

福島海域顆粒傳輸擴散系統

釋放源參數化模組開發與結果分析

王啓竑^{1*}, 鄭皓宇¹, 于嘉順¹,

曾慧婷², 鄧仁星²

¹西灣海環科技股份有限公司

²中央氣象署海象氣候組



BayTech
西灣海環

研究背景與動機



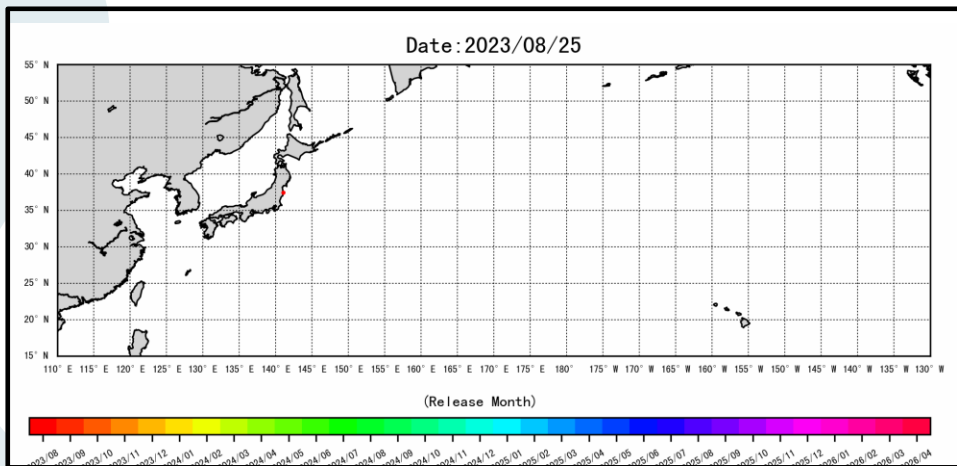
福島廢水持續排放

2023年8月起含氚廢水持續排放入海，
需掌握其於西北太平洋之傳輸擴散趨勢!!



