MODELLING OF CO_2 DISPERSION LEAKED FROM SEAFLOOR OFF JAPANESE COAST

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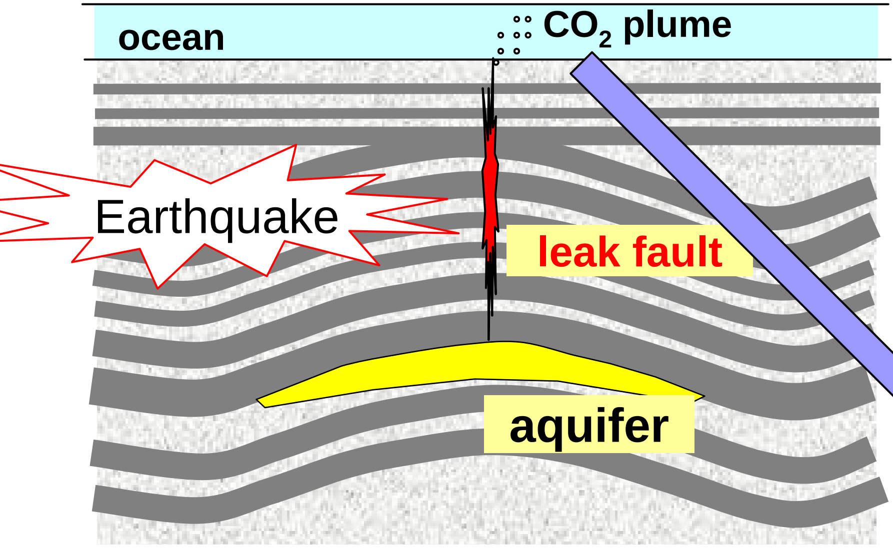
Backgrounds: Risk of CO_2 leakage in Geological Storage



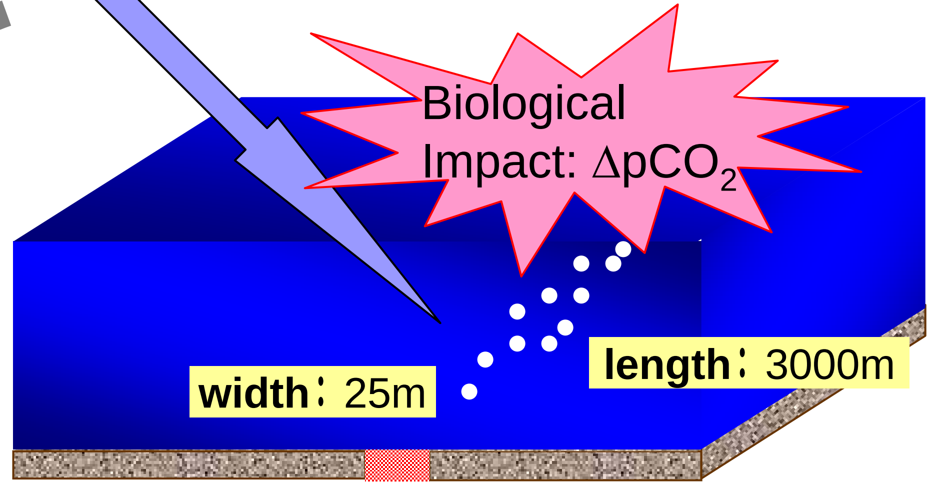
Leak-Source Band

Width : 25 m

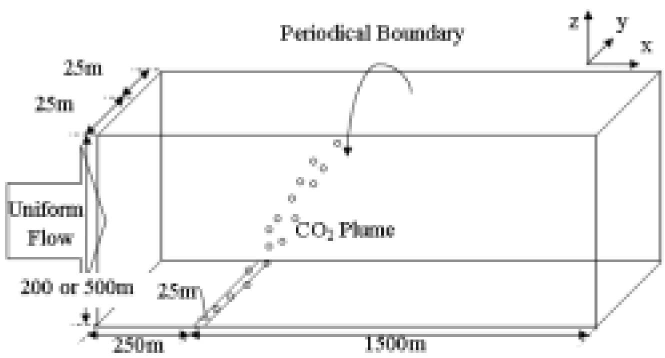
Length: mid 3000m of 8000m (fault)

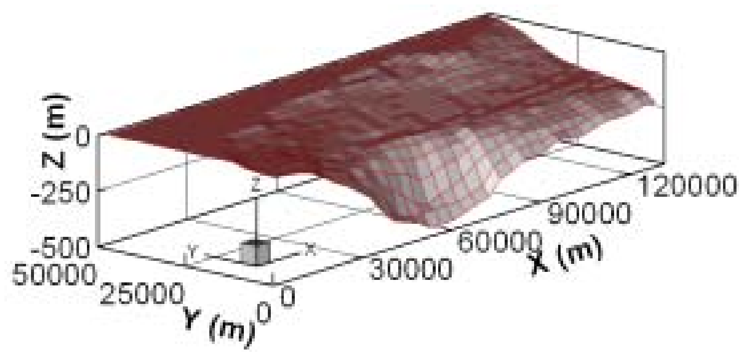
Flow-rate of CO_2: 4 x 10^{-5} kg/s/m^2

RITE CO_2 sequestration project
2003 annual report

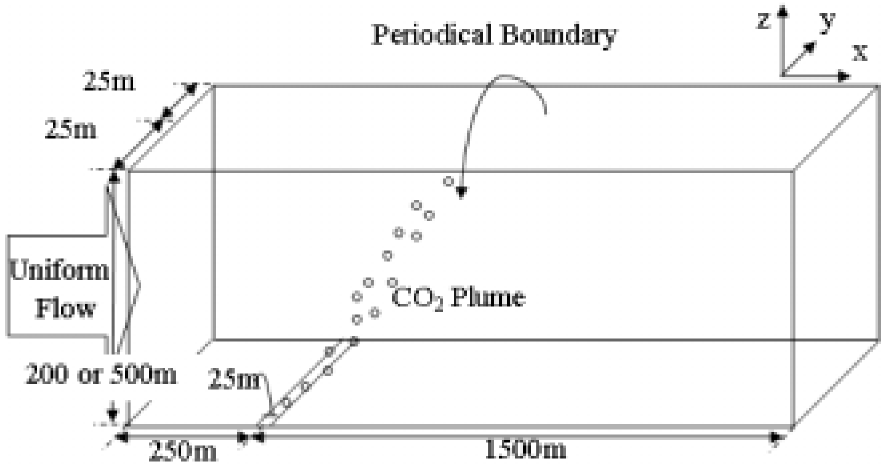


- Objects
- Build numerical model and present its simulations on the behaviour of leaked CO_2 originally stored under the seabed and ΔpCO_2 in seawater caused by it.
    1. Conduct parameter studies to see the impacts of conditions of CO_2 leakage and those of seawater.
    2. Conduct a more realistic simulation with topography and tidal current.





