CO2海域地中貯留の環境影響評価

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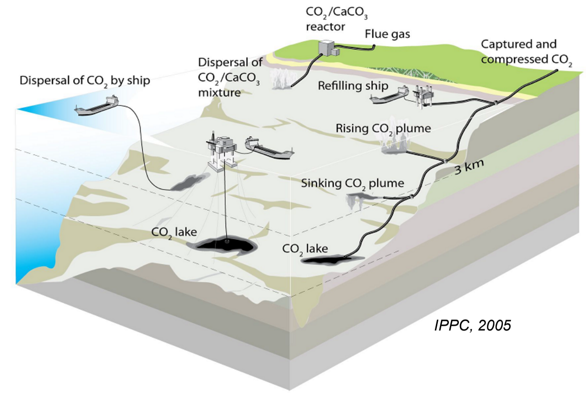
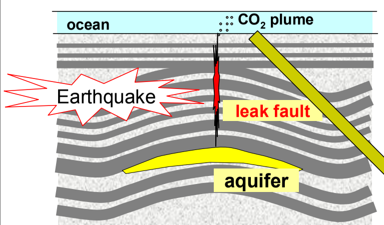
Options for CCS (Carbone Capture and Storage)



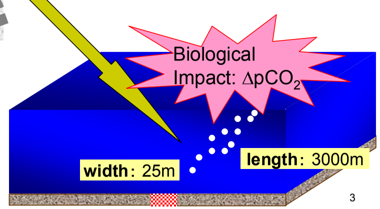
IPPC, 2005

Backgrounds: Risk of CO_2 leakage in Geological Storage



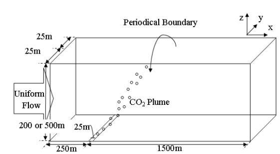
Leak-Source Band
Width : 25 m
Length: mid 3000m of 8000m (fault)
Flow-rate of CO_2: 4 x 10^{-5} kg/s/m²

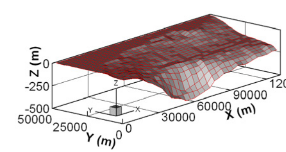
RITE CO_2 sequestration project 2003 annual report



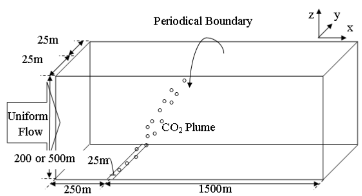
Objectives

- Build a numerical model and simulate the behaviour of leaked CO_2 originally stored under the seabed and ΔpCO_2 in seawater.
  1. Conduct parameter studies to see the effects of conditions of leaked CO_2 and ambient seawater.
  2. Conduct a more realistic simulation with real topography and observed tidal current.

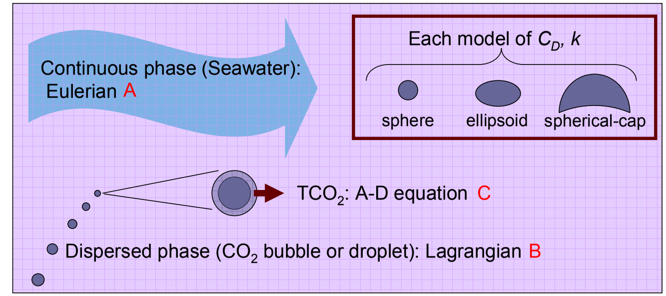




Two-phase Flow Simulation in a simple domain and uniform flows



Two-phase flow model

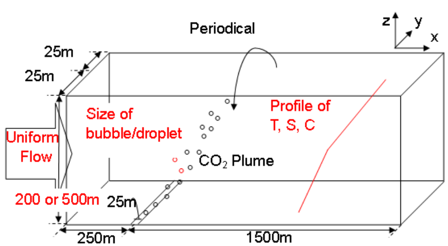


A: $$\frac{\partial}{\partial t}(\alpha_c \rho_c \mathbf{u}_c) + \nabla \cdot (\alpha_c \rho_c \mathbf{u}_c \mathbf{u}_c) + \frac{1}{V_{cell}} \sum_{n=1}^{n_d} \frac{D_d}{Dt}(\rho_d V_d \mathbf{u}_d) = \nabla P + \nabla \cdot [\alpha_c \rho_c (\nu_c + \nu_t) \mathbf{d}_c]$$

