APN Forum: The Future of Climate Change and the Marine Environment - Towards Sustainable Oceans -,
March 18, 2025@Kobe

Current Status of Marine Environmental Issues and Strategic Approach by Digital Twin

Yusuke Uchiyama (Department of Civil Eng., Kobe University, Japan)

Lecture Contents (Tentative)

1. Self-Introduction
2. Coastal and Marine Research in the Field of Civil Engineering
3. Current Status of Marine Environmental Issues
4. Ocean Digital Twin Development at Kobe University
5. Strategic Approach to Marine Environmental Issues Using a Digital Seto Inland Sea
   - 5.1 Marine Plastic Issues in Hiroshima Bay
   - 5.2 Eelgrass Ecosystem Network Structure in the Seto Inland Sea
   - 5.3 Problems of Discharge from Sewage Treatment Plants to Seas
   - 5.4 Towards a Low-Carbon Shipping Industry (Weather Routing)
6. Conclusion

Self-Introduction (Resume Summary)

Sep 2021–	Ocean Modelling, Editor
Jun 2019–	Coastal Engineering Journal, Editor-in-Chief
Sep 2020–Aug 2024	AOGS OS Section President (International Society)
Sep 2016–Sep 2017	UCLA, USA (JSPS Grant-in-Aid for Fund for the Promotion of Joint International Research)
Apr 2011–	Department of Civil Engineering, Kobe University
Apr 2005–Mar 2011	UCLA, USA (Institute of Geophysics and Planetary Physics) →Oceanography
Mar 2002–Mar 2004	UC Berkeley, USA (JST/JSPS Overseas Research Fellow)
Apr 1998–Mar 2005	Port and Airport Research Institute (National Research and Development Agency)
Mar 1998	Ph.D. (Engineering), Tokyo Institute of Technology
Mar 1993	Graduated from the Department of Civil Engineering, Faculty of Engineering, Tokyo Institute of Technology

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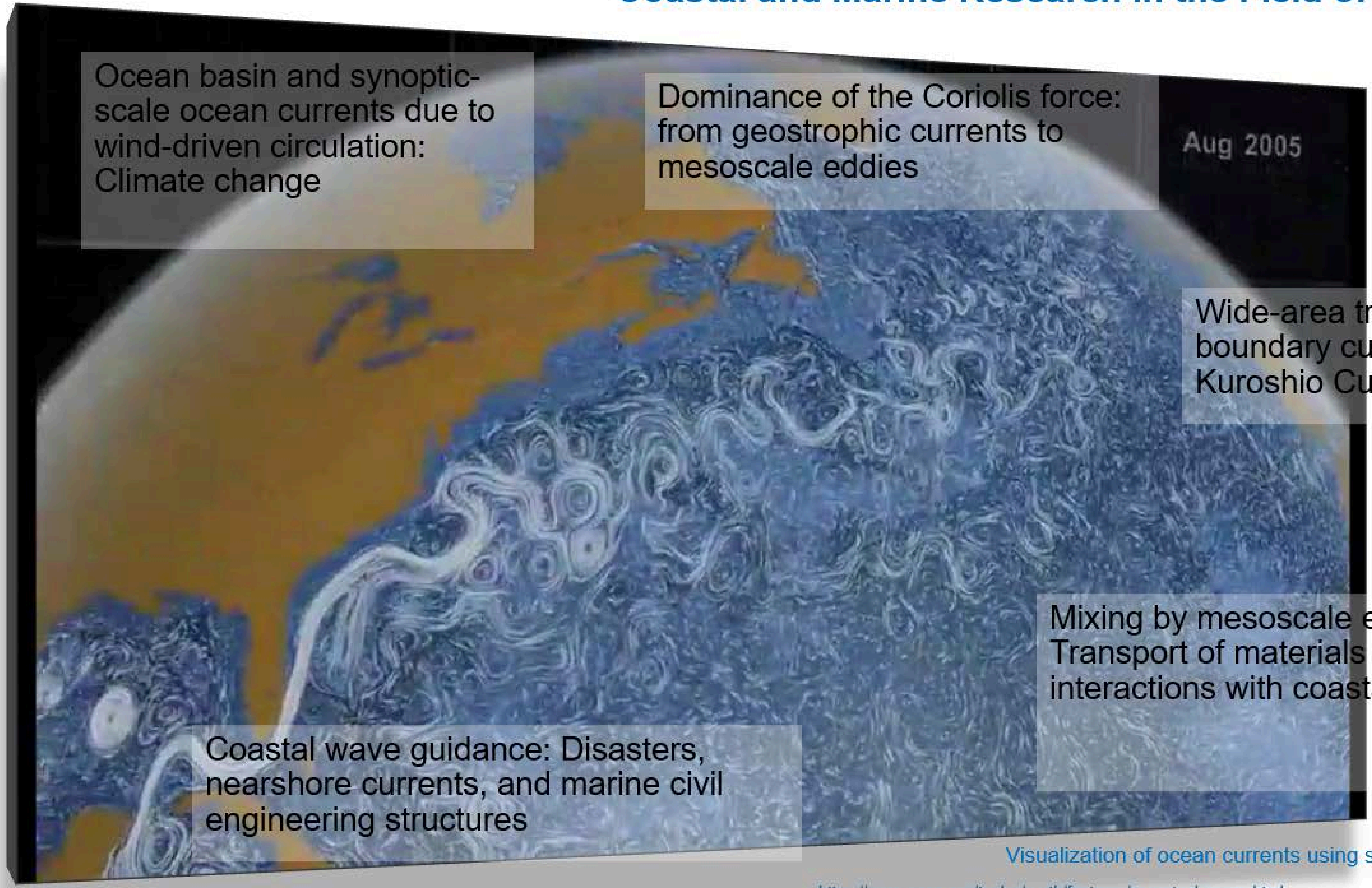
Civil Engineering and Coastal/Marine Issues: Other Research Topics

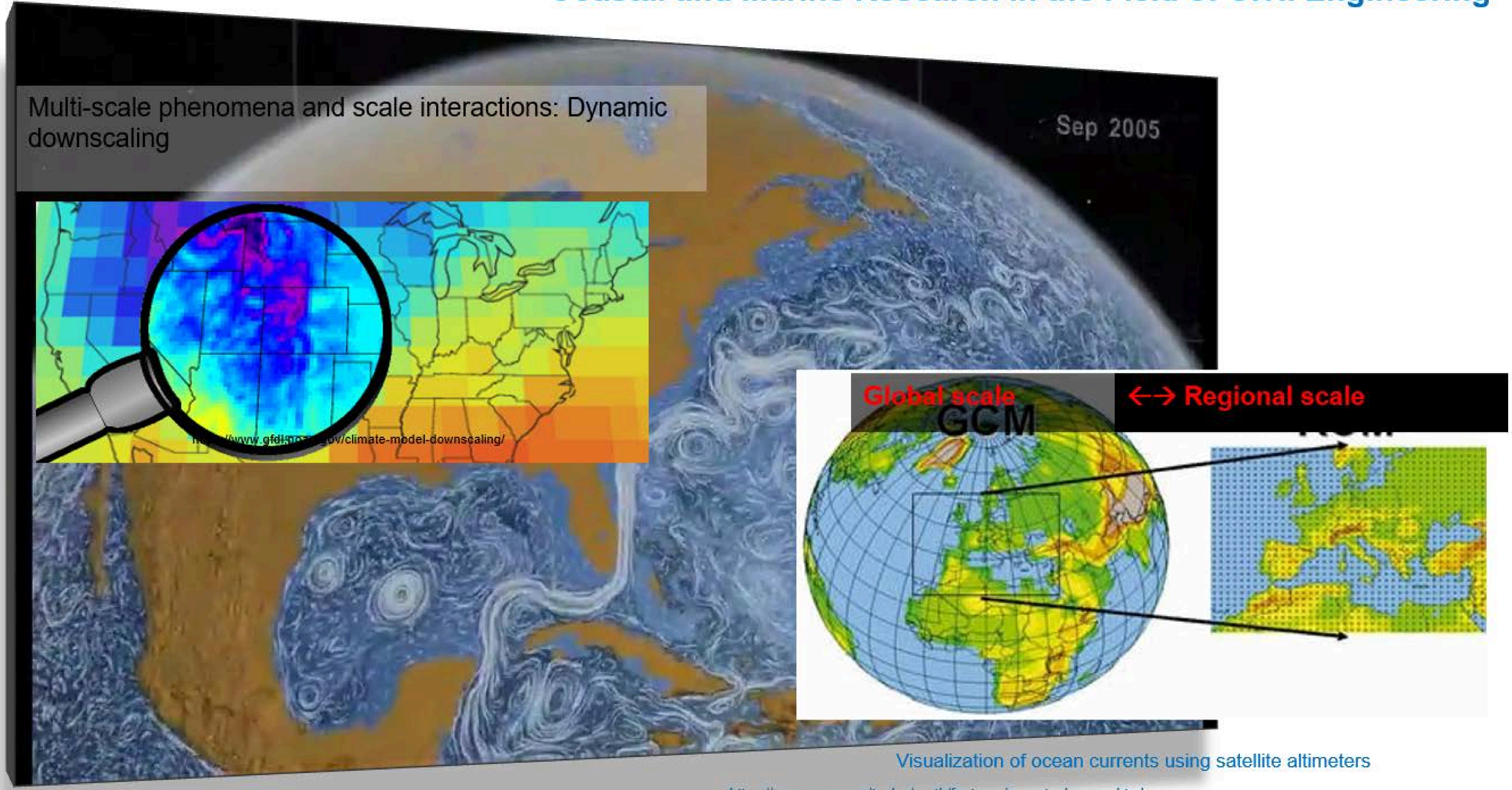
Coastal and Marine Research in the Field of Civil Engineering