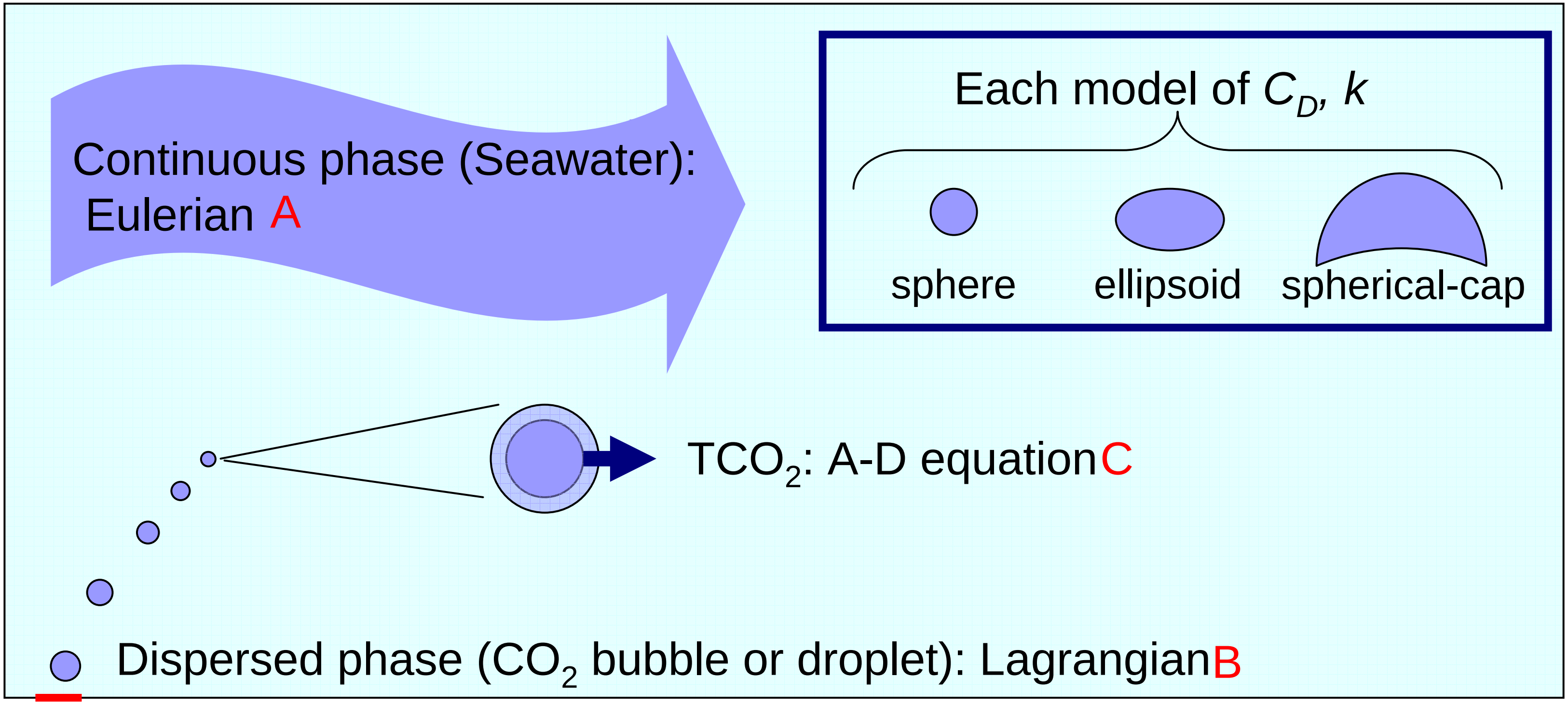
Two-phase Flow Simulation by Full-3D model



Parameter studies
with simple domain and uniform flow

See the impacts of conditions of CO_2 leakage
and those of seawater

Two-phase flow simulation by Full-3D model: Method

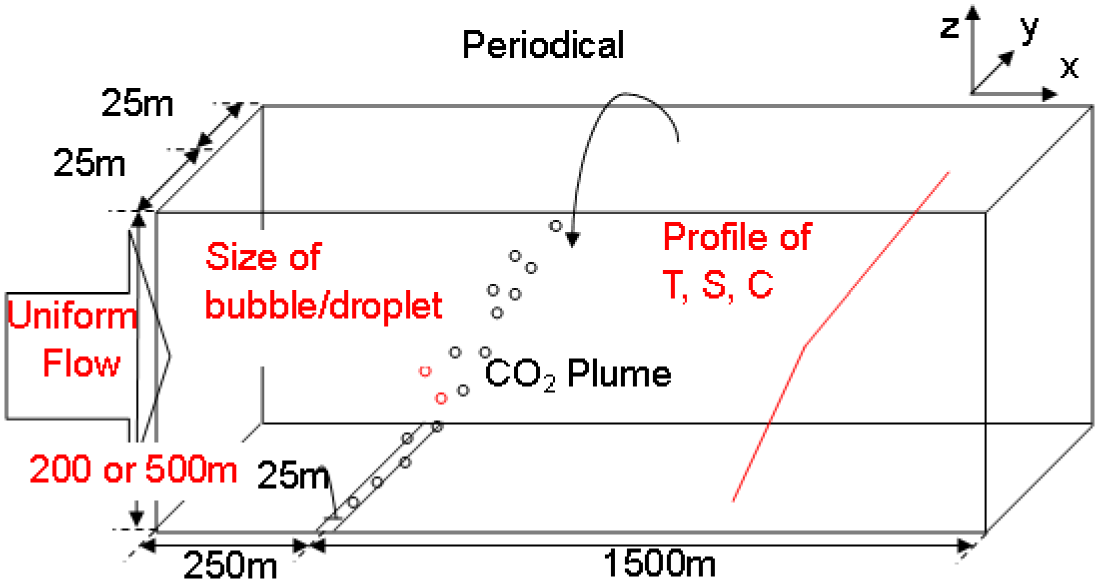


A: $$\frac{\partial}{\partial t}(\alpha_B \rho_B \mathbf{u}_B) + \nabla \cdot (\alpha_B \rho_B \mathbf{u}_B \mathbf{u}_B) + \frac{\partial}{\partial t}(\alpha_A \rho_A \mathbf{u}_A) + \nabla \cdot (\alpha_A \rho_A \mathbf{u}_A \mathbf{u}_A)$$
$$= -\nabla P + \nabla \cdot \left[\alpha_B \rho_B (v_B + v_t) \mathbf{d}_B\right] + \alpha_B \rho_B \mathbf{g}$$

B: $$\frac{D_A}{Dt}(\alpha_A \rho_A \mathbf{u}_A) + \frac{D_B}{Dt}(\beta \alpha_A \rho_B \mathbf{u}_A) - \frac{D_A}{Dt}(\beta \alpha_A \rho_B \mathbf{u}_B) = \alpha_A \left(-\nabla P + \rho_A \mathbf{g} - \frac{3}{8r} C_D \frac{3}{4r} \rho_B |\mathbf{u}_r| \mathbf{u}_r - \mathbf{f}_L\right)$$

C: $$\frac{\partial}{\partial t}(\alpha_B C) + \mathbf{u}_B \nabla(\alpha_B C) = \nabla\left[\alpha_B \left(D + \frac{v_t}{Sc_t}\right) \nabla C\right] + \pi d^2 k (C_I - C)$$

- Two-phase flow simulation by Full-3D model: Computational domain



Simulation diagram

Domain & Grids

Domain: 1650 m x 50 m x 200 or 500 m

Grid:132 x 25 x 100 or 250

Minimum grid spacing: 2 m x 2 m x 2m

Boundary conditions

T,S,C,P:

X,Z-directions: inflow-fixed

outflow-zero gradient

Y-direction : Periodical

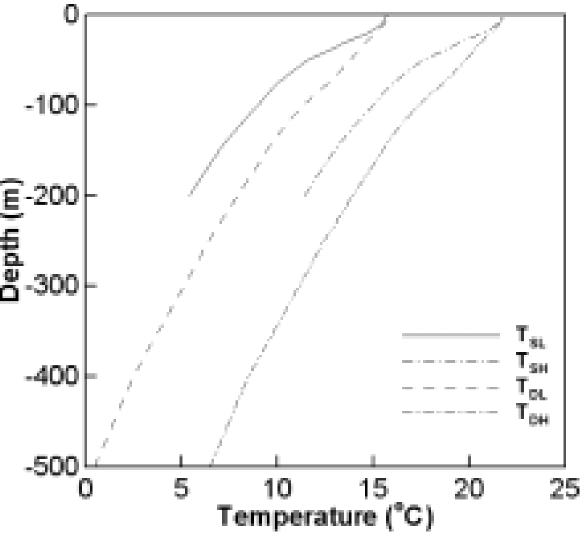
Velocity : Free-slip conditions

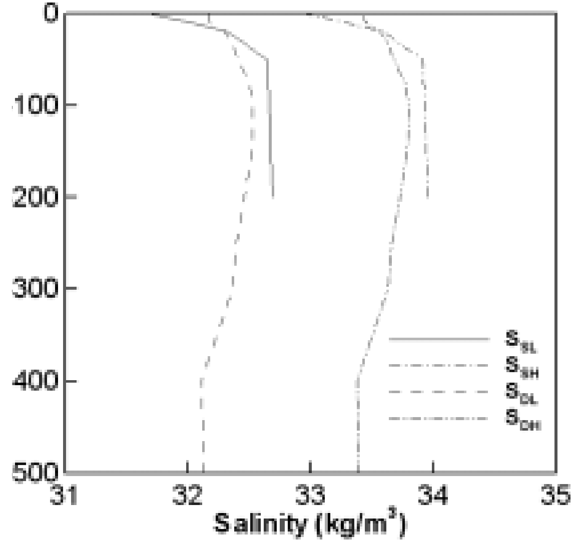
- Two-phase flow simulation by Full-3D model: Case studies