B: $$\frac{D_d}{Dt}[(\rho_d + \beta \rho_c) V_d \mathbf{u}_d] = V_d[-\nabla P + (\rho_c - \rho_d)\mathbf{g} - \mathbf{f}_D - \mathbf{f}_L]$$

C: $$\frac{\partial}{\partial t}(\alpha_c C) + \mathbf{u}_c \nabla(\alpha_c C) = \nabla\left[\alpha_c\left(D_C + \frac{\nu_t}{Sc_t}\right)\nabla C\right] + \frac{1}{V_{cell}} \sum_{n=1}^{n_d} \Gamma$$

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

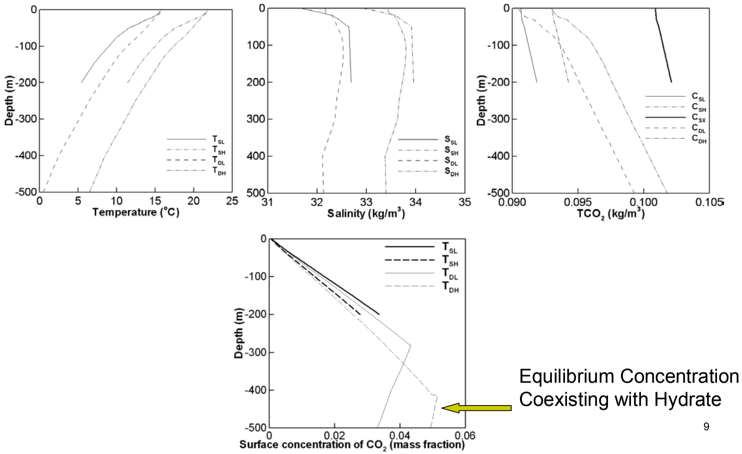
Velocity : Free-slip conditions

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

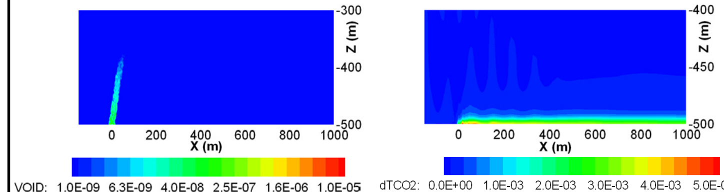
Initial Conditions



Results & Discussions

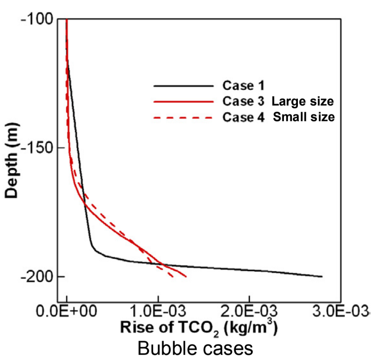
+ Volume fraction of CO_2 liquid and gas

+ ΔTCO_2 (kg/m^3)



Results & Discussions

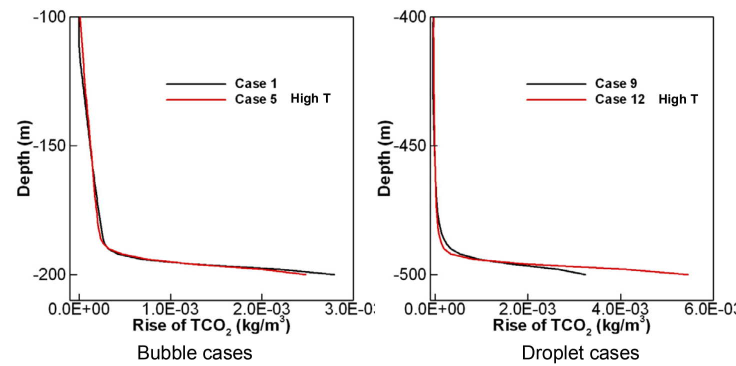
+ Vertical profile of ΔTCO_2 --- Size Effect