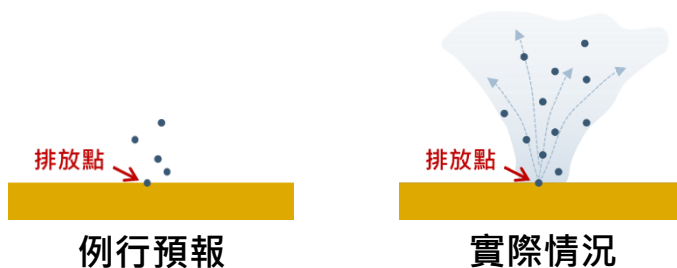
既有預報系統

已建置CWA-OCM-FH三維海流作業化預報系統，
搭配拉格朗日粒子追蹤模組每日例行預報



簡化假設

粒子以無初速條件置於海底排放口



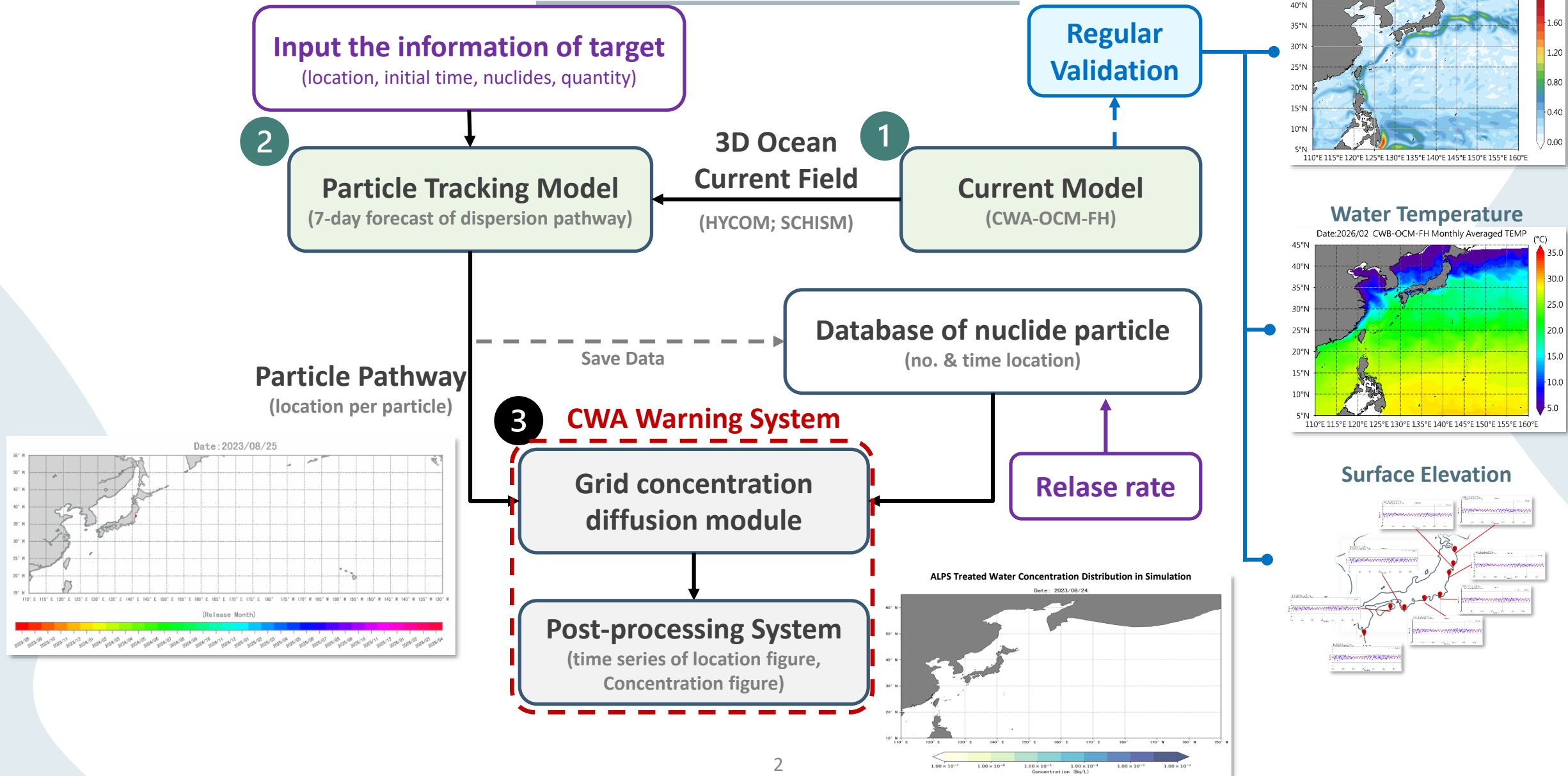
未反映實際的排放過程



目前沒有遠洋採樣資料可供校驗

透過介接小尺度CFD流場，讓模式結果能在近域進行校驗，
間接確保傳輸擴散系統的可信度

System Architecture Overview



CWA-OCM-FH Model Framework

Wind Field

- CWA-WRF
- CWA-TGFS (Backup)

Hydrodynamics

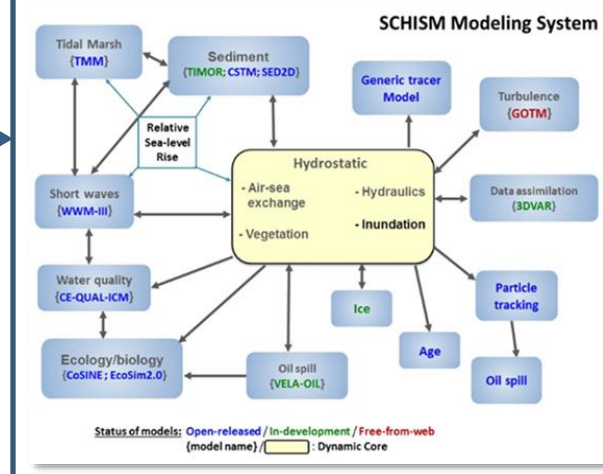
- Bathymetry
- Tides
- Ocean Current
- River Discharge

Optimization

- Pre-processing
- Data Assimilation

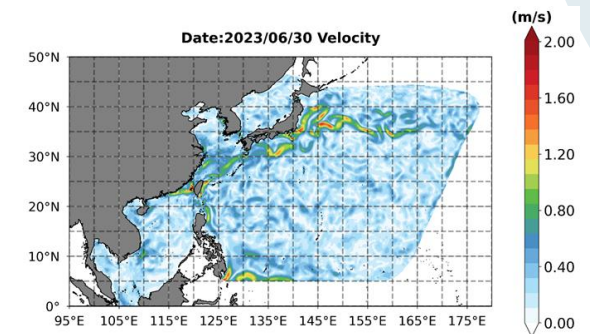
CWA-OCM-FH

SCHISM (3D Ocean Model)