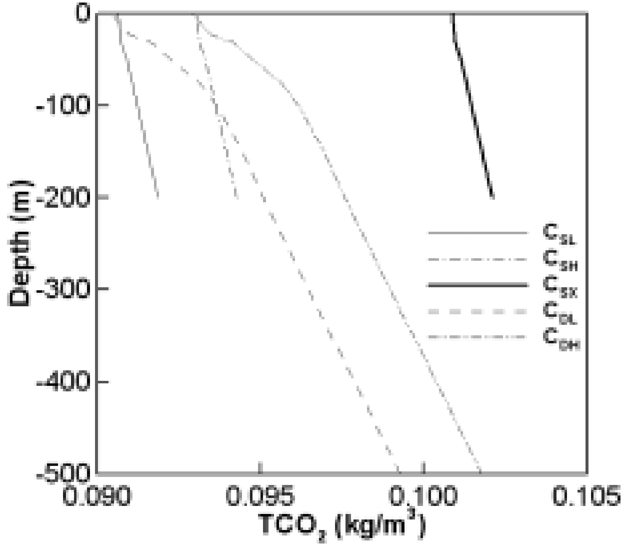
Case	Seabed depth (m)	Inflow velocity (m/s)	Mean initial diameter (m)	Temperature profile	Salinity profile	TCO_2 profile
1	200	0.05	0.020	T_{SL}	S_{SL}	C_{SL}
2	200	0.1	0.020	T_{SL}	S_{SL}	C_{SL}
3	200	0.05	0.040	T_{SL}	S_{SL}	C_{SL}
4	200	0.05	0.011	T_{SL}	S_{SL}	C_{SL}
5	200	0.05	0.020	T_{SH}	S_{SL}	C_{SL}
6	200	0.05	0.020	T_{SL}	S_{SH}	C_{SL}
7	200	0.05	0.020	T_{SL}	S_{SL}	C_{SH}
8	200	0.05	0.020	T_{SL}	S_{SL}	C_{SX}
9	500	0.05	0.020	T_{DL}	S_{DL}	C_{DL}
10	500	0.05	0.011	T_{DL}	S_{DL}	C_{DL}
11	500	0.05	0.0072	T_{DL}	S_{DL}	C_{DL}
12	500	0.05	0.020	T_{DH}	S_{DL}	C_{DL}
13	500	0.05	0.020	T_{DL}	S_{DH}	C_{DL}
14	500	0.05	0.020	T_{DL}	S_{DL}	C_{DH}

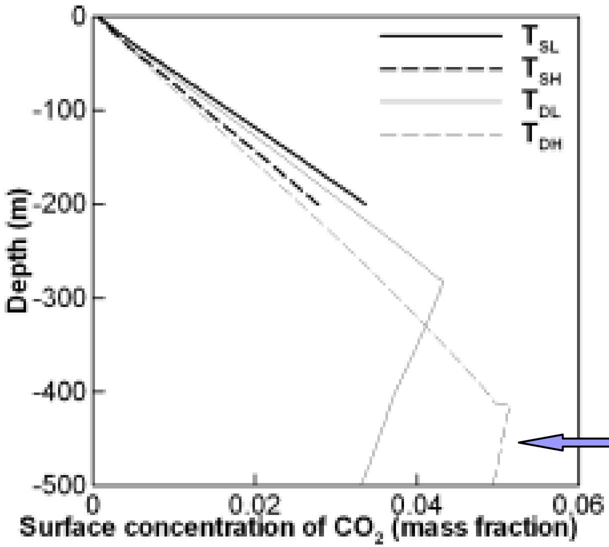
S: 200 m case, D: 500 m case, L: Low, H: High, X: Super high

- Two-phase flow simulation by Full-3D model: Initial Conditions







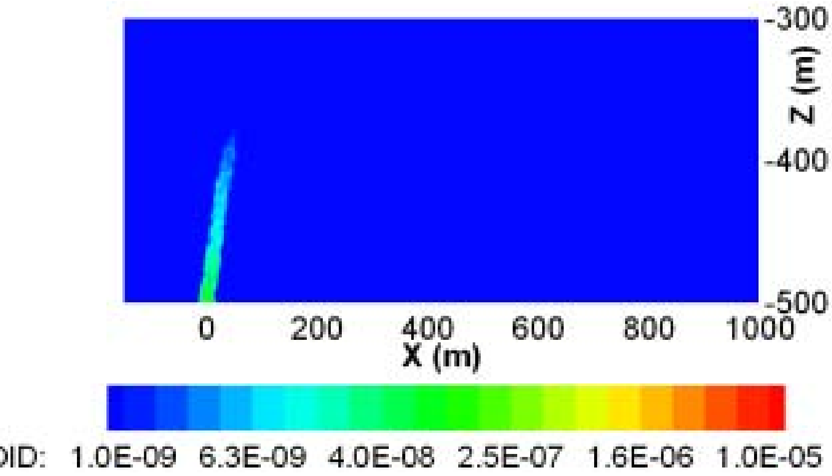


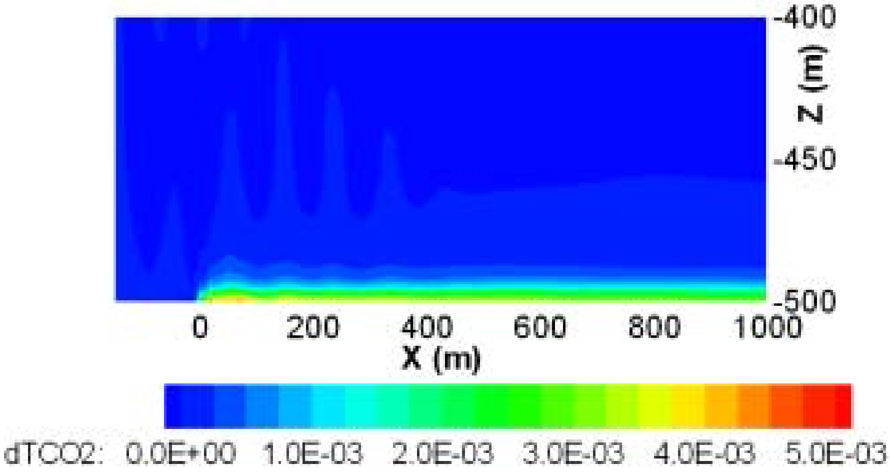
Equilibrium Concentration
Coexisting with Hydrate