Visualization of ocean currents using satellite altimeters

https://www.nasa.gov/topics/earth/features/perpetual-ocean.html

Multi-scale phenomena and scale interactions: Dynamic downscaling



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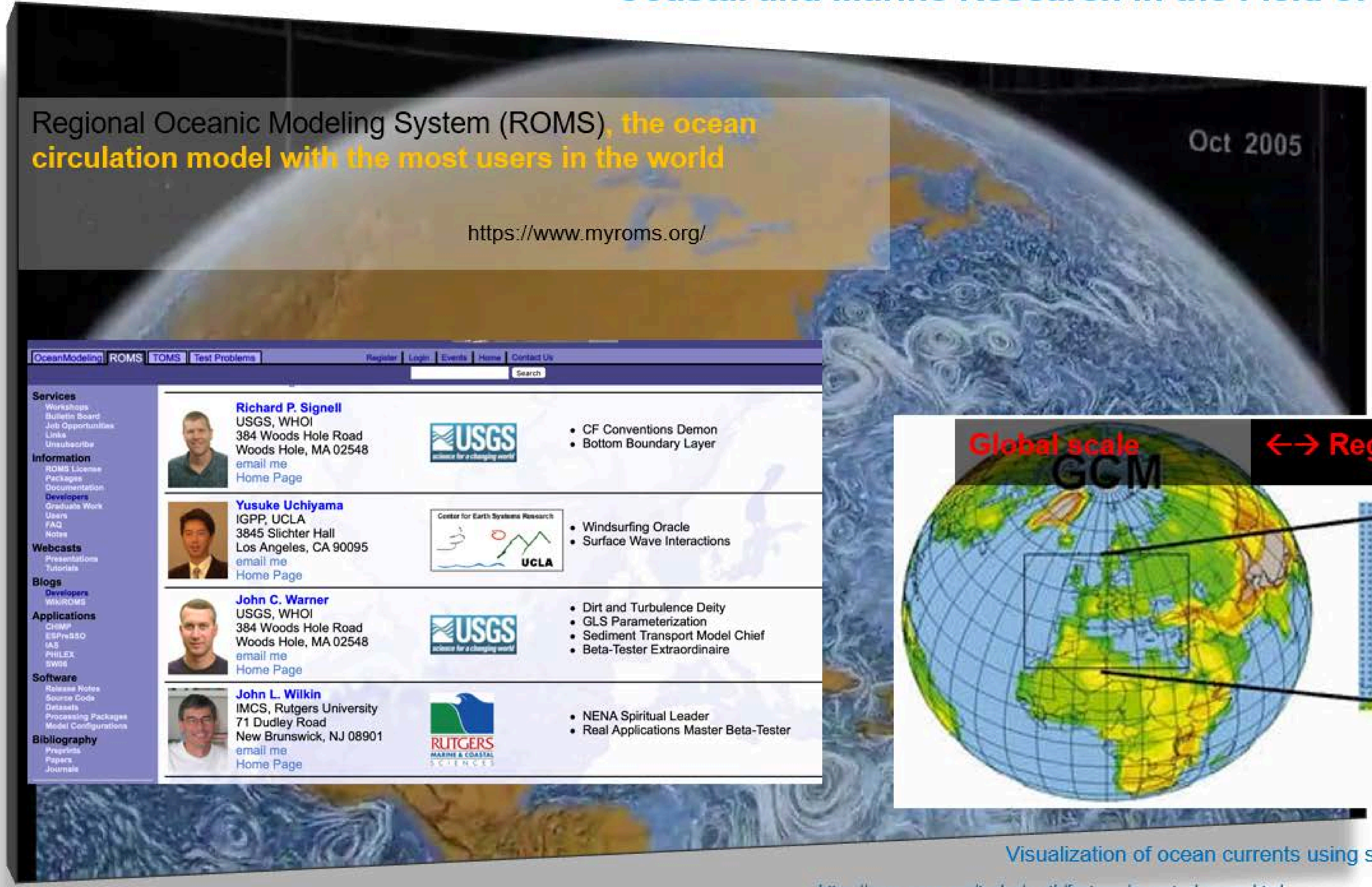
Coastal and Marine Research in the Field of Civil Engineering



Regional Oceanic Modeling System (ROMS), **the ocean circulation model with the most users in the world**

https://www.myroms.org/

OceanModeling | ROMS | TOMS | Test Problems — Register | Login | Events | Home | Contact Us — Search

Services
- Workshops
- Bulletin Board
- Job Opportunities
- Links
- Unsubscribe

Information
- ROMS License
- Packages
- Documentation
- Developers
- Graduate Work
- Users
- FAQ
- Notes

Webcasts
- Presentations
- Tutorials

Blogs
- Developers
- WikiROMS

Applications
- CHIMP
- ESPreSSO
- IAS
- PHILEX
- SW06

Software
- Release Notes
- Source Code
- Datasets
- Processing Packages
- Model Configurations

Bibliography
- Preprints
- Papers
- Journals

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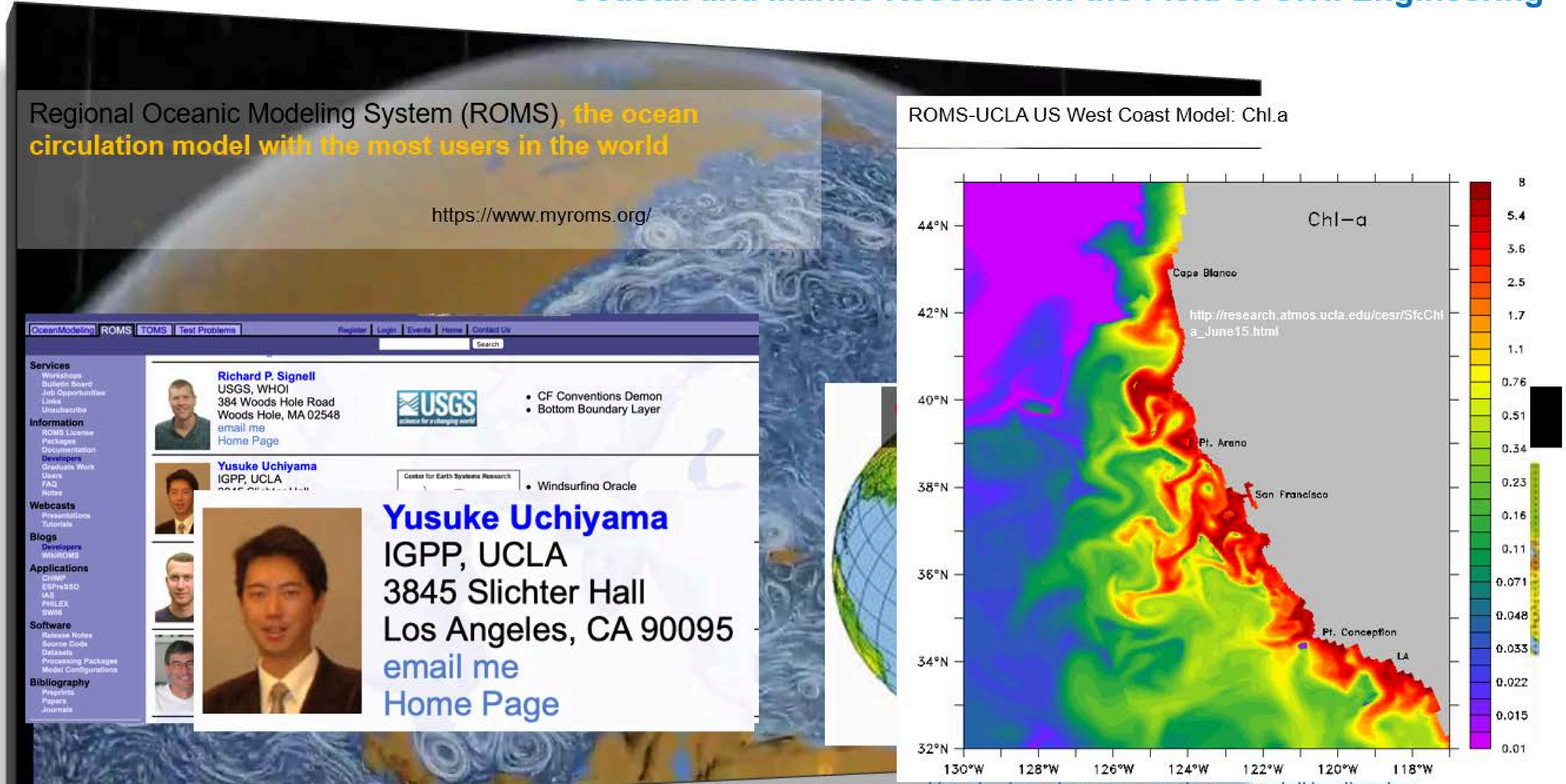
John C. Warner USGS, WHOI 384 Woods Hole Road Woods Hole, MA 02548 email me Home Page	USGS science for a changing world	• Dirt and Turbulence Deity • GLS Parameterization • Sediment Transport Model Chief • Beta-Tester Extraordinaire
John L. Wilkin IMCS, Rutgers University 71 Dudley Road New Brunswick, NJ 08901 email me Home Page	RUTGERS MARINE & COASTAL SCIENCES	• NENA Spiritual Leader • Real Applications Master Beta-Tester