Forecast Output

- 3D Ocean Current
- 3D Water Temperature
- 3D Salinity
- 2D Surface Elevation



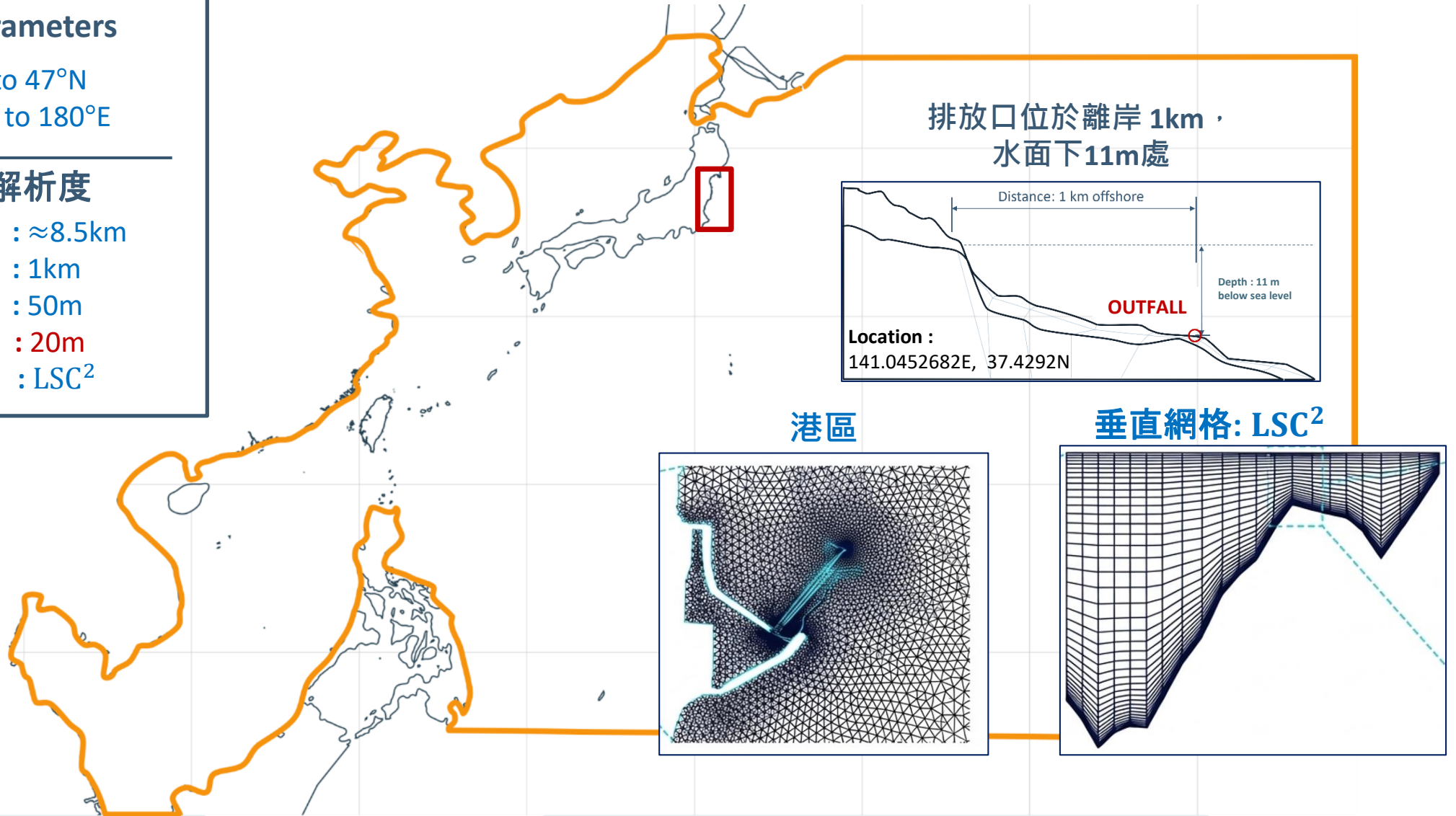
海流模式範圍與網格配置

Key Parameters

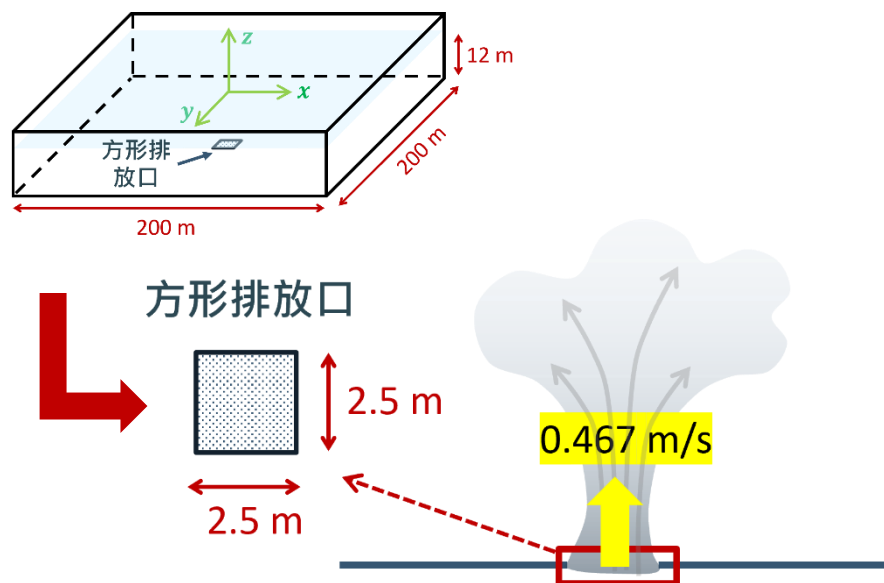
LAT : 0°N to 47°N
LON : 98°E to 180°E

網格解析度

遠域 : $\approx 8.5\text{km}$
近域 : 1km
港區 : 50m
排放口 : 20m
垂直網格 : LSC^2



CFD 近域流場模態



執行單位:

國家原子能科技研究院執行小尺度 CFD 模擬

模擬設定:

水平範圍 200m×200m、水深 11m、噴流口初速 0.467 m/s

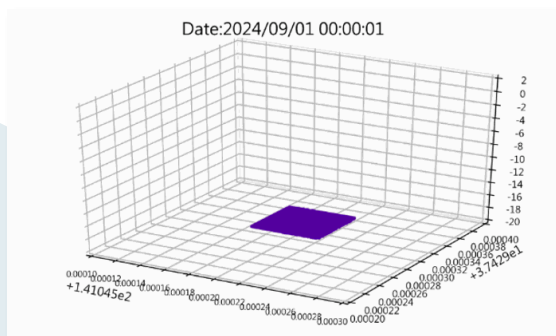
多背景流速模擬:

針對 0、0.1、0.5 m/s 等背景流速，**模擬小尺度近場噴流流場**

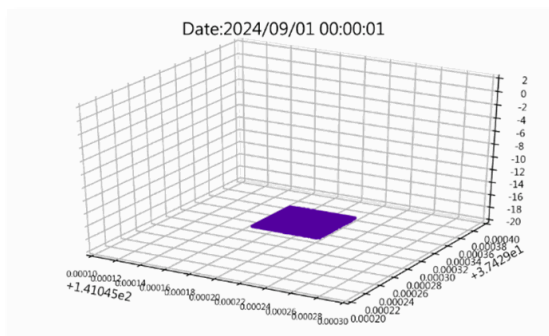
產出流場模態庫:

建立近場流場「模態」，供後續參數化模組即時調用

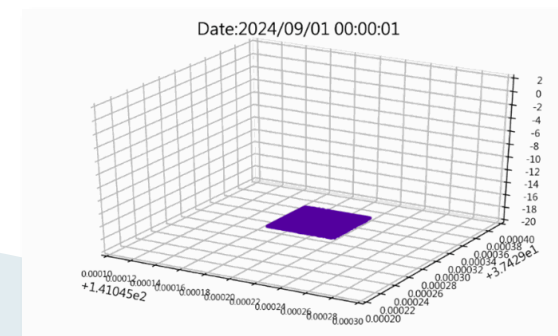
U=0.0 m/s



U=0.1 m/s



U=0.5 m/s



釋放源參數化模組架構

參數化的「位置-流速」迴歸方法(四次多項式)

$$u = \mathbf{a}U_b^4 + \mathbf{b}U_b^3 + \mathbf{c}U_b^2 + \mathbf{d}U_b + \mathbf{e} + \mathbf{A}(\text{deep}) + \mathbf{B}(\text{Intensity})$$

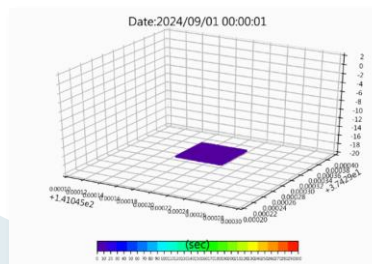
$U_b < 0.9$ (臨界值): $\mathbf{a} = a1$, $\mathbf{b} = b1$, $\mathbf{c} = c1$, $\mathbf{d} = d1$, $\mathbf{e} = e1$