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

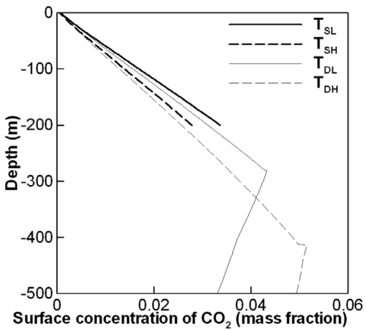
Results & Discussions

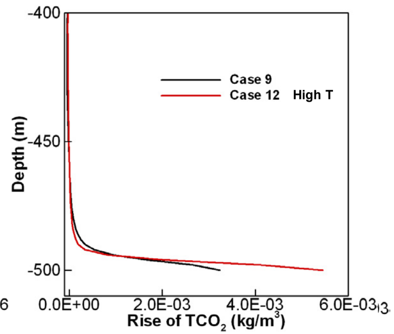
+ Vertical profile of ΔTCO_2 --- Temperature Effect



Results & Discussions

+ Vertical profile of ΔTCO_2 --- Temperature Effect

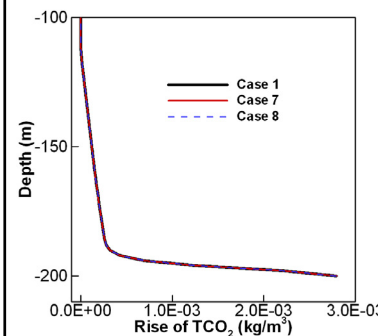


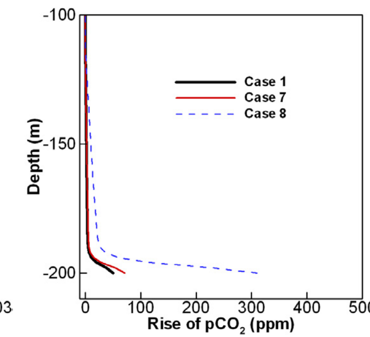


Droplet cases

Results & Discussions

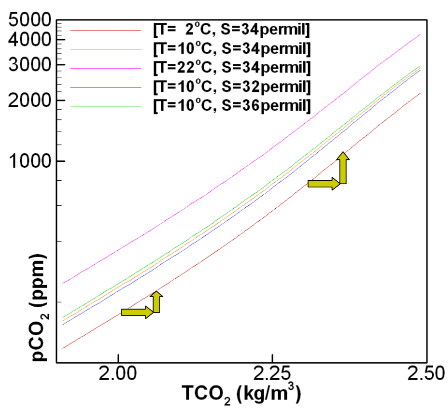
+ Vertical profile of ΔpCO_2 --- Effect of Background TCO_2