Global scale ←→ Regional scale

Visualization of ocean currents using satellite altimeters

https://www.nasa.gov/topics/earth/features/perpetual-ocean.html

Coastal and Marine Research in the Field of Civil Engineering



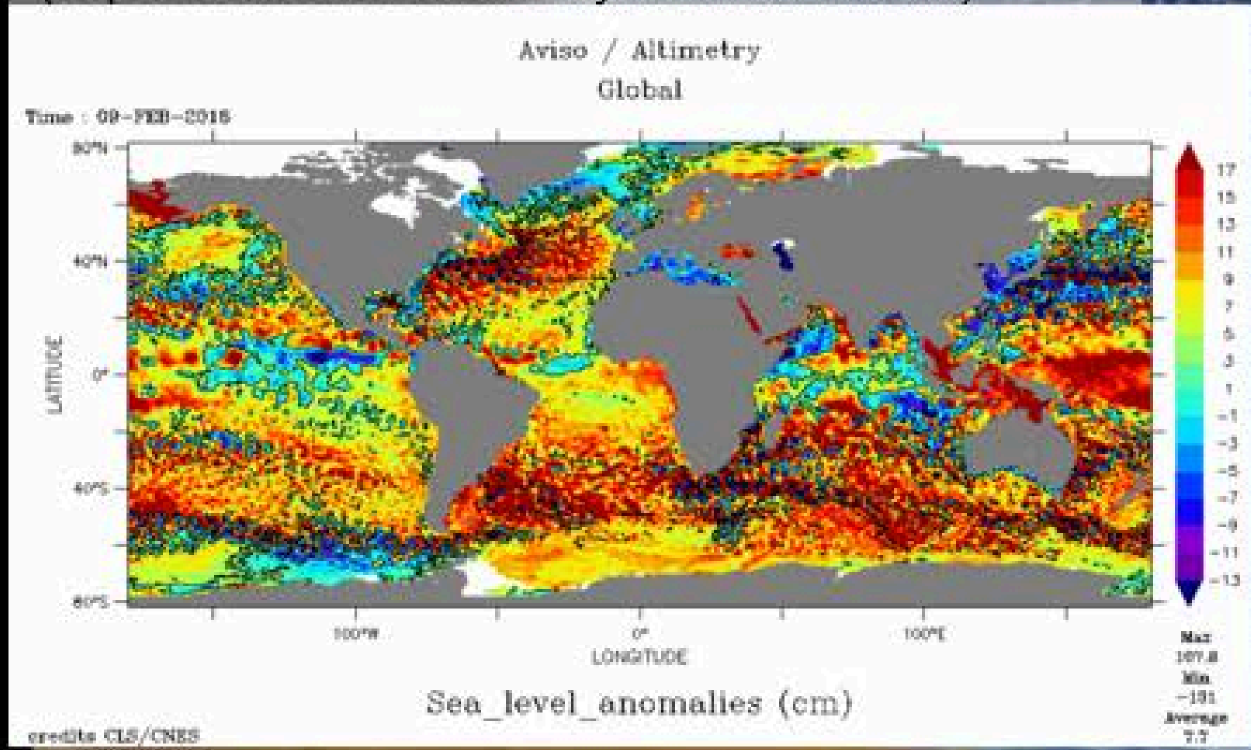
Visualization of ocean currents using satellite altimeters

https://www.nasa.gov/topics/earth/features/perpetual-ocean.html

Coastal and Marine Research in the Field of Civil Engineering

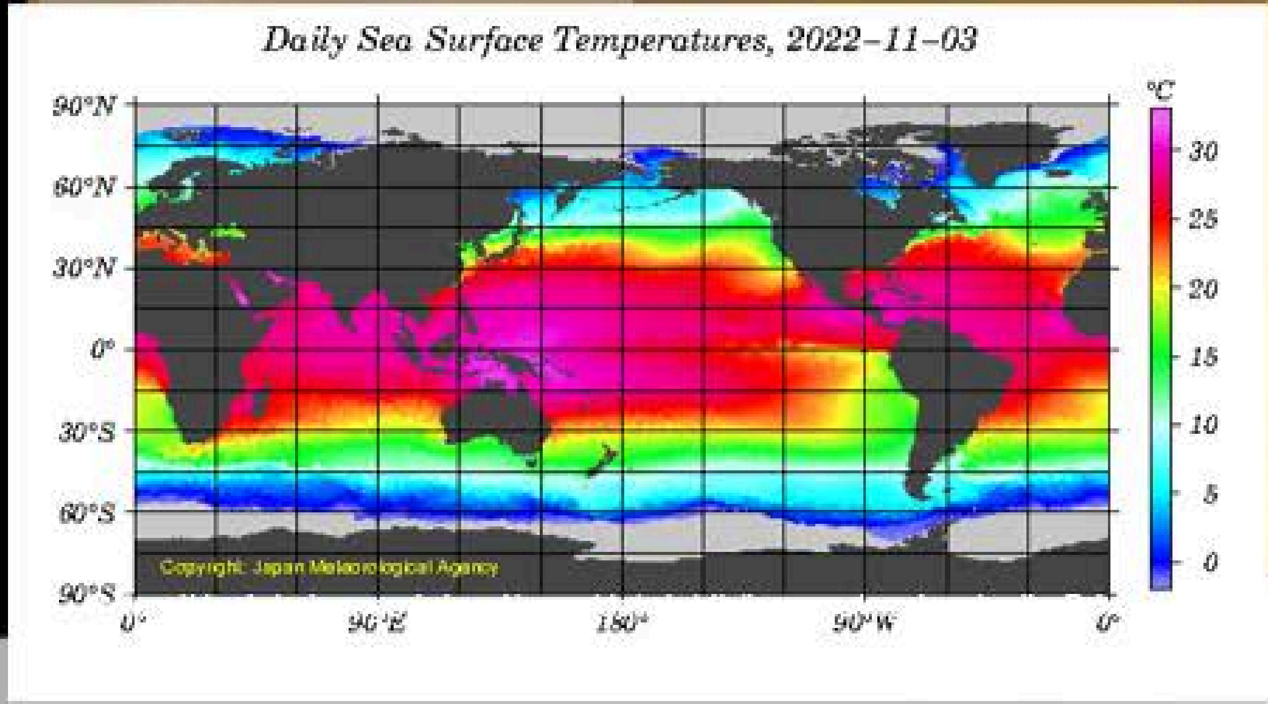
Satellite remote sensing: Ocean observation from space

Sea surface altimeter (geostrophic current velocity)
(https://www.aviso.altimetry.fr/en/home.html)