$U_b \geq 0.9$ (臨界值): $\mathbf{a} = a2$, $\mathbf{b} = b2$, $\mathbf{c} = c1$, $\mathbf{d} = d1$, $\mathbf{e} = e1$

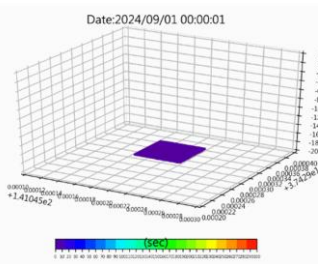
建立「CFD 模態」與「背景場流速」的關係函數

根據迴歸函數結果決定CFD模態

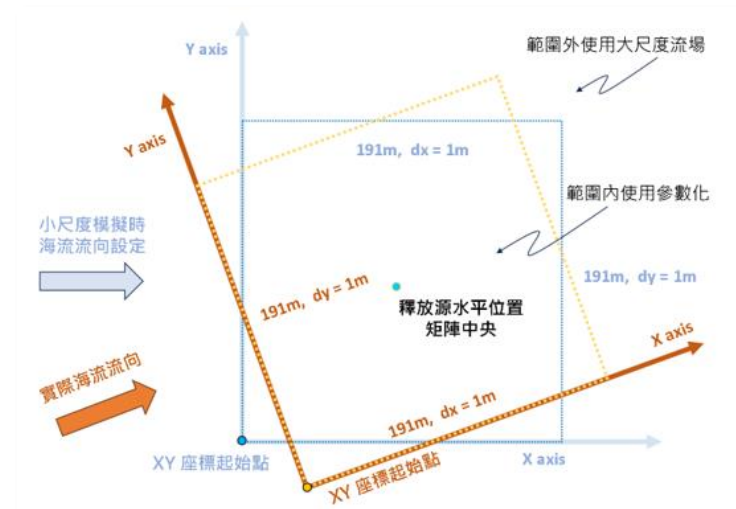
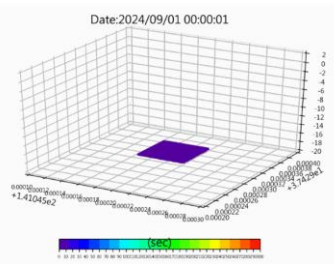
U=0.0 m/s



U=0.1 m/s



U=0.5 m/s



根據背景海流方向，將CFD流場進行座標軸旋轉，以符合實際流場變化

進行顆粒模擬，取得排放口附近之顆粒分佈

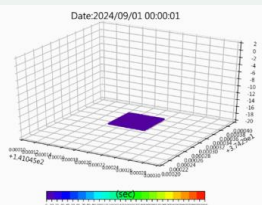
福島海域顆粒傳輸流程

釋放源參數化模組

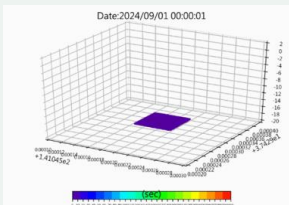
「位置-流速」迴歸函數

根據海流資料決定CFD模擬(國原院團隊提供)