- Two-phase flow simulation by Full-3D model: Results & Discussions

+ Volume fraction of CO_2 liquid and gas

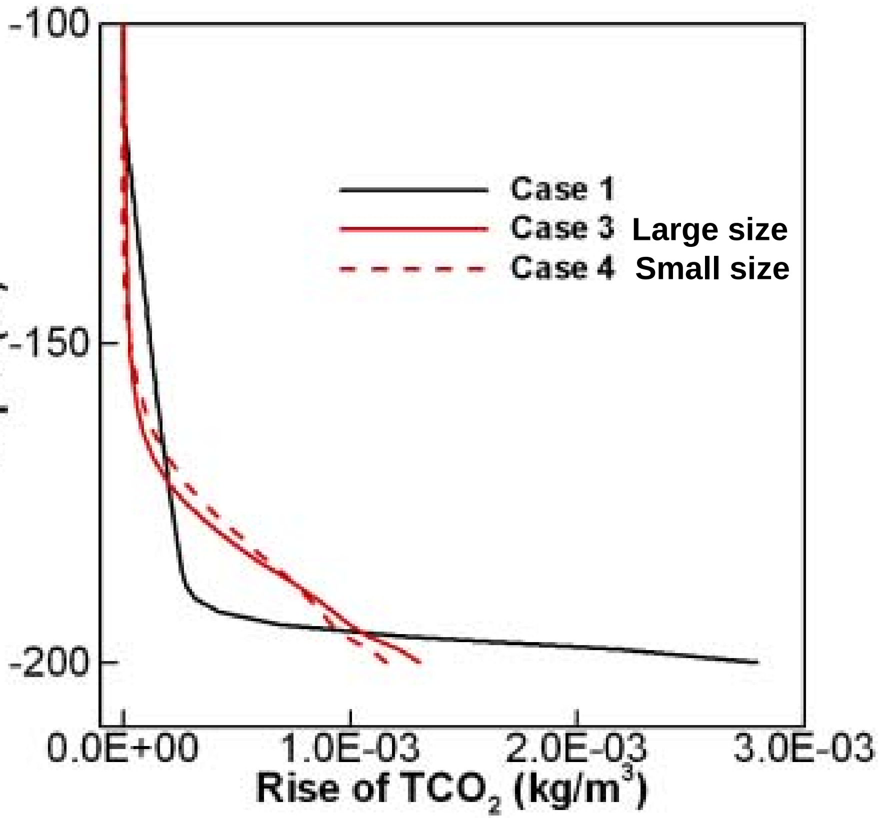
+ ΔTCO_2 (kg/m^3)





- Two-phase flow simulation by Full-3D model: Results & Discussions

+ Vertical profile of ΔTCO_2 --- Size Effect

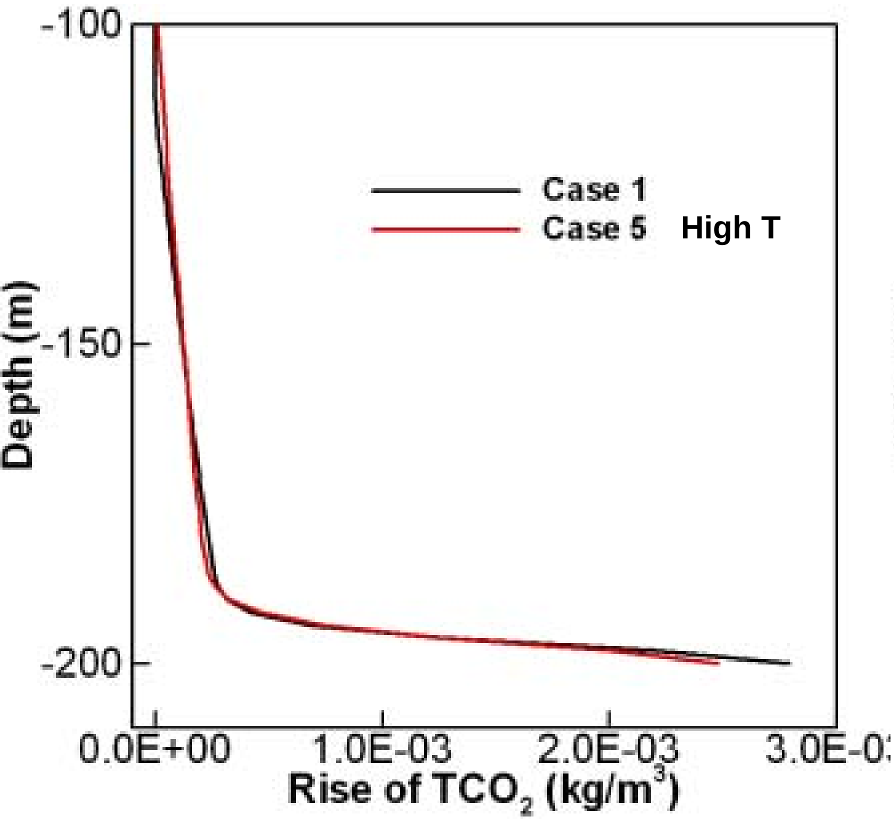


Bubble cases

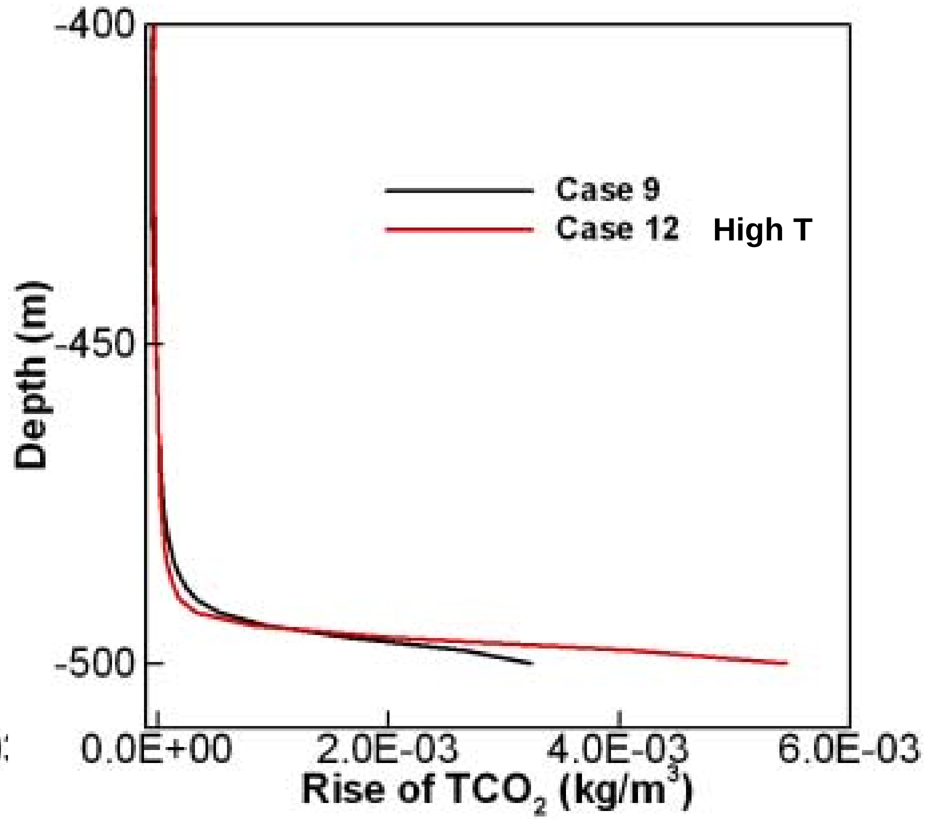
$$F_T = \underline{kA_T}(C_I - C_\infty)$$