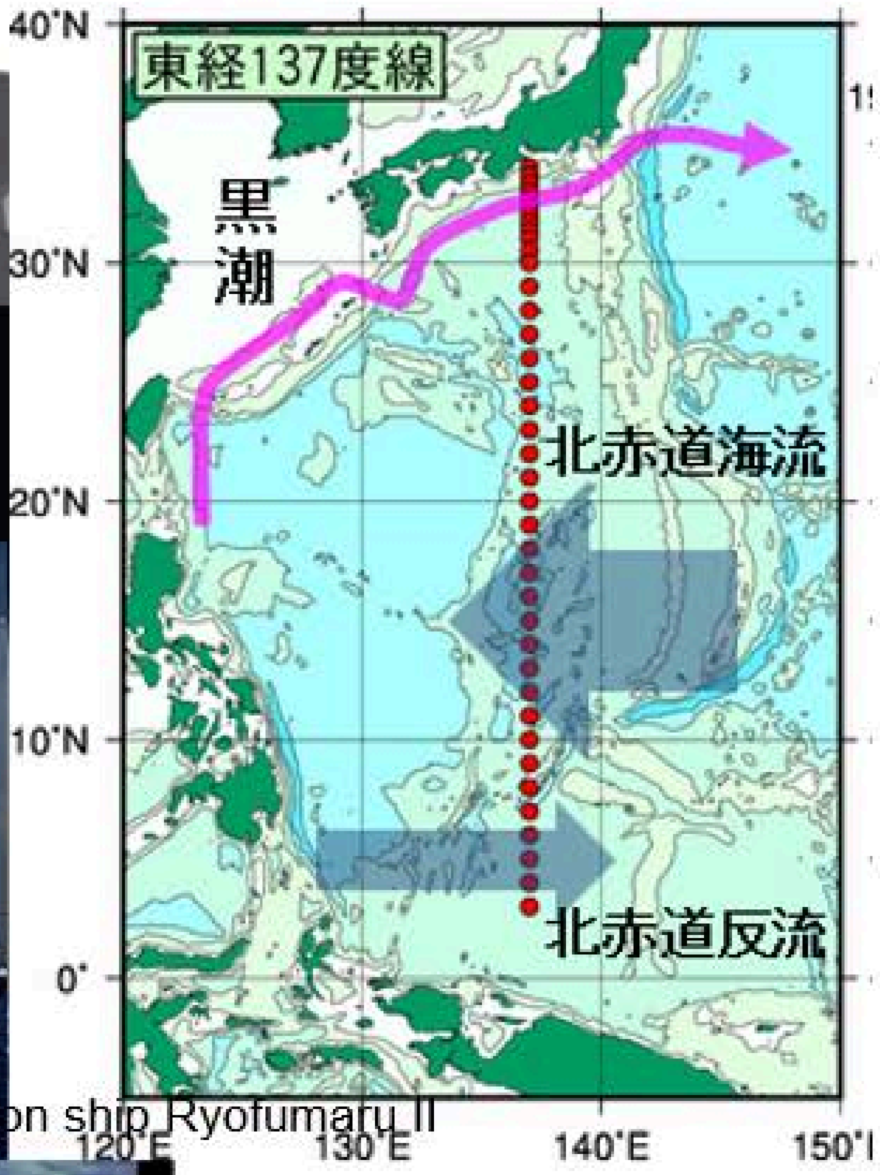
Sea surface temperature

MGD-SST



Field observation: Deep sea observation using ships

Japan Meteorological Agency observation ship Ryofumaru II



Visualization of ocean currents using satellite altimeters

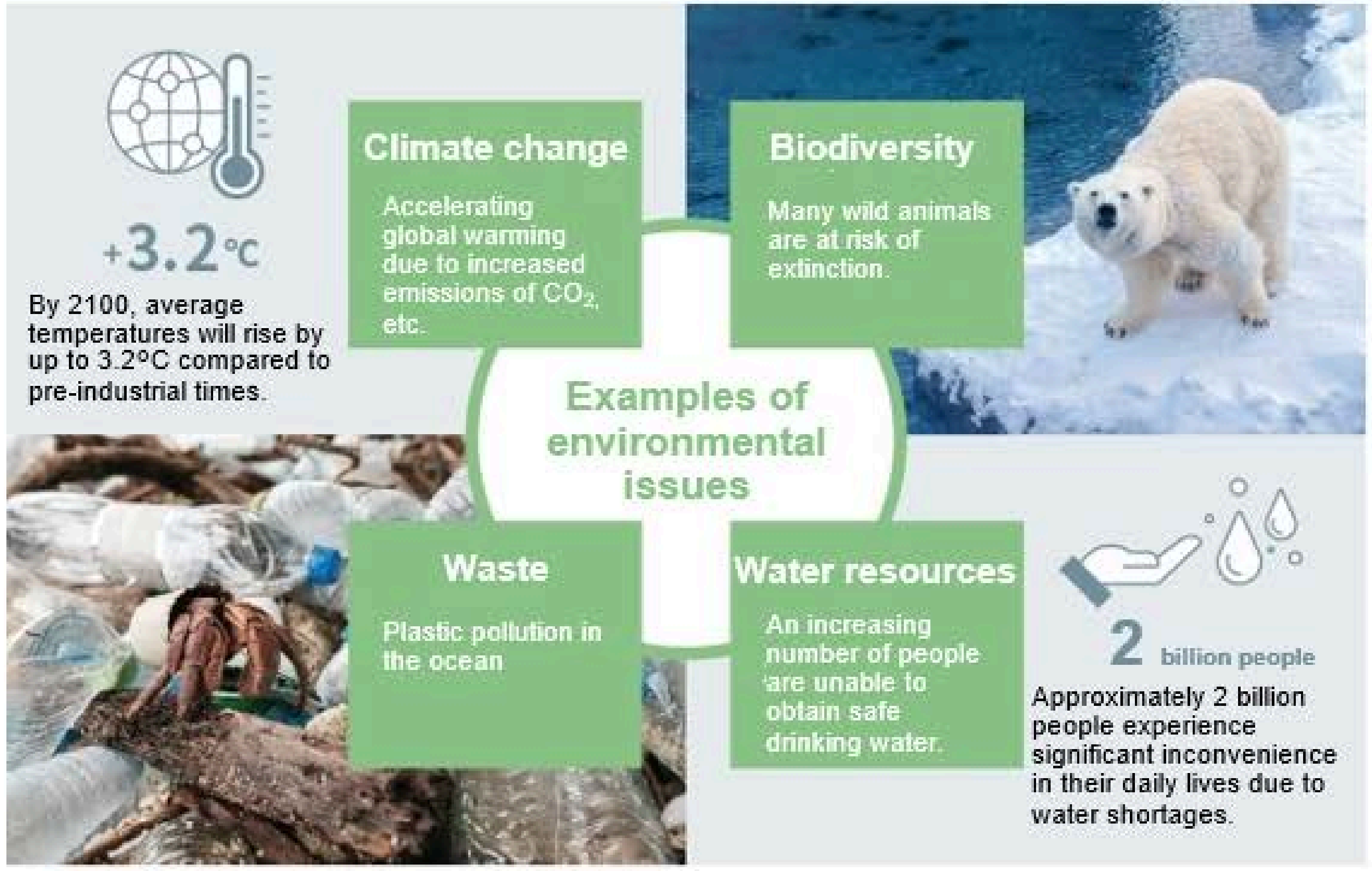
https://www.nasa.gov/topics/earth/features/perpetual-ocean.html

Lecture Contents

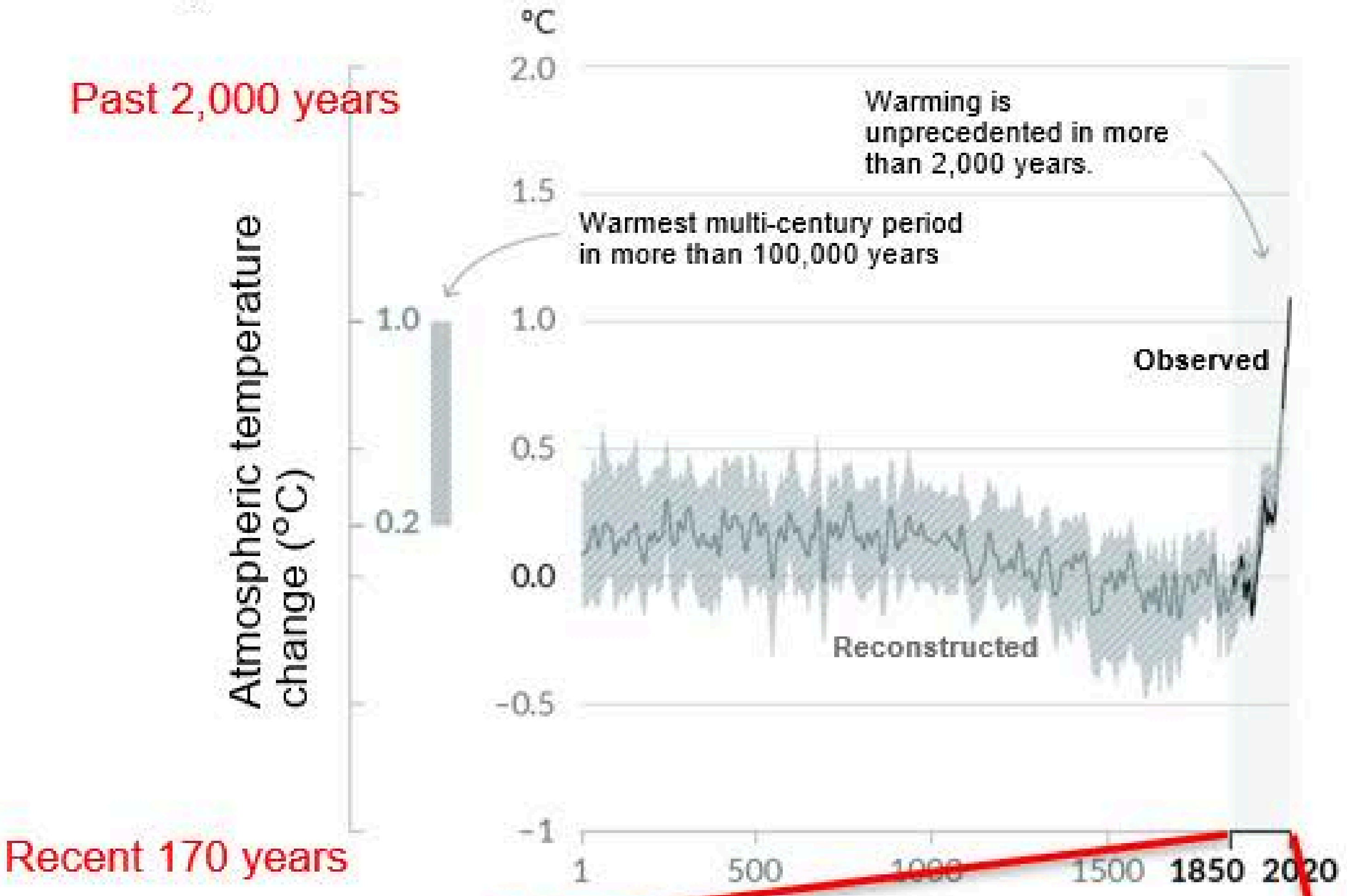
Current Status of Marine Environmental Issues