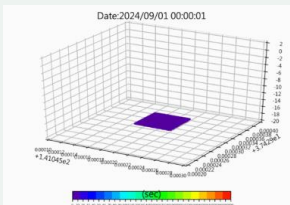
U=0



U=0.1

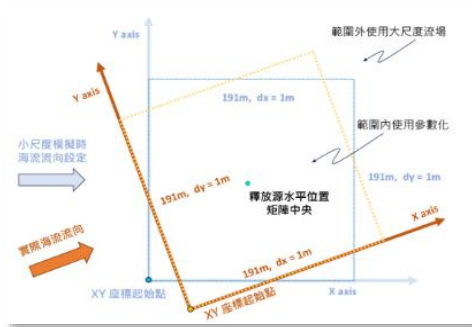


U=0.5



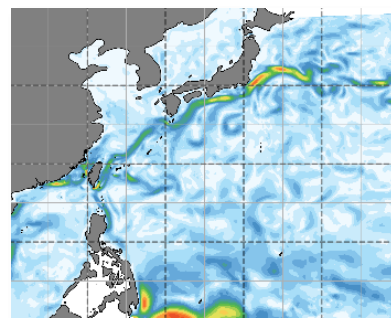
座標軸旋轉

根據海流方向，旋轉座標軸

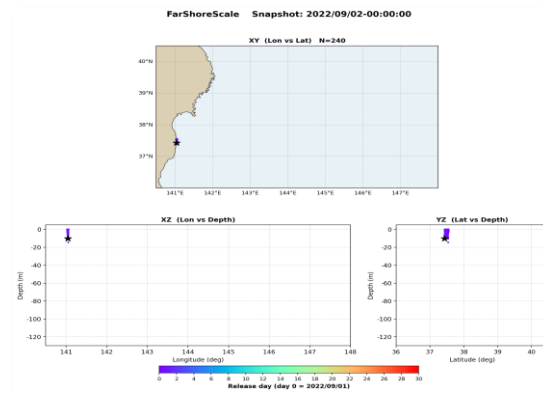


顆粒傳輸擴散系統

1 讀取海流資料



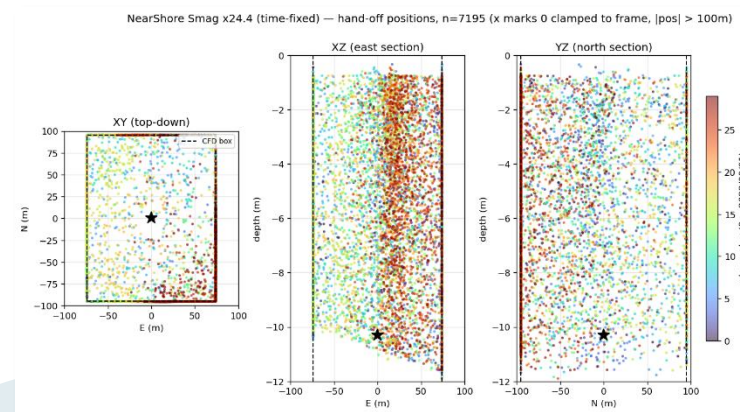
4 福島汽水擴散模擬



3 介接排放口附近顆粒位置

排放口附近顆粒分布

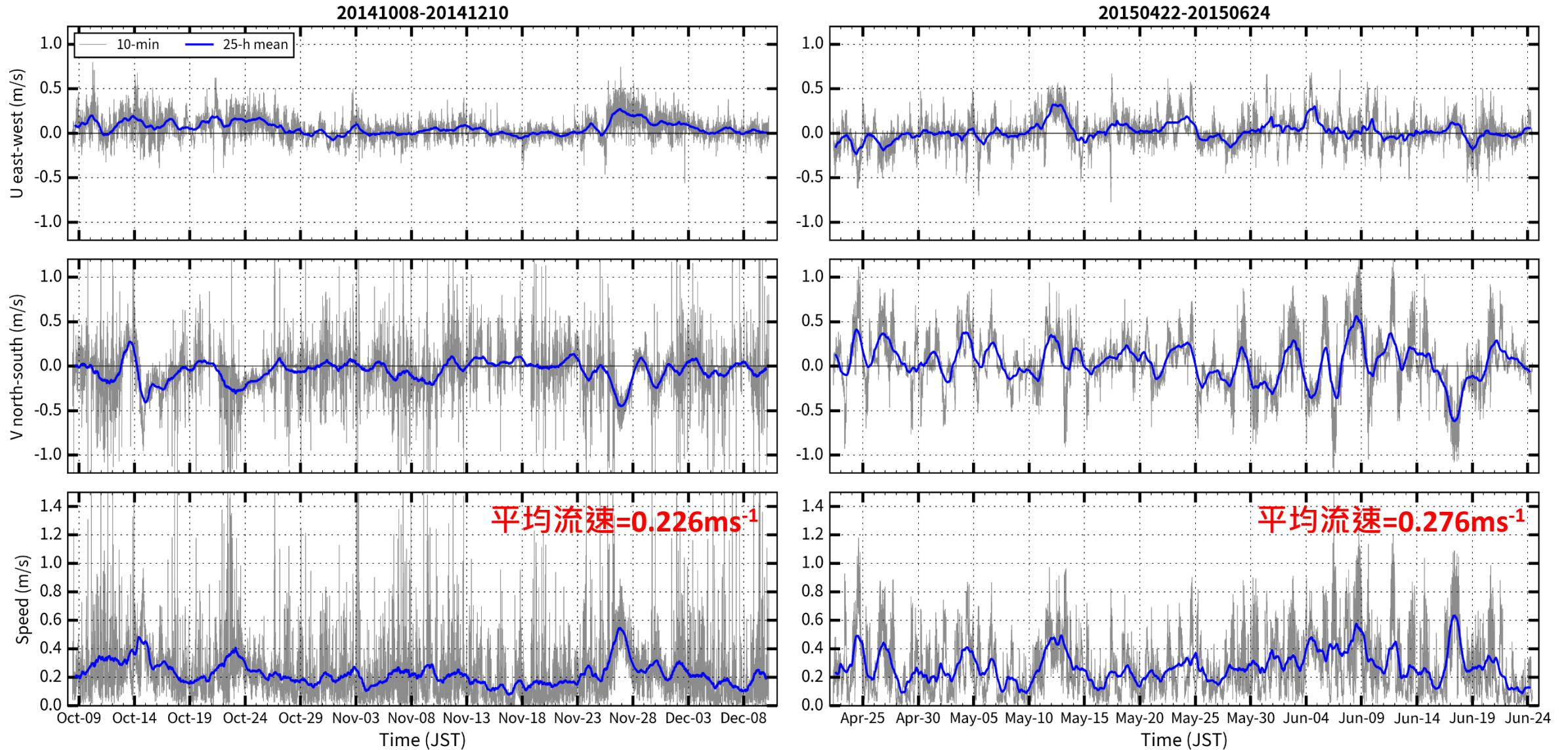
2 顆粒模擬



DOI00247_文獻中的資料

藍線為25 小時置中滑動平均，
10分鐘*250筆=25小時