- Two-phase flow simulation by Full-3D model: Results & Discussions

+ Vertical profile of ΔTCO_2 --- Temperature Effect



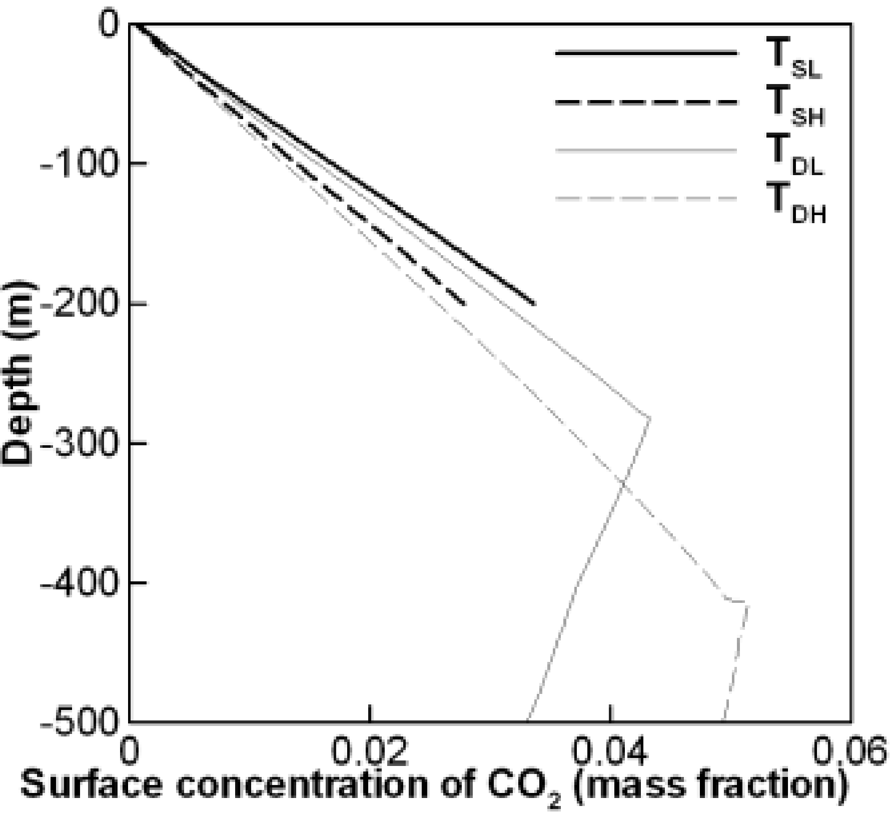
Bubble cases

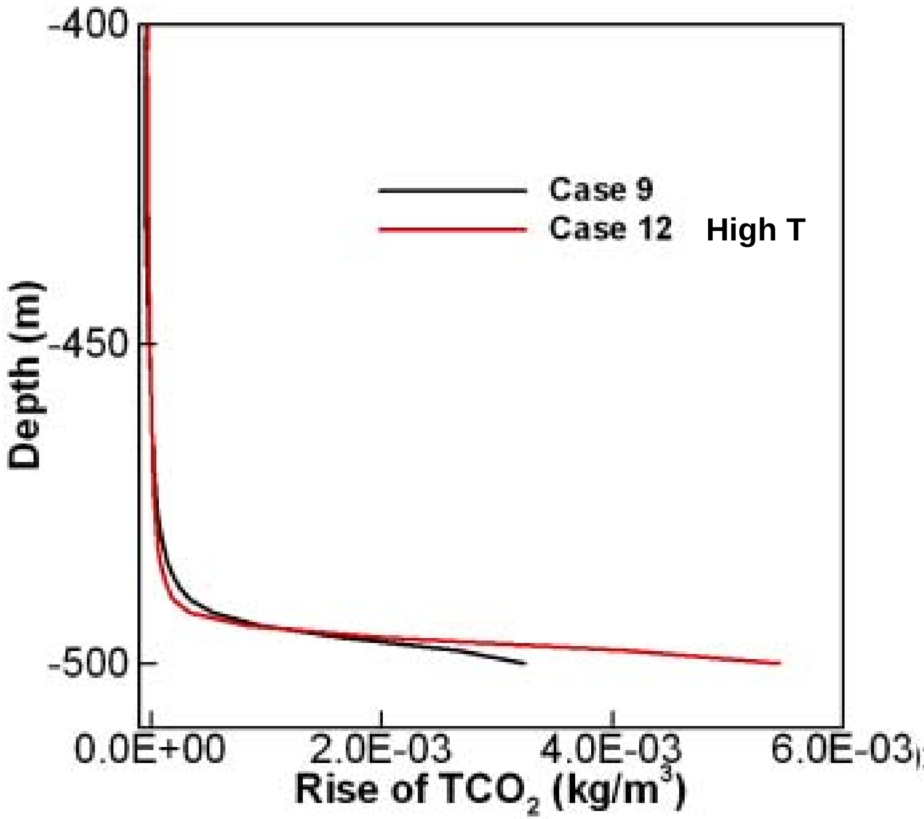


Droplet cases

- Two-phase flow simulation by Full-3D model: Results & Discussions

+ Vertical profile of ΔTCO_2

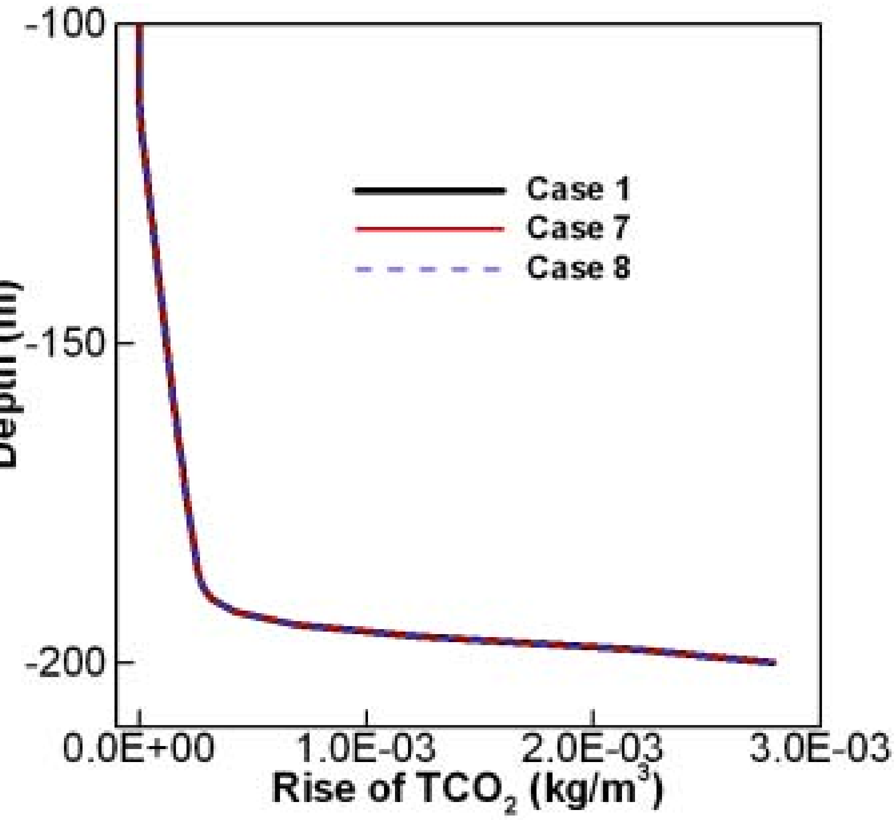