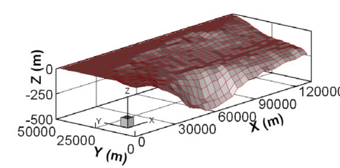


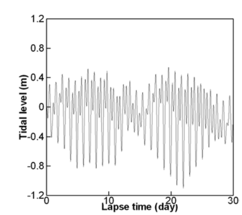
Results & Discussions

+ Correlation between TCO_2 and ΔpCO_2

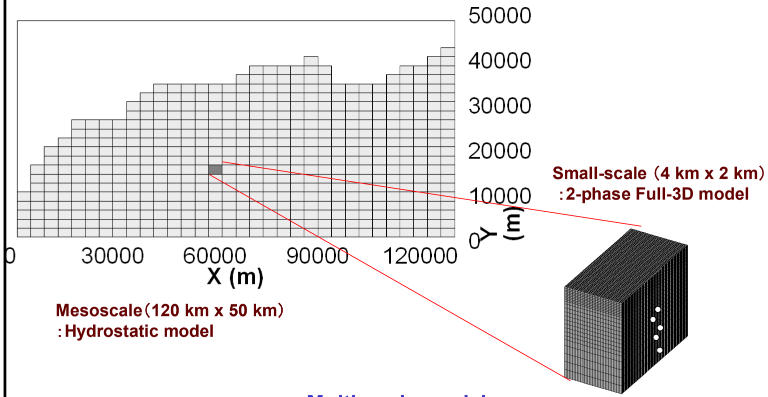


Ocean model simulation with real topography and tidal current



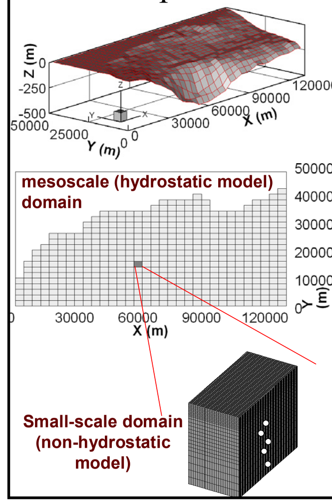


■ Multi-scale model



Multi-scale model

□ Computational conditions



mesoscale

model: hydrostatic model (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 size: 2 m

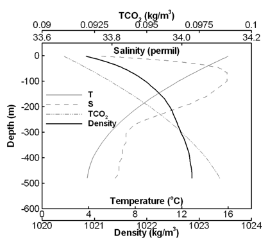
small scale

model: full-3D 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 size: 2 m

boundary conditions

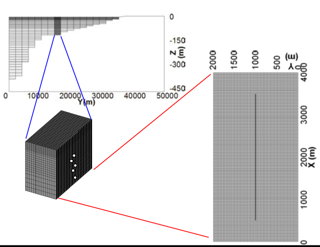
T,S,C: inflow-fixed & outflow-zero gradient
wave: no-reflection

■ Calculation conditions



environment:

temperature & salinity (annual average)
initial CO_2 concentration (observed)
: uniform in the horizontal direction
tide: 4 major tidal constituents
(M2, S2, K1, O1)



leakage conditions:

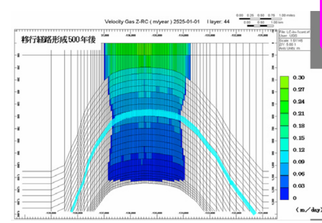
site: about 20 km off coast,120 m depth
path: uniform fault band (25m x 3000m)
form: 100 % CO_2 bubble

■ Calculation conditions: Leakage rate

leakage rate:

ocean fumaroles activity:
Wakamiko Caldera (Japan) 3430–41600 t/yr in 4 km^2 (Sugiura et al., 1981)
Tyrrhenian Basin (Italy) 25000 t/yr in 15 km^2 (Italiano et al., 2001)
continental EOR site:
Rangely (USA) 170-3800 t/yr in 78 km^2 (Klusman, 2003)
economic acceptable:
0.01%/yr of total injected mass (…ple and Benson, 2003)

Reasonable Case



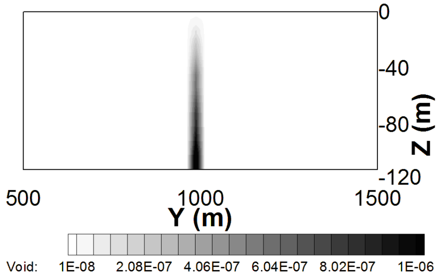
Extreme Case

RITE (2003)

storage mass: 73 Mt
size of fault: 25 m x 8000 m
permeability: 1 md
maximum leakage rate: 94600 t/yr
(about 0.13%/yr of total CO_2)

Results & Discussions

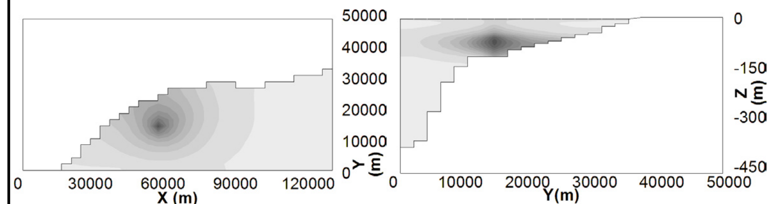
+ Volume fraction of un-dissolved CO_2 at the leakage site



Almost all CO_2 dissolved out in the seawater and does not come back to the surface.