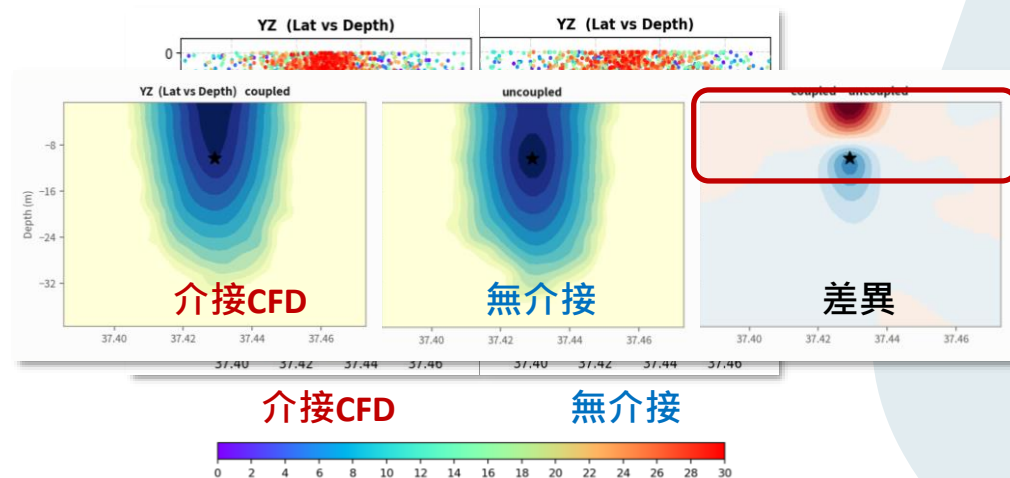
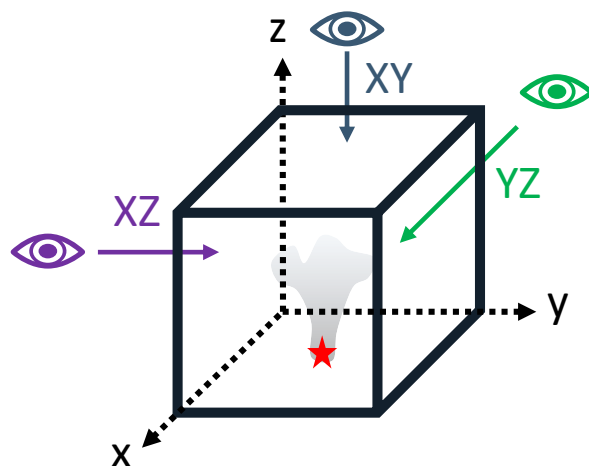
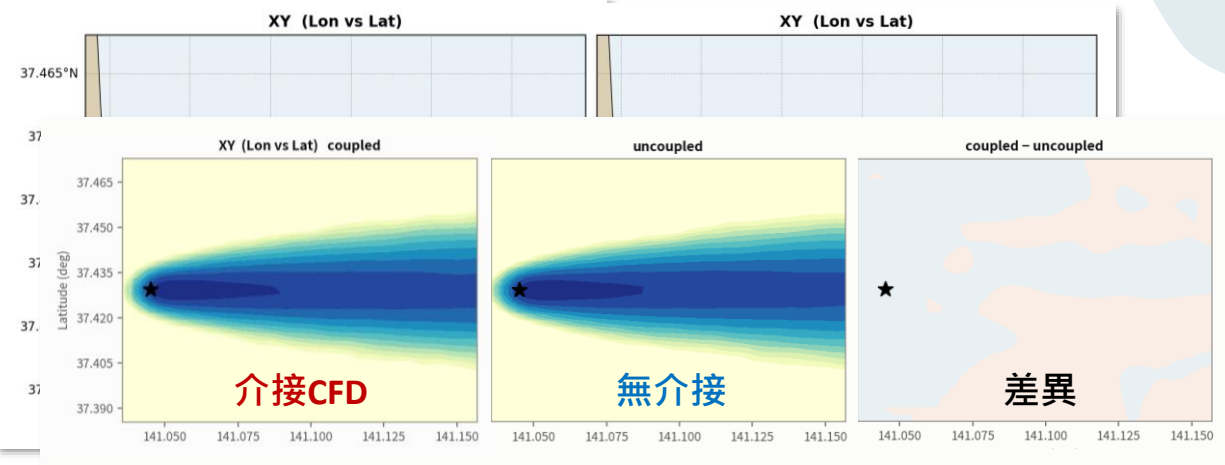
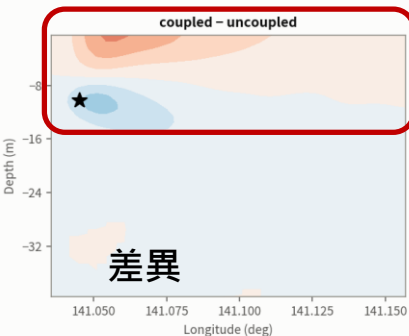
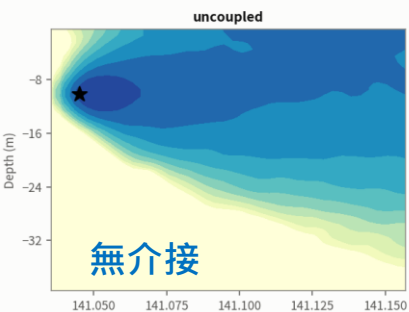
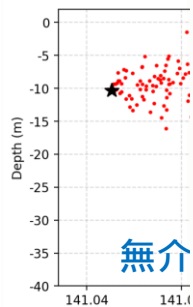
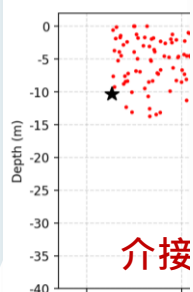
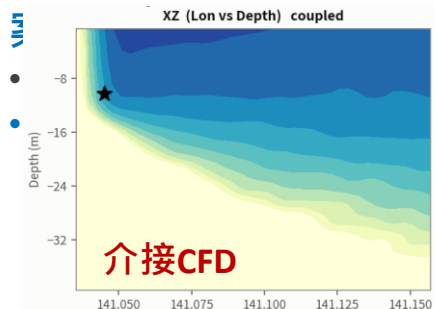
DOI00247 ADCP surface current — both deployments
ADCP off Fukushima Dai-ichi NPP (37°22.60'N, 141°03.70'E, 21 m)