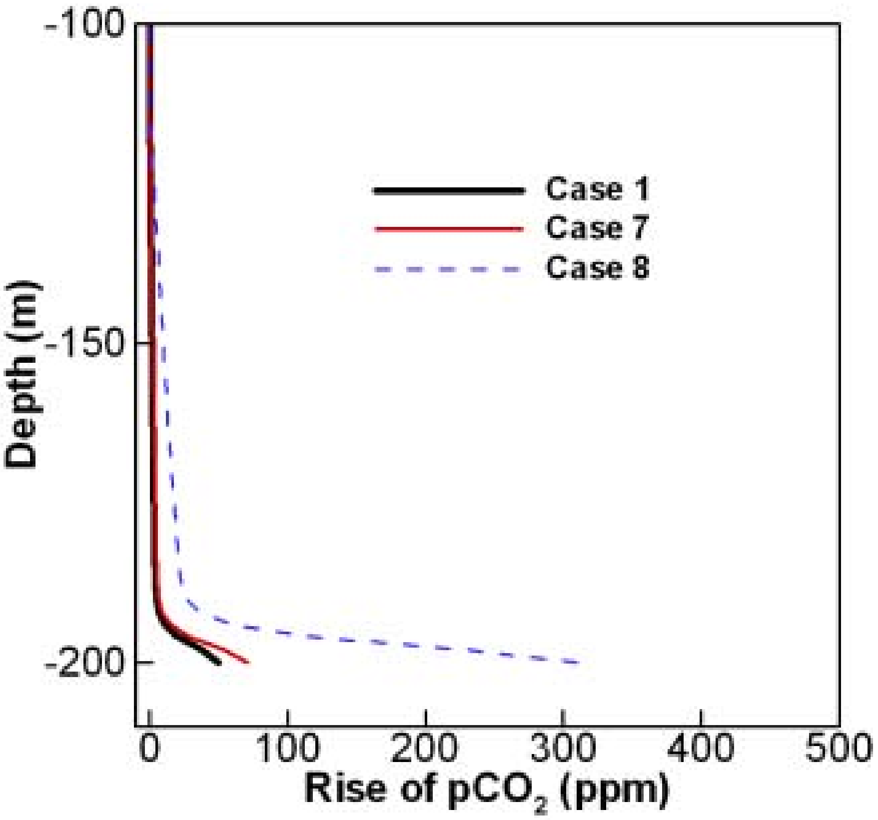


Droplet cases

- Two-phase flow simulation by Full-3D model: Results & Discussions

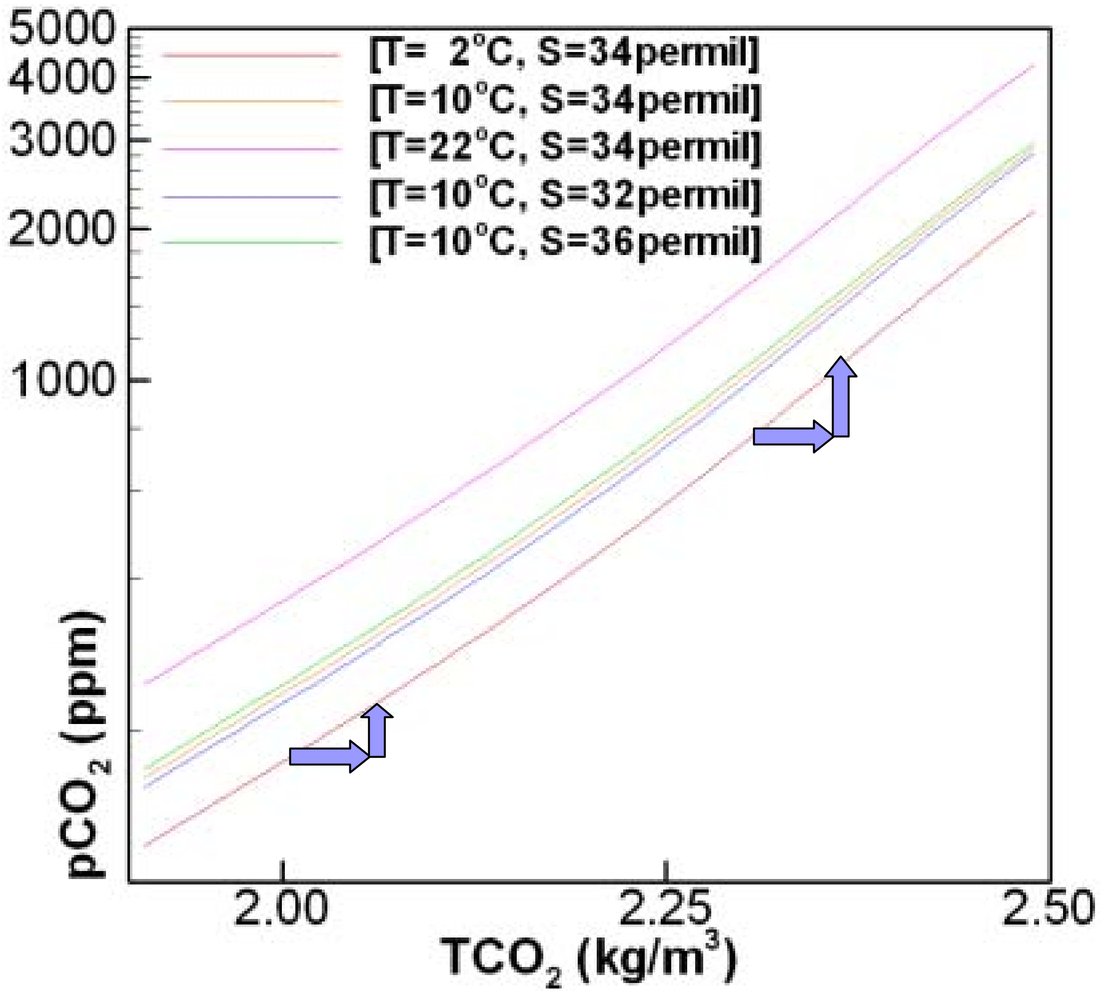
+ Vertical profile of ΔpCO_2 --- Effect of Background TCO_2



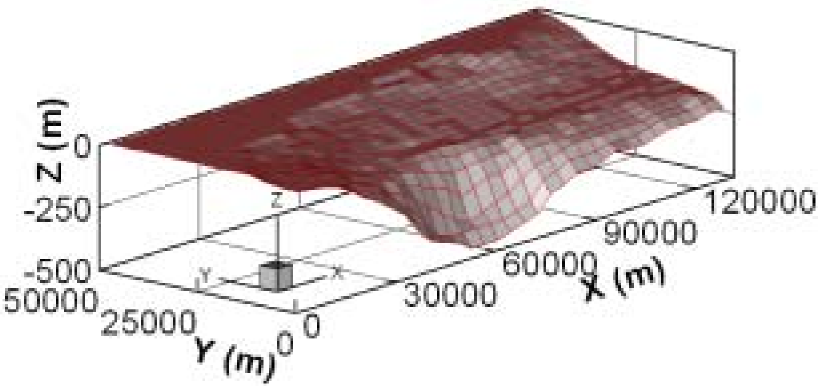


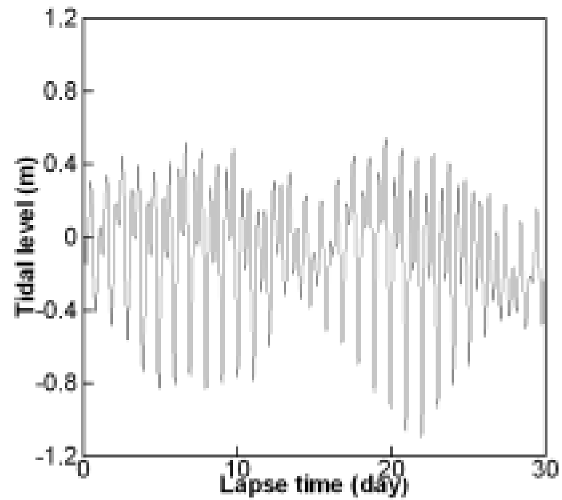
- Two-phase flow simulation by Full-3D model: Results & Discussions