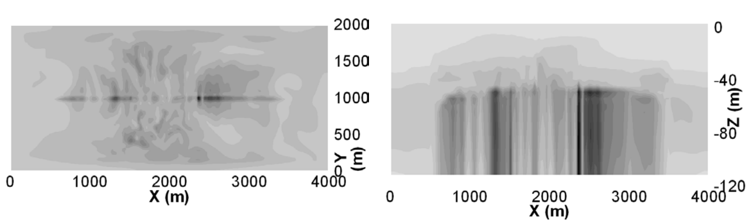
Results & Discussions

+ Distribution of ΔpCO_2 in the mesoscale model domain



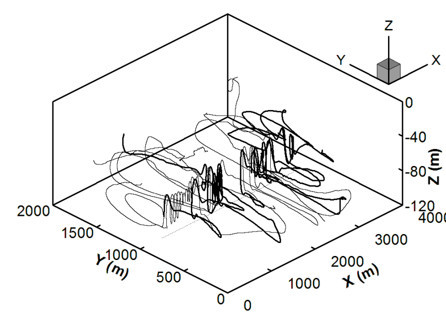
Results & Discussions

+ Distribution of ΔpCO_2 in the small-scale model domain



Results & Discussions

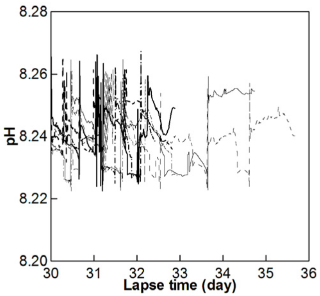
+ Biological impact for floating organisms



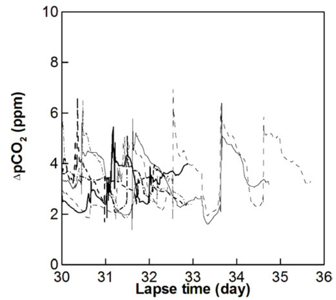
Trajectories of zooplanktons as passive tracers