理想案例比對-介接差異

案例1：

- 0.06 m/s 向東背景流
- 介接CFD小尺度



介接CFD小尺度流場後，更多粒子被送到表面

理想案例比對-背景流影響

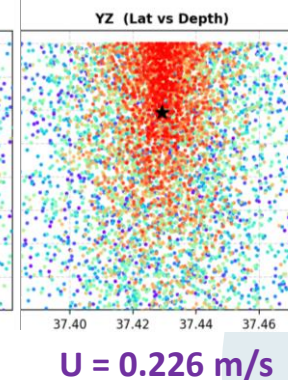
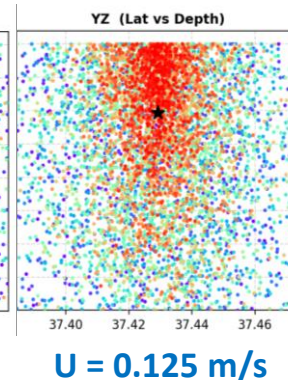
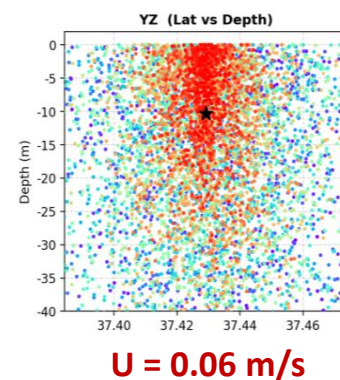
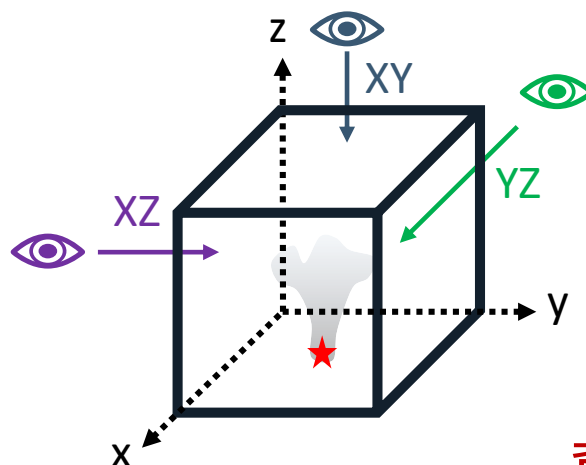
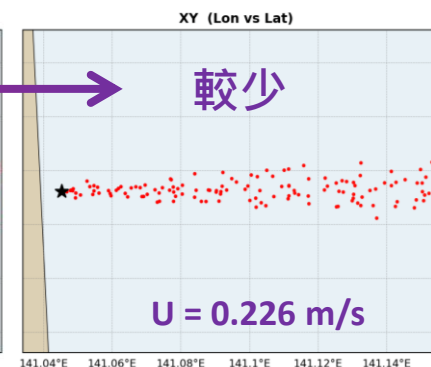
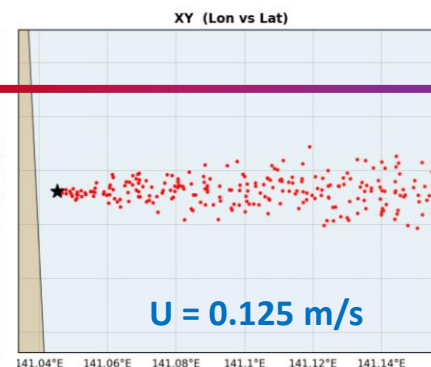
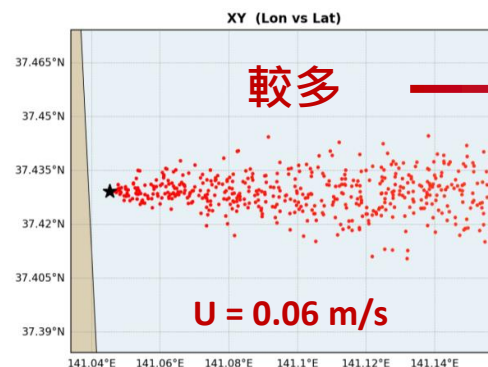
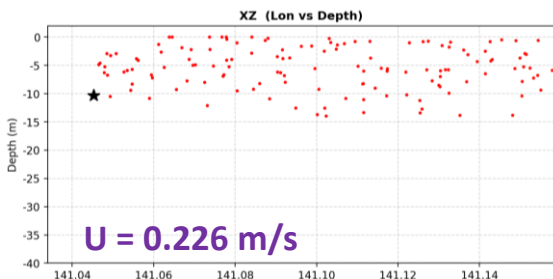
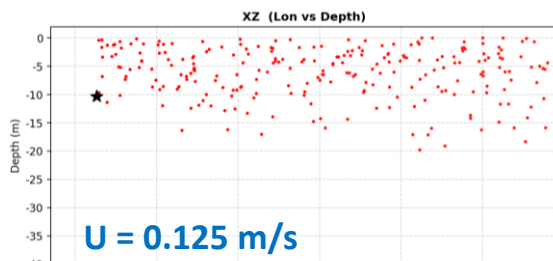
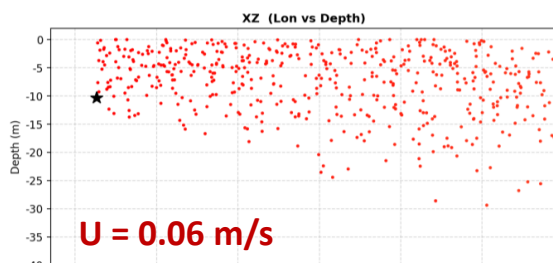
案例1 : 0.06 m/s 向東背景流