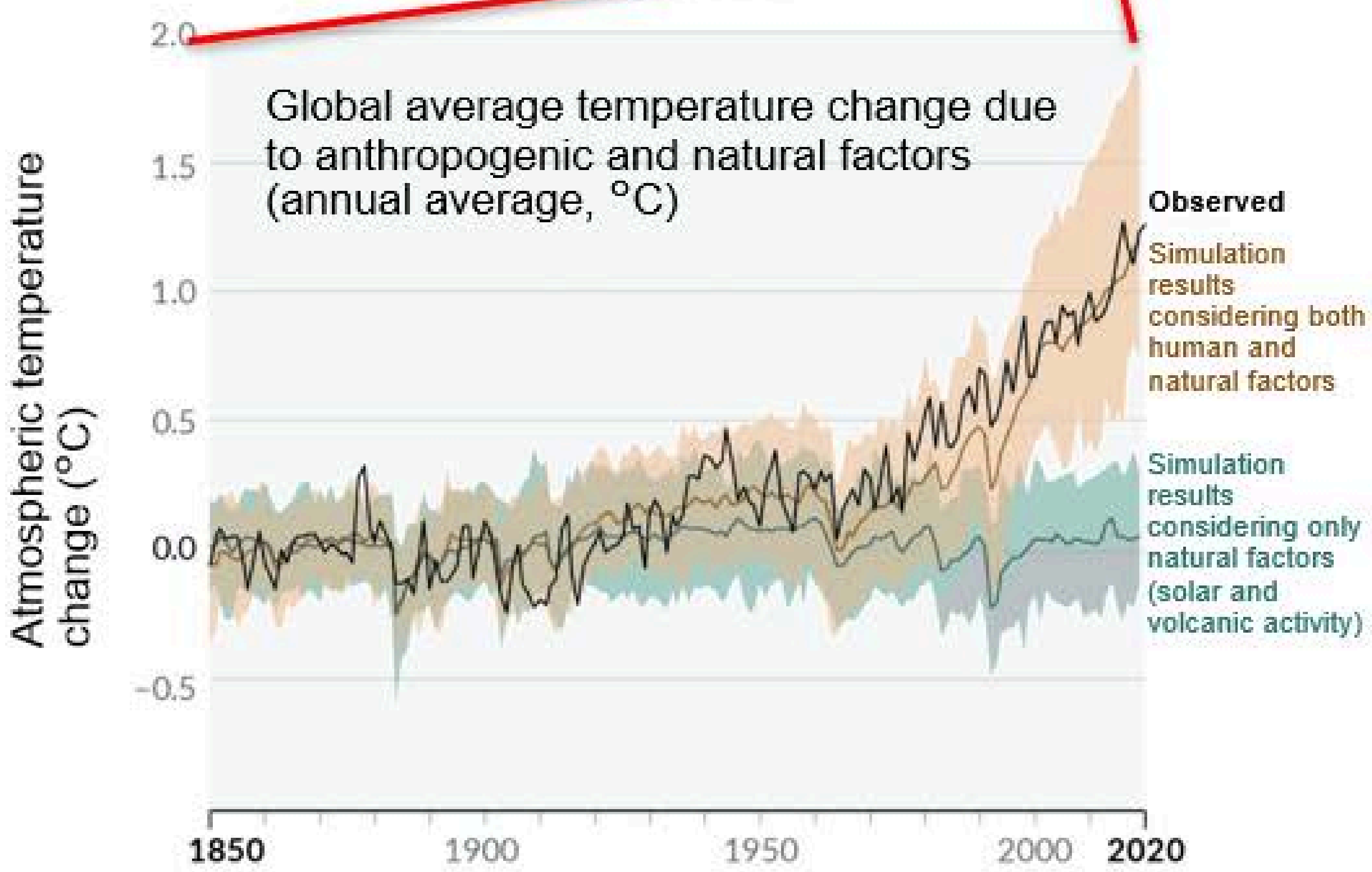
- **ESG**: Investment, management, and business activities that take into consideration the environment, society, and governance
  ESG is a means to achieve **the SDGs** (discussed later).
- Environmental issues are not a burden; but rather, actively working to resolve them creates (corporate) value.

Example of ESG (from the Cabinet Office website): Environmental issues are related to the ocean.



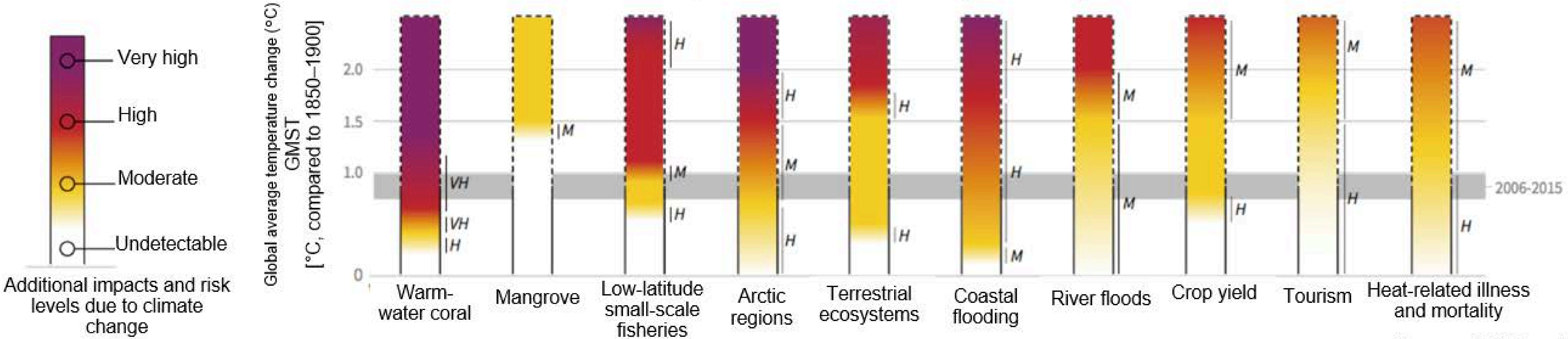
Global average temperature change (10-year average) according to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6)





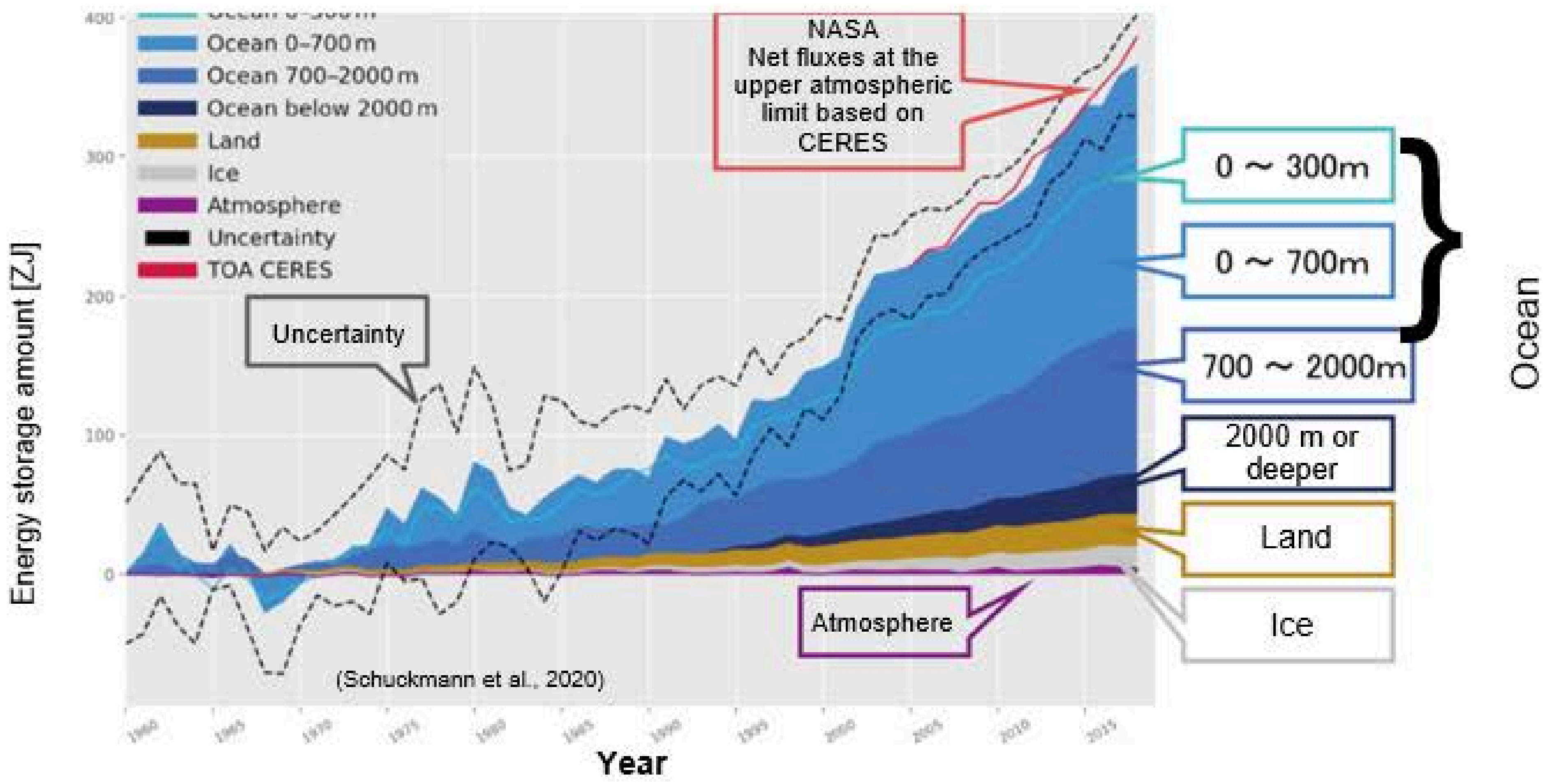
Current status (and future) of marine environmental issues

Risks of global warming to nature and human society (IPCC-AR6)