Results & Discussions: Reasonable case

+ Biological impact for floating organisms



pH experienced by zooplanktons

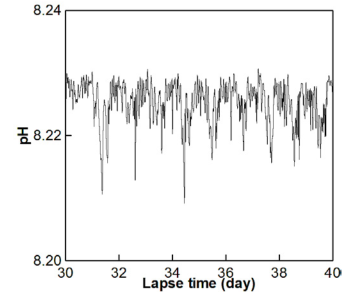


ΔpCO_2 experienced by zooplanktons

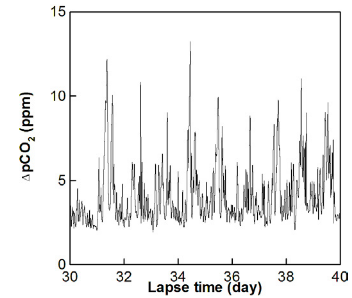
25

Results & Discussions: Reasonable case

+ Biological impact for benthic organisms



pH at the bottom cell

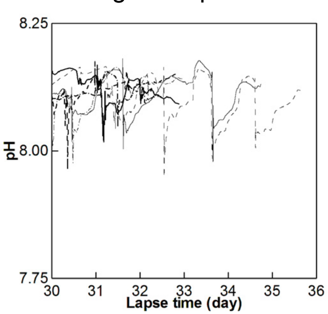


ΔpCO_2 at the bottom cell

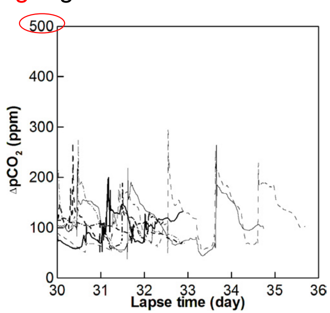
26

Results & Discussions: Extreme case

+ Biological impact for floating organisms



pH experienced by zooplanktons

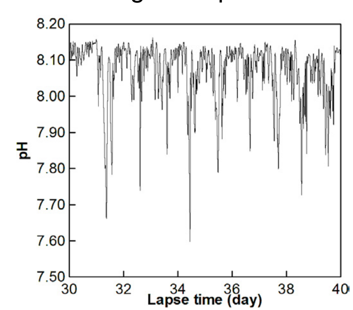


ΔpCO_2 experienced by zooplanktons

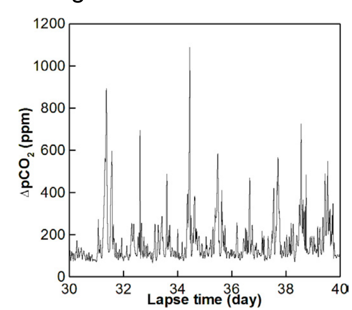
27

Results & Discussions: Extreme case

+ Biological impact for benthic organisms



pH at the bottom cell



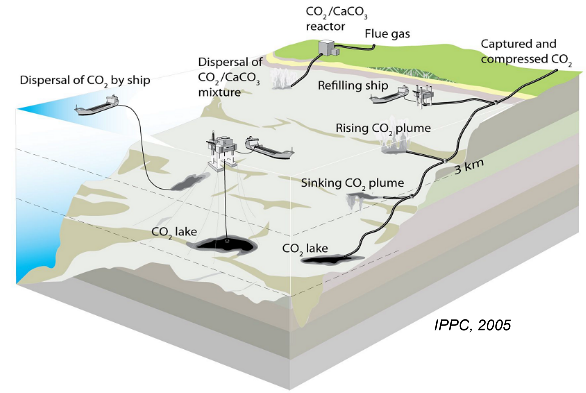
ΔpCO_2 at the bottom cell

28

Conclusion

- In the reasonable leakage-rate case (3800 t/y), calculated changes in pCO_2 and pH experienced by both the floating and immobile organisms were within the natural fluctuation. Therefore, this case causes no damage on any marine biota.
- In the extreme leakage-rate case (94600 t/y), floating organisms never experienced the ΔpCO_2 of more than 300 ppm. This may suggest that the impact of leaked CO2 on plankton is trivial. On the other hand, rarely travelling organisms living directly on the leak-band may experience high ΔpCO_2, up to 1000 ppm, for a short time, if repeatedly.

Options for CCS (Carbone Capture and Storage)

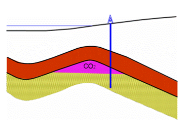


IPPC, 2005

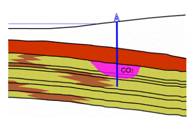
Capacity of subsea geological in Japan

Categories of Geological Storage		Storage Potential
Structured Aquifer	Core & seismic data measured (A2)	5.2Gt CO_2
	Seismic data measured (A3)	21.4Gt CO_2
Unstructured Aquifer (water depth<200m)	Core & seismic data measured (B1)	27.5Gt CO_2
	Seismic data measured (B2)	88.5Gt CO_2

(RITE)



structured



unstructured

Expected CCS Amount : 0.5 - 4.0GtCO_2/year for 2025-2100
"Vision of Energy Technology for Very Long Term" by METI

Difference in Risks

- Subsea geological storage
  - Total amount stored in 1 site is uncertain.
  - Risk is biological impact of leaked CO2. But leakage probability and its rate are uncertain.
  - The uncertainties makes the management of the risk and consequent public acceptance difficult.
  - The risk is handed to the next generation.
- Ocean sequestration
  - Target of risk management is near-field because CO2 concentration is highest near injection points and diffused by turbulence in the far field.
  - It is possible to quantify hazards when many biological impact data are available in the near future.
  - When we know the no-effect concentration, technology innovation can dilute CO2 below the value. Then, the risk can be managed.