+ Correlation between TCO_2 and ΔpCO_2



Ocean model simulation

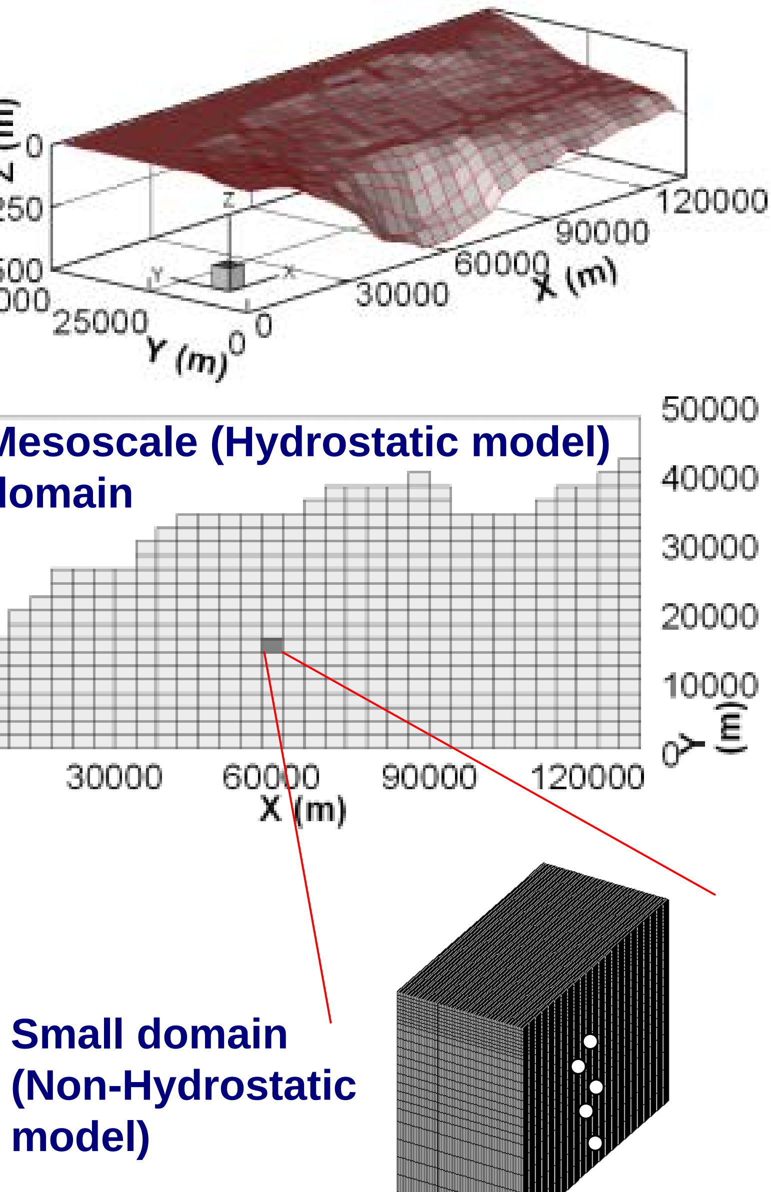




Mesoscale simulation incorporating Full-3D model into small domain

See the impacts of realistic topography and tidal current around Japanese coast

■ Ocean model simulation: Computational conditions



Mesoscale

Model: Hydrostatic-approximated NS-equatio
(MEC Ocean Model)
Domain: 132 km x 50 km x 460 m
Grid:33 x 25 x 48
Horizontal grid spacing: 4 km x 2 km
Minimum vertical grid spacing: 2 m

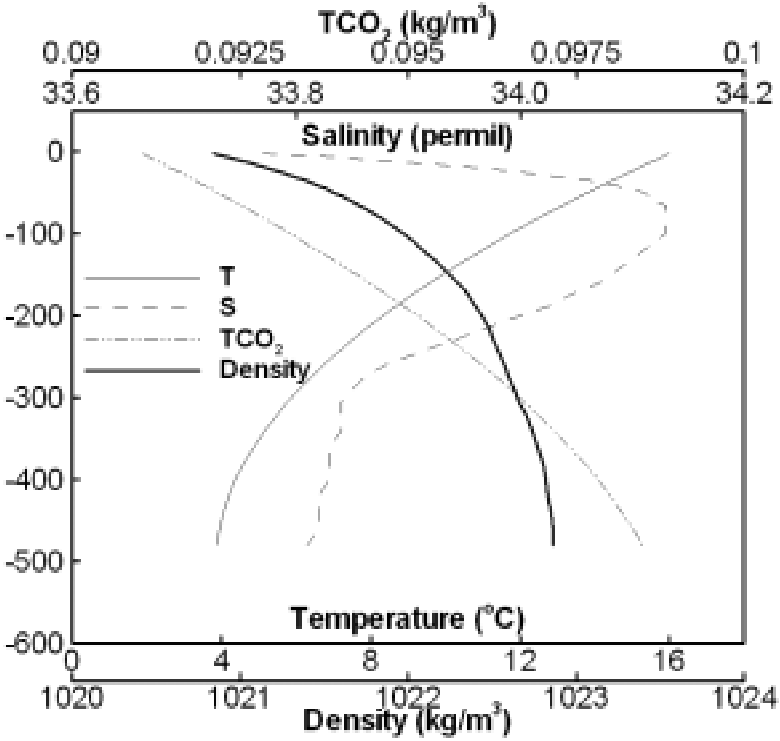
Small scale

Model: Full-3D NS-equation
(Two-phase flow model)
Domain: 4 km x 2 km x 120 m
Grid:160 x 80 x 25
Horizontal grid spacing: 25 m x 25 m
Minimum vertical grid spacing: 2 m

Boundary conditions

T,S,C: inflow-fixed & outflow-zero gradient
Wave height: No-reflection

■ Ocean model simulation: Computational conditions



Input Data

T,S: Annual average (JODC)

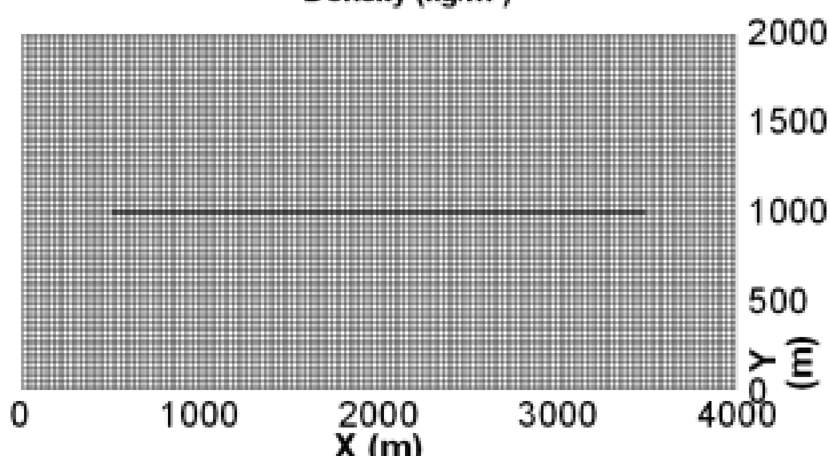
Surface condition: Annual average (JMA)