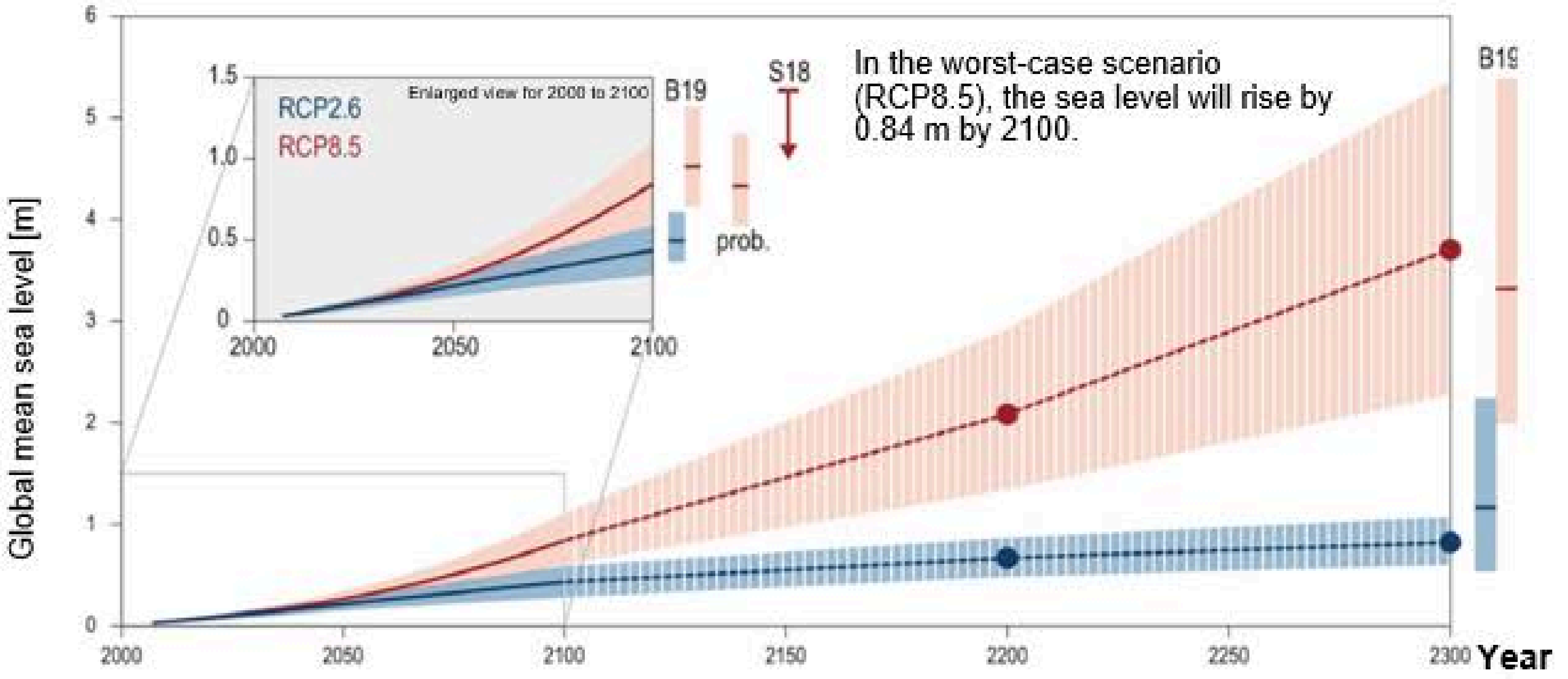


Source: SR1.5 and SPM.2 (illustrations)

The oceans store about 90% of the Earth's heat.

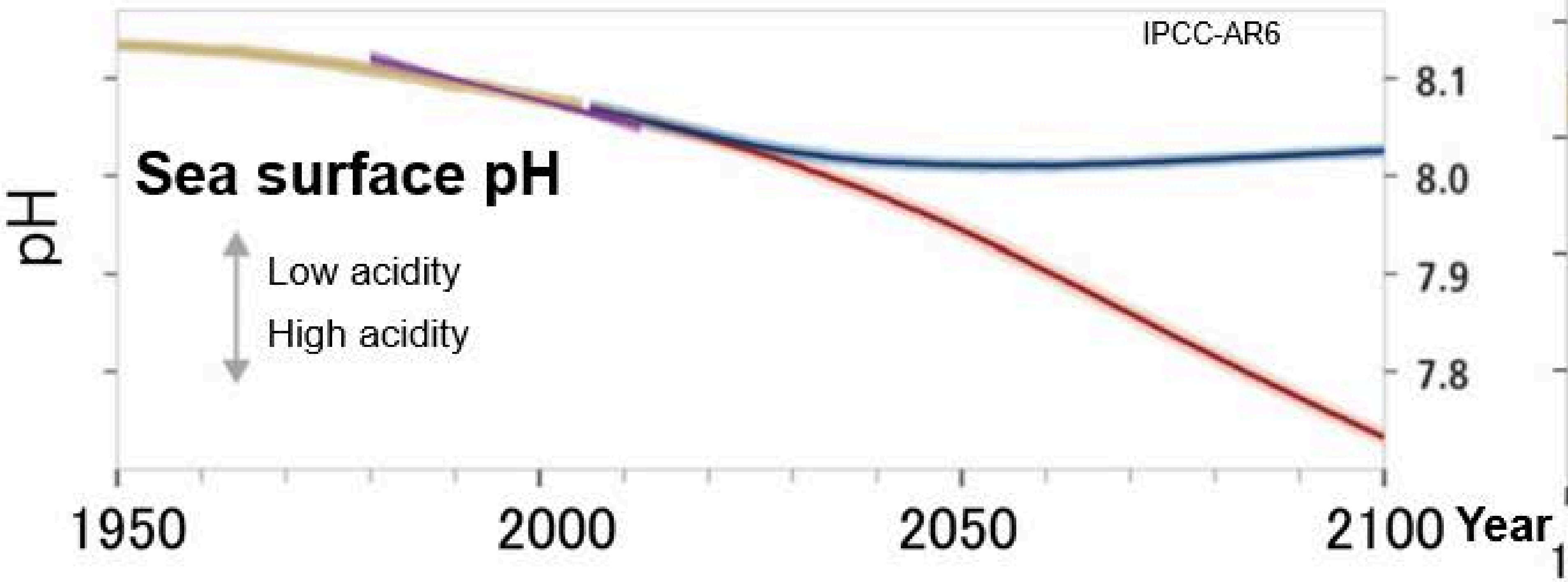


Global average sea level rise by 2300 (IPCC-AR6)

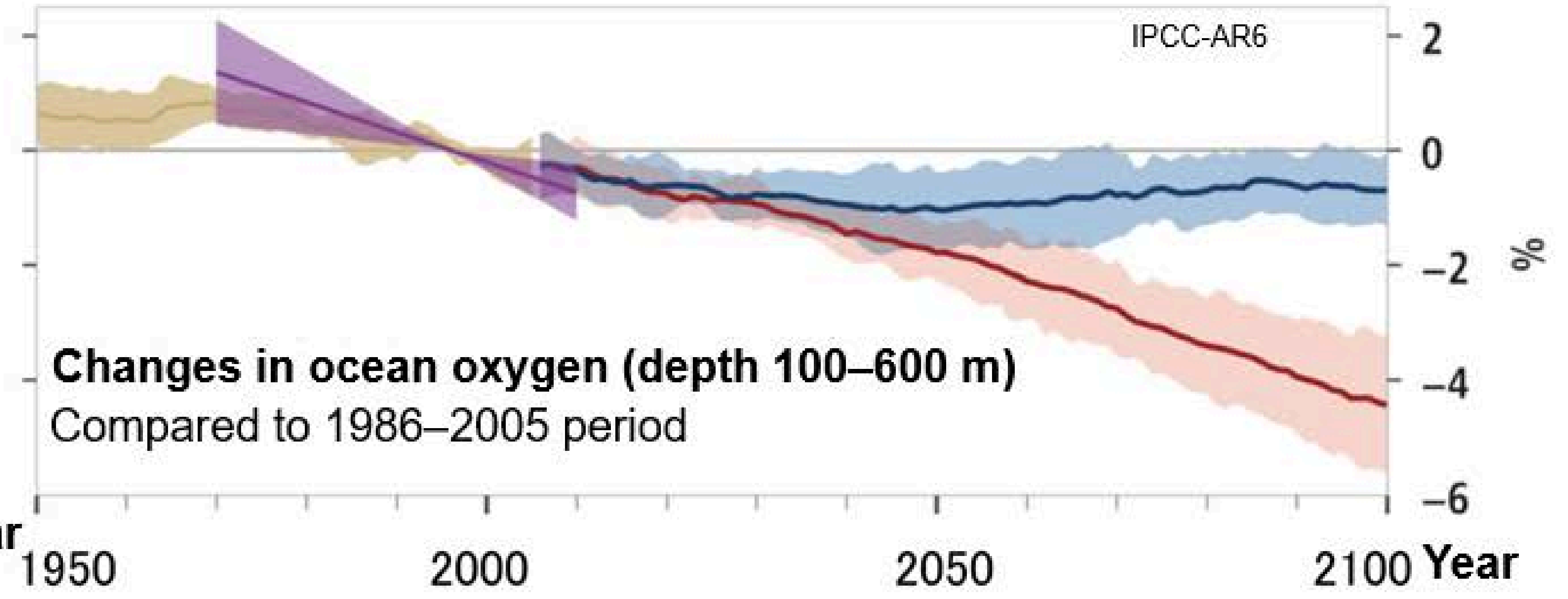


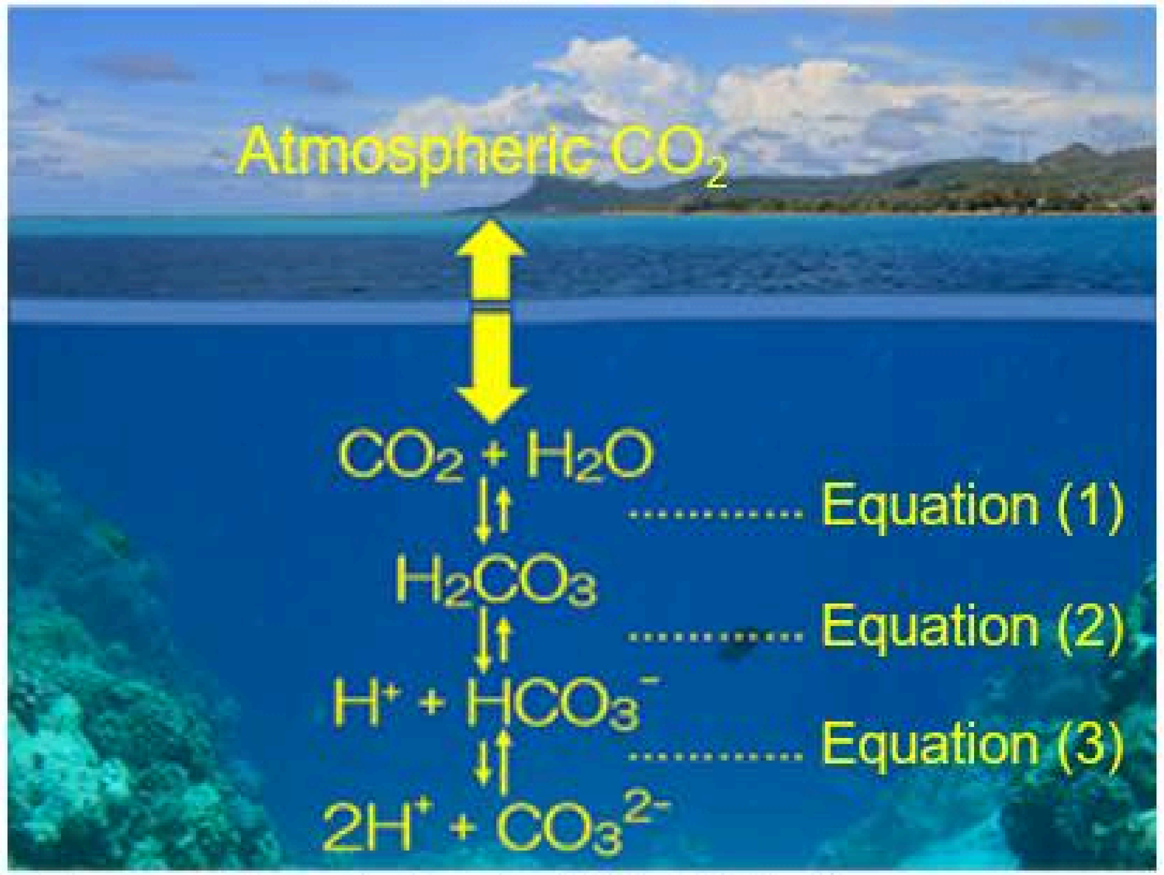
Current status and future of marine environmental issues