案例2 : 0.125 m/s 向東背景流

案例3 : 0.226 m/s 向東背景流

較多

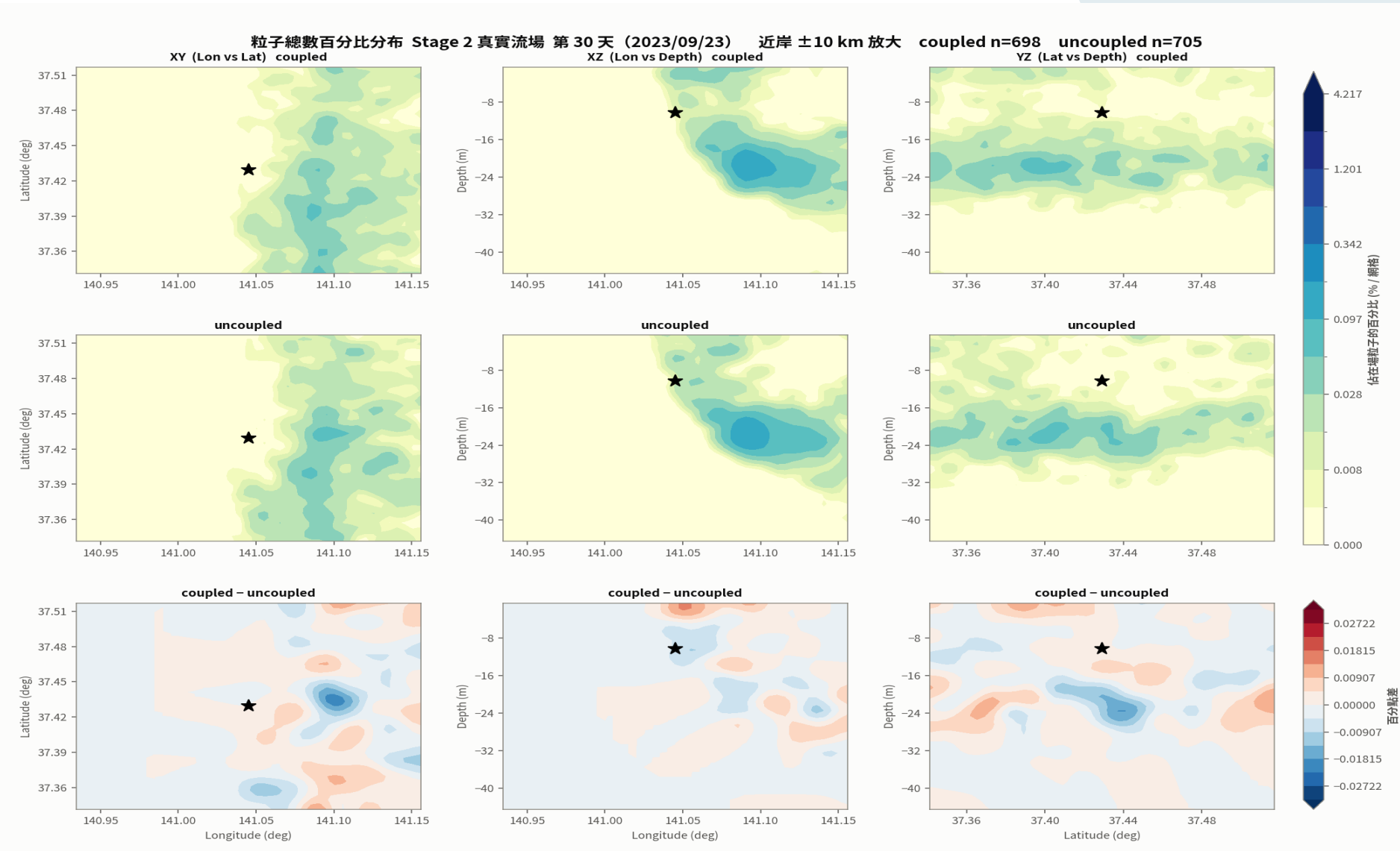
較少



背景流場越大，粒子之水平移動增加，
導致在近岸區域海表面粒子數下降

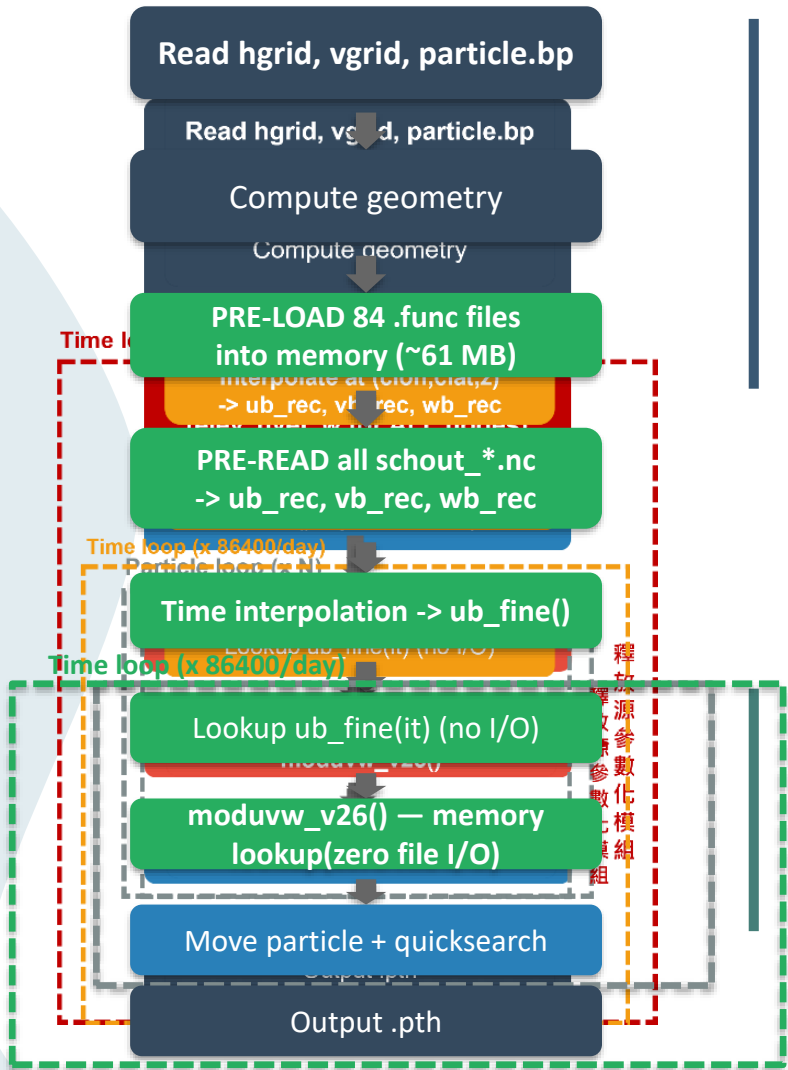
真實案例比對-第一批次排放測試

- 第一次排放時間：
2023/8/24~
2023/9/10
- 排放10天表面差異約
百分0.03
- 停止排放後兩周，顆粒
大致都移動至10公里
外，差異下降至百分之
0.02以下



效能優化:Pre-load策略

ver6



I/O 過重:
每時間步重複讀取全節點海流場

Scenario	v4	v5	v6
3 hr simulation	~15 hours	~1.5 hours (measured)	~7 minutes
1 day x 240 particles	~5 days	~12 hours	<10 minutes
8 days x 1920 particles	~40 days	~4 days	<1 hour

預處理化:
讀取與插值移至迴圈前一次完成

查找表化:
預先完成排放口位置之時序插值，無須重複開檔與計算

結論與未來展望

建立參數化模組，提升預警能力

- 建立釋放源參數化模組，**降低表層濃度低估風險，提升對含氫廢水在近域之描述能力**

效能大幅提升

- 執行效能**提升約10倍**

歷史案例分析

- 持續比對歷史案例，**驗證模組穩定性與準確性**

類作業化平行測試

- 階段性驗證執行效率，並**評估納入每日作業化預報排程之可行性**

Thank You For
Your Attention