Tide: M2, K1, O1, S2

Bubble size: 2 cm diameter

Calculation period: 45 days

Calculation time step: 1 second



Leak-Source Band

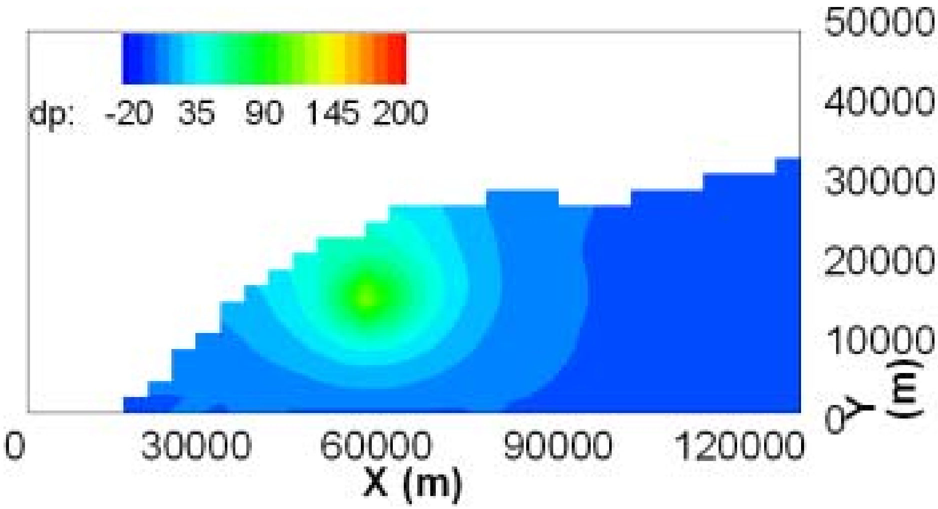
Width : 25 m

Length: 3000m

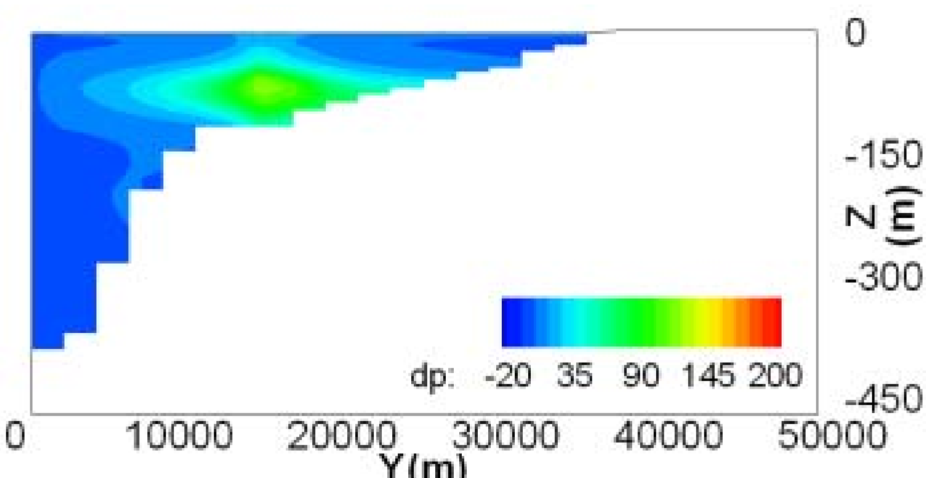
Flow-rate of CO_2: 4 x 10^{-5} kg/s/m^2

- Ocean model simulation: Results

+ Distribution of ΔpCO_2 in the mesoscale domain



70 m depth



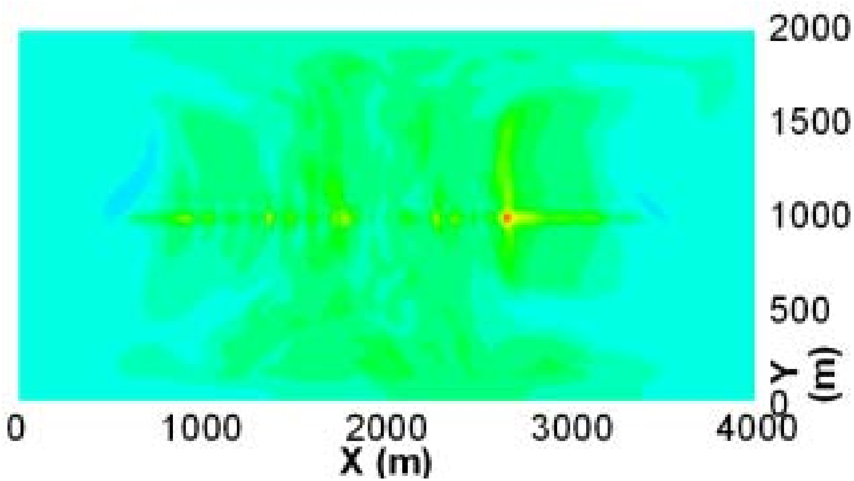
X = 60000 m

- CO_2-rich water diffuses and flows by tidal current

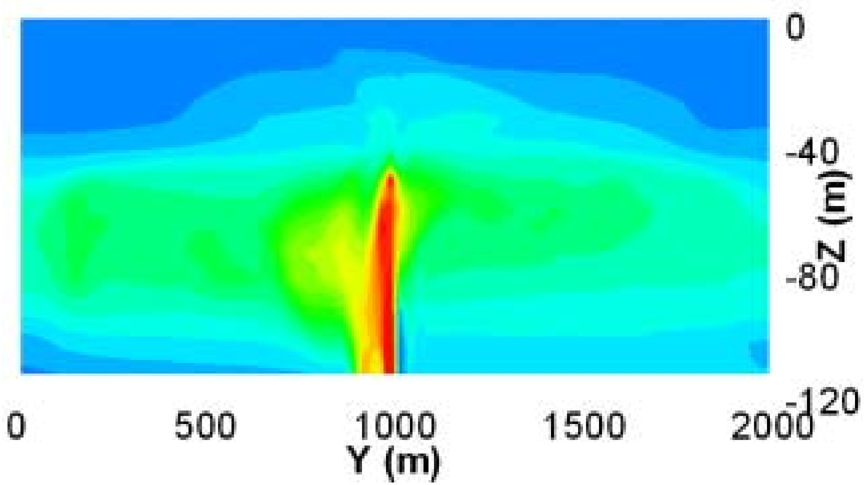
ΔpCO_2 in the mesoscale domain does not exceed 200 ppm.

- Ocean model simulation: Results

+ Distribution of ΔpCO_2 in the small domain



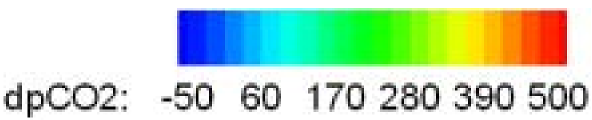
120 m depth



X = 2000 m

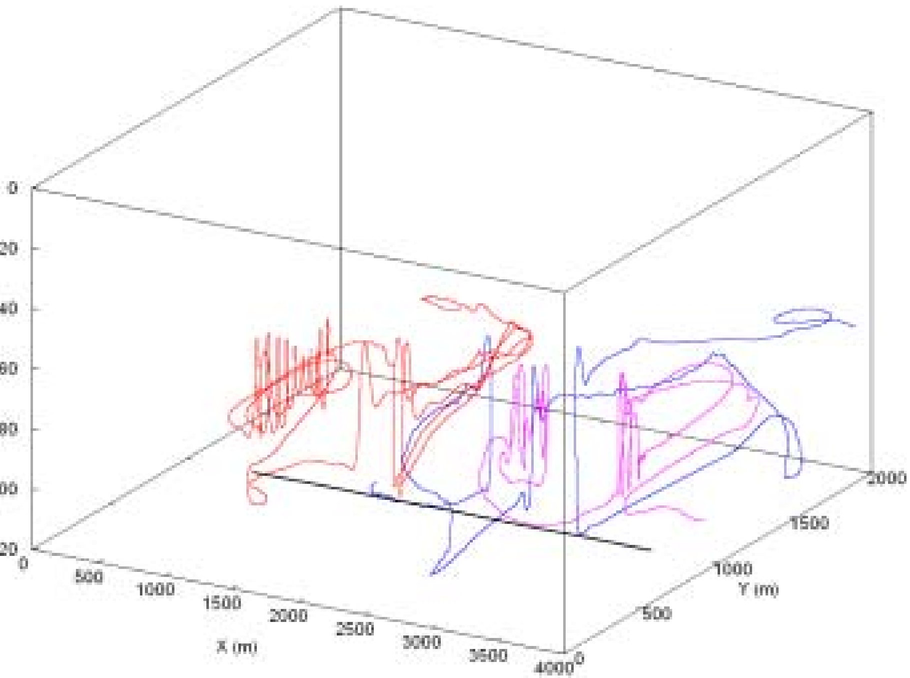
- Intrusion by density flow
- Distribution change by tidal current

ΔpCO_2 in the small domain sometimes exceeds 500 ppr above the leak-source band

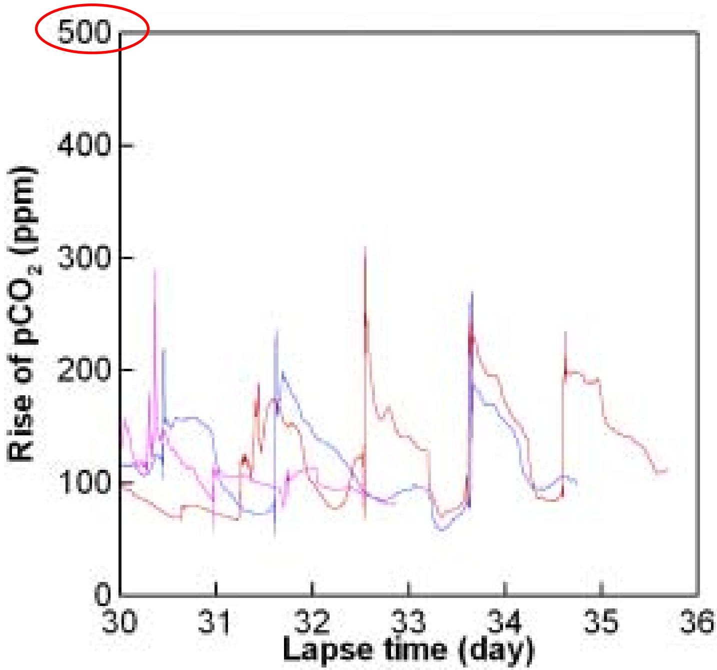


- Ocean model simulation: Results

+ Biological impact on zooplanktons



Trajectories of zooplanktons



ΔpCO_2 experienced by zooplanktons

The maximum ΔpCO_2 is less than 300 ppm.

- Conclusions

- Numerical model was built and its simulation results were presented on the behaviour of leaked CO_2 and ΔpCO_2 caused by it.
- Parameter studies show the large impact of temperature, size of bubbles/droplets, and background $TCO_{2.}$
- ΔpCO_2 sometimes exceeded 500 ppm in the case of realistic topography and tidal current.
- Impact of leaked CO_2 on floating marine organisms, such as zooplanktons, may not be significant in the present cases.
- More detailed and careful examination on impact on marine organisms which rarely travel, such as benthos.
- Accurate validity of the present simulation
  --- Natural Analogue may be useful.