Global mean sea surface pH by 2100



Global average ocean surface oxygen content (100–600 m) by 2100





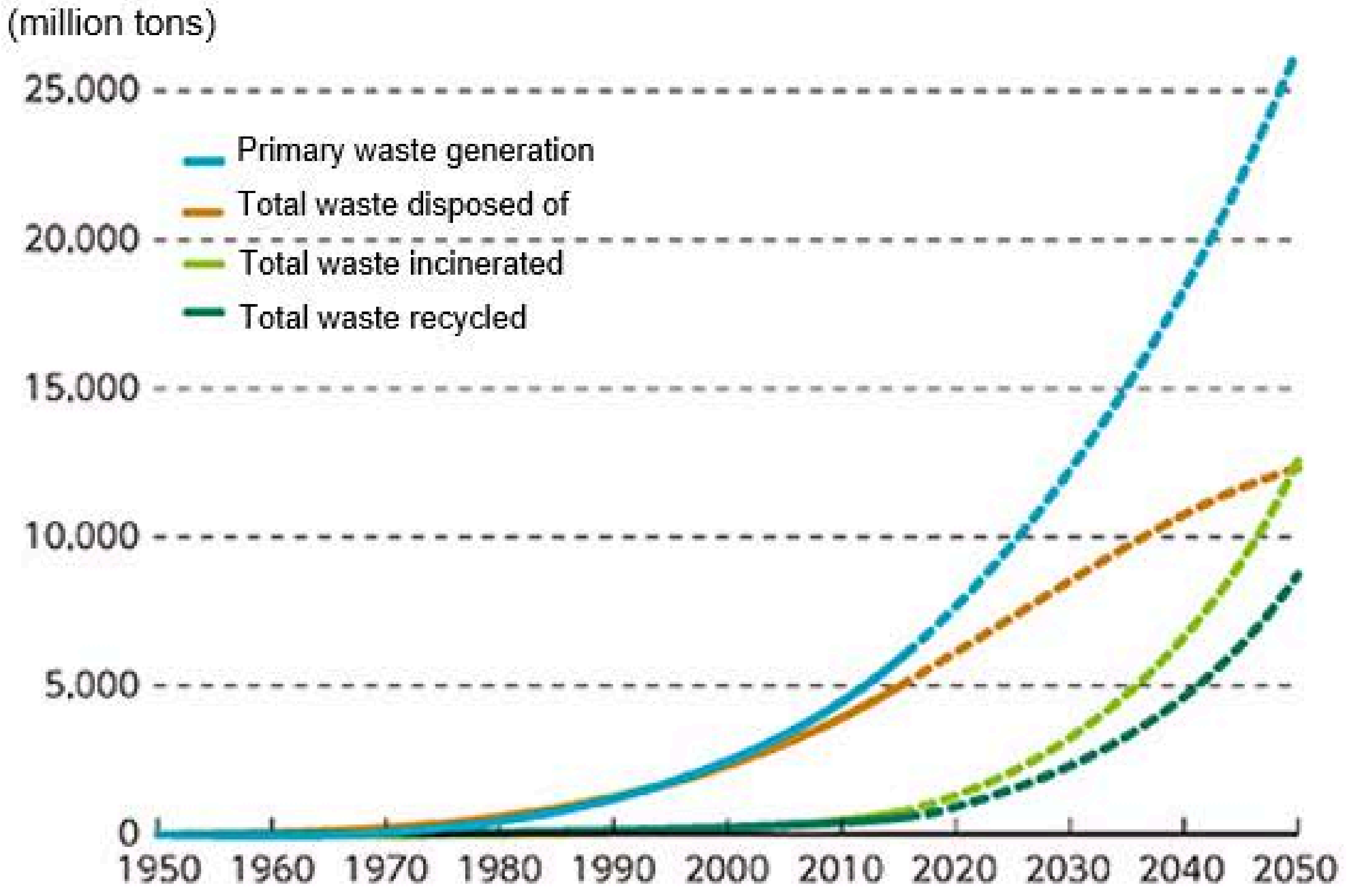
(https://www.cger.nies.go.jp/ja/library/qa/6/6-1/qa_6-1-j.html)

- Carbon dioxide (CO_2) dissolved in the ocean changes to carbonic acid (H_2CO3), and hydrogen ions (H^+) dissociate to produce bicarbonate ions (HCO_3^-) and carbonate ions (CO_3^{2-}). As a result, the pH decreases due to an increase in H^+.
- **Although** the pH is acidic at <7, **at pH <7.84** the production of calcium carbonate ($CaCO_3$) is inhibited, resulting in a decrease in the number of calcified organisms with shells or skeletons.
- The atmospheric CO_2 concentration that would bring the pH of surface ocean water to 7.84 is **approximately 640 ppm**, a concentration that could be reached as early as the second half of the 21st century.

- By 2100, ocean oxygen levels will decline globally.
- At the same time, nitrate, primary production, and carbon fluxes will also decrease.

Current status and future of marine environmental issues

Estimated amount of plastic waste generated

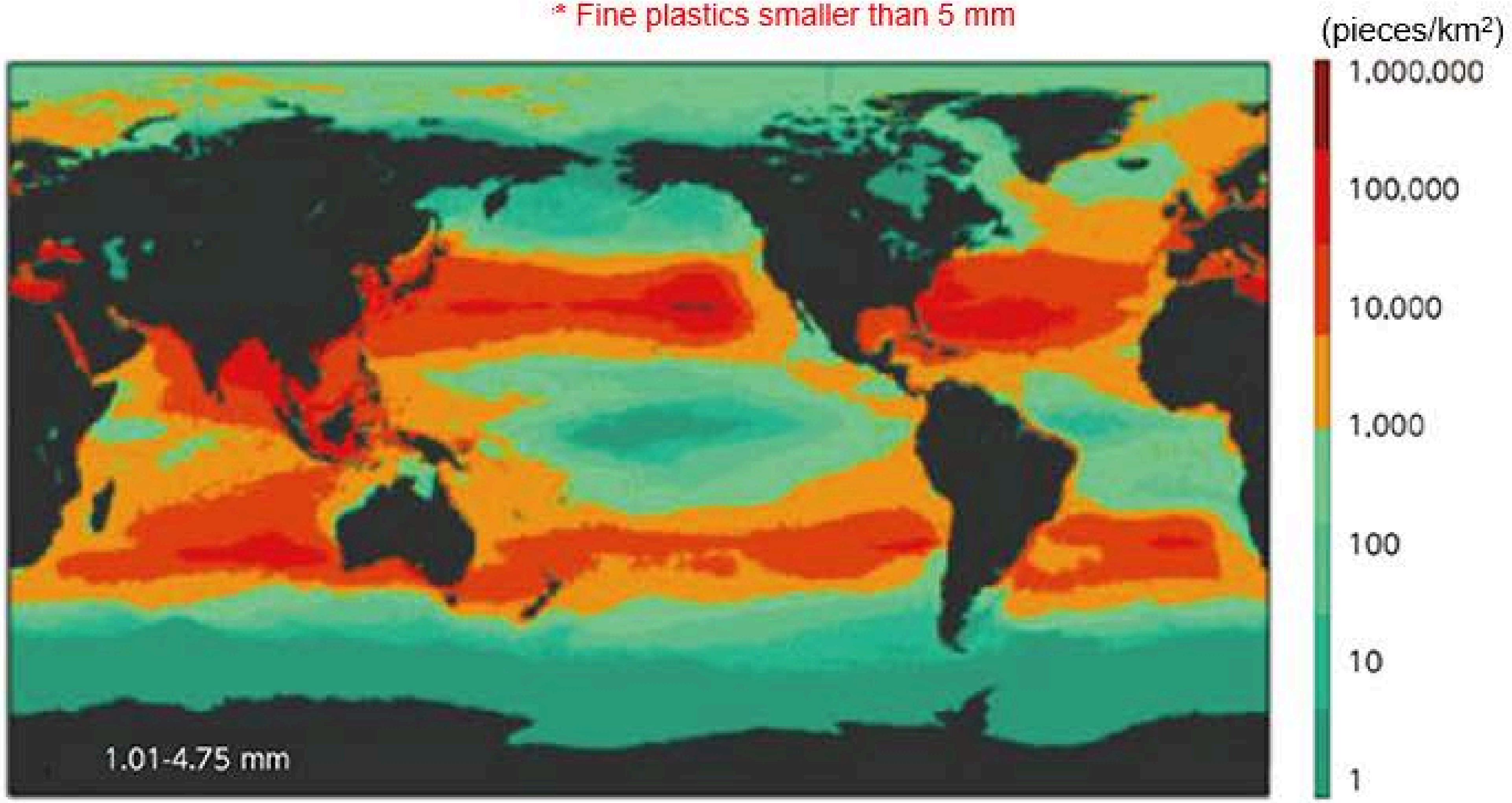


Source: Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. Science advances, 3(7), e1700782.

Since 1950, over 8.3 billion tons of plastic have been produced, of which 6.3 billion tons have been discarded as waste. It is predicted that by 2050, 25 billion tons of plastic waste will be generated, and more than 12 billion tons will be landfilled or dumped in nature.

Density distribution of microplastics* (1–4.75 mm) (model prediction)

* Fine plastics smaller than 5 mm



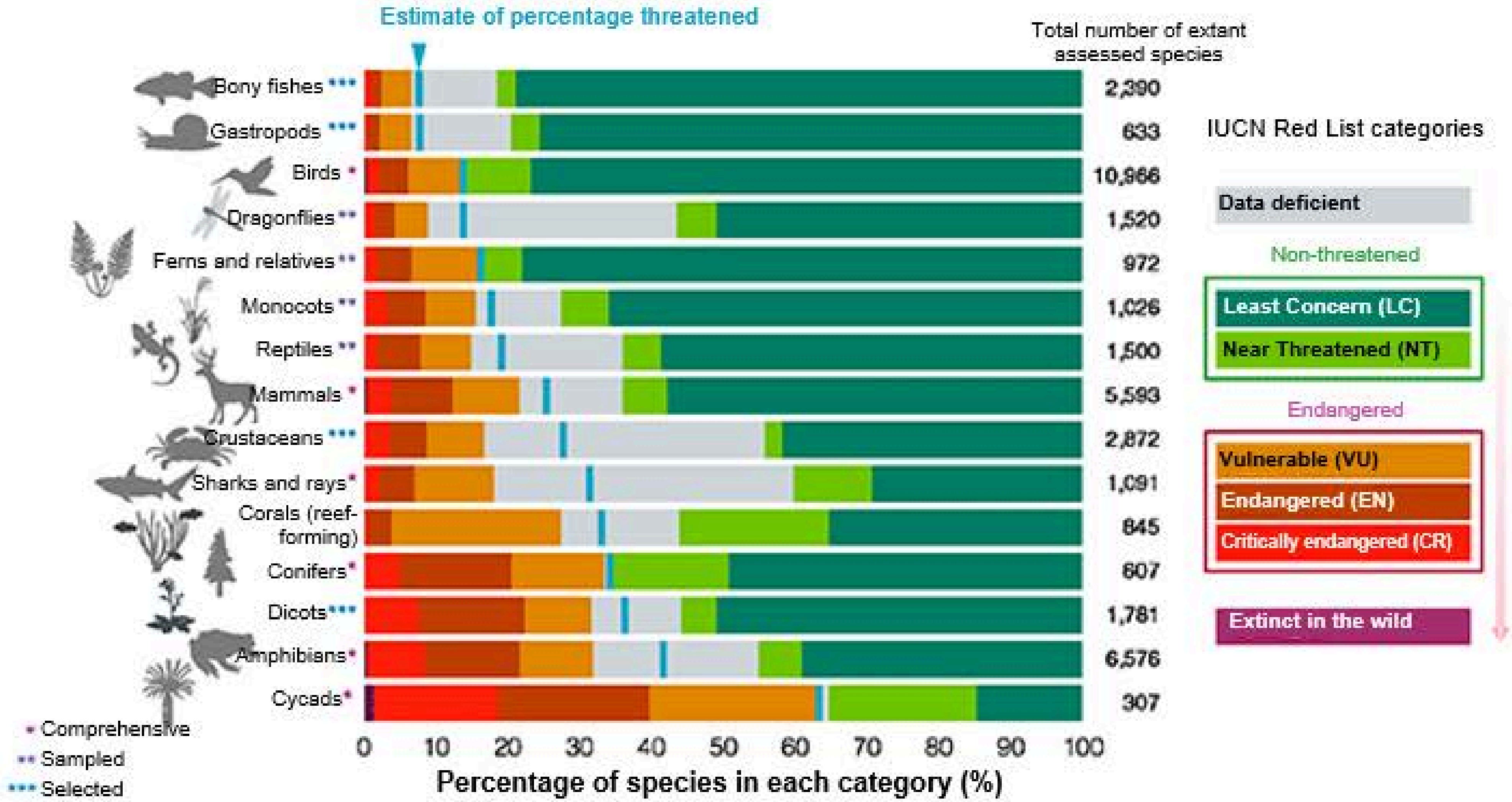
Source: Erikson (2014). "Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea" PLoS One 9 (12), doi: 10.1371/journal.pone.0111913

Microplastics have been found throughout the world, including in the Arctic and Antarctic, and are causing marine pollution on a global scale. According to some estimates, the main sources of emissions are from East Asia and Southeast Asia.

https://www.env.go.jp/policy/hakusyo/r02/html/hj20010103.html

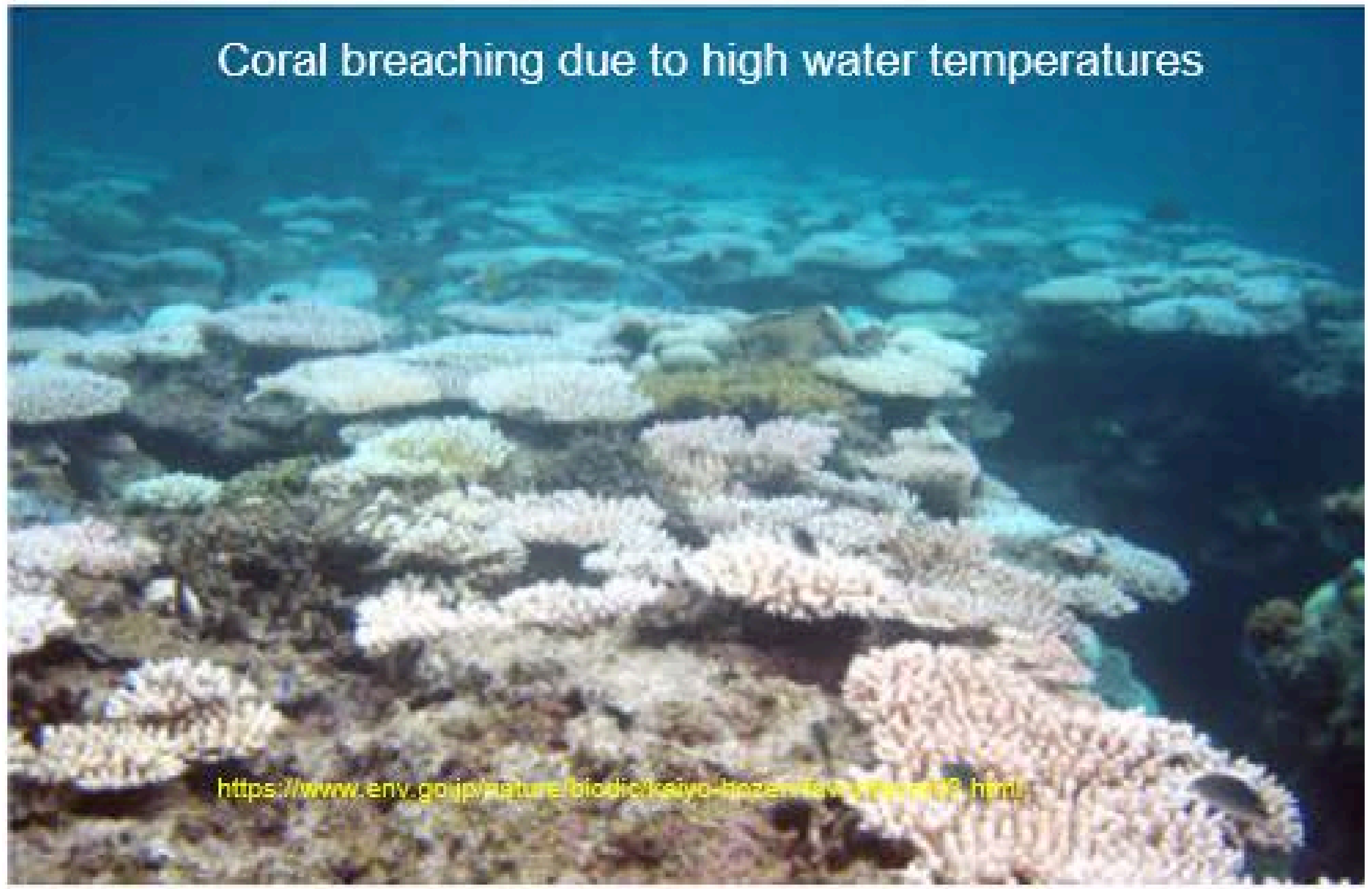
Current status and future of marine environmental issues

Current global extinction risk in different species groups



Note: the percentage of threatened species in each taxonomic group according to the International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species
The evaluation results have been obtained in one of three ways: comprehensive, sampled, or selected.

Source: a material compiled by the Ministry of the Environment from the Summary for Policymakers of Global Assessment Report on Biodiversity and Ecosystem Services of IPBES



Coral breaching due to high water temperatures

