 10   | 252.4 | 243.2 | 223.7 | <b>69.8</b>  | 207.1 | 87.2  | 117.7 | 109.7 |
| 30   | 473.4 | 449.3 | 300.2 | <b>131.9</b> | 260.2 | 165.9 | 207.7 | 198.8 |
| 75   | 550.2 | 541.3 | 290.9 | <b>125.5</b> | 219.8 | 173.7 | 207.7 | 198.8 |
| Avg. | 351.6 | 340.5 | 234.5 | <b>88.2</b>  | 198.4 | 91.7  | 116.3 | 113.2 |

## S2. Segment-based trajectory skill

To reduce the influence of accumulated downstream separation after the early bifurcation, observed and simulated DX trajectories were evaluated independently in 3-day segments. GSWE produced the lowest mean segment MAE (28.7 km) and standard deviation (3.7 km), followed by GSW (31.3 km).

Table S3. Segment-based PTM-DX MAE (km), calculated independently within 3-day intervals. G, E, S, and W denote geostrophic current, Ekman current, Stokes drift, and windage; AVG and STD are the mean and standard deviation across the listed intervals.

| Interval (days) | 0-3   | 3-6  | 6-9  | 27-30 | 72-75 | AVG         | STD        |
|-----------------|-------|------|------|-------|-------|-------------|------------|
| G               | 120.0 | 37.0 | 31.5 | 41.8  | 37.4  | 53.5        | 33.4       |
| GE              | 113.1 | 38.1 | 29.9 | 37.1  | 41.3  | 51.9        | 30.8       |
| GS              | 103.0 | 32.2 | 30.6 | 27.5  | 27.3  | 44.1        | 29.5       |
| GW              | 83.4  | 27.4 | 31.6 | 31.9  | 53.4  | 45.5        | 21.0       |
| GSE             | 91.6  | 33.1 | 29.4 | 25.8  | 28.9  | 41.8        | 25.0       |
| GEW             | 67.6  | 27.9 | 30.1 | 28.6  | 57.2  | 42.3        | 16.8       |
| GSW             | 46.4  | 22.4 | 33.3 | 27.4  | 27.1  | 31.3        | 8.3        |
| GSWE            | 33.6  | 23.7 | 31.9 | 25.4  | 29.0  | <b>28.7</b> | <b>3.7</b> |

## S3. Stochastic-ensemble sensitivity

The simulations were repeated with 10 numerical particles (realisations) for each observed drifter initial location, varying only the Gaussian random sequences. Absolute MAE values changed slightly, but C7 remained best for PTM-DX after day 5 and C8 remained best for PTM-DO.

Table S4. Original single-particle MAE (km), using one numerical particle per observed drifter initial location.

| PTM    | Day | C1    | C2    | C3    | C4    | C5    | C6    | C7          | C8           |
|--------|-----|-------|-------|-------|-------|-------|-------|-------------|--------------|
| PTM-DX | 5   | 134.5 | 107.3 | 122.7 | 90    | 106.1 | 57    | 22          | <b>19.3</b>  |
| PTM-DX | 10  | 251.4 | 242.6 | 221.1 | 166   | 209.6 | 92.6  | <b>24.1</b> | 35.8         |
| PTM-DX | 30  | 475.8 | 460.7 | 308.6 | 209   | 265.6 | 92    | <b>54</b>   | 91           |
| PTM-DX | 75  | 562.5 | 606.1 | 347   | 145   | 243.9 | 90.8  | <b>73.8</b> | 83.2         |
| PTM-DO | 5   | 75.7  | 64.1  | 79.3  | 68.7  | 68.8  | 59.2  | 68.7        | <b>55.3</b>  |
| PTM-DO | 10  | 146.5 | 135.6 | 140.2 | 123.1 | 129.4 | 113.8 | 120.1       | <b>107</b>   |
| PTM-DO | 30  | 318   | 286.5 | 304.9 | 235.6 | 216.9 | 175.5 | 201.4       | <b>110.7</b> |
| PTM-DO | 75  | 537   | 487.9 | 487.9 | 377.1 | 459.6 | 322.6 | 410.3       | <b>185.2</b> |

Table S5. Ensemble-mean MAE (km), using 10 numerical particles (realisations) per observed drifter initial location.

| PTM    | Day | C1    | C2    | C3    | C4    | C5    | C6    | C7          | C8          |
|--------|-----|-------|-------|-------|-------|-------|-------|-------------|-------------|
| PTM-DX | 5   | 130.2 | 128.2 | 123.1 | 89    | 106.3 | 60.9  | 25.3        | <b>20.4</b> |
| PTM-DX | 10  | 252.4 | 243.2 | 223.7 | 162.3 | 207.1 | 104.5 | <b>29.5</b> | 43.9        |
| PTM-DX | 30  | 473.4 | 449.3 | 300.2 | 216.4 | 260.2 | 104.6 | <b>55.6</b> | 114         |
| PTM-DX | 75  | 550.2 | 541.3 | 290.9 | 164.6 | 219.8 | 98.3  | <b>61.2</b> | 105.4       |
| PTM-DO | 5   | 70.5  | 64.8  | 77.4  | 67    | 67.5  | 57.8  | 67.5        | <b>53</b>   |
| PTM-DO | 10  | 142.9 | 133.5 | 143.1 | 125.7 | 129.4 | 114.3 | 120.1       | <b>106</b>  |

| PTM    | Day | C1    | C2    | C3    | C4    | C5    | C6    | C7    | C8           |
|--------|-----|-------|-------|-------|-------|-------|-------|-------|--------------|
| PTM-DO | 30  | 315.6 | 273.7 | 296.2 | 276   | 211   | 166.6 | 194.9 | <b>117.7</b> |
| PTM-DO | 75  | 528.1 | 488.7 | 477   | 472.9 | 359.2 | 285   | 330.9 | <b>182.6</b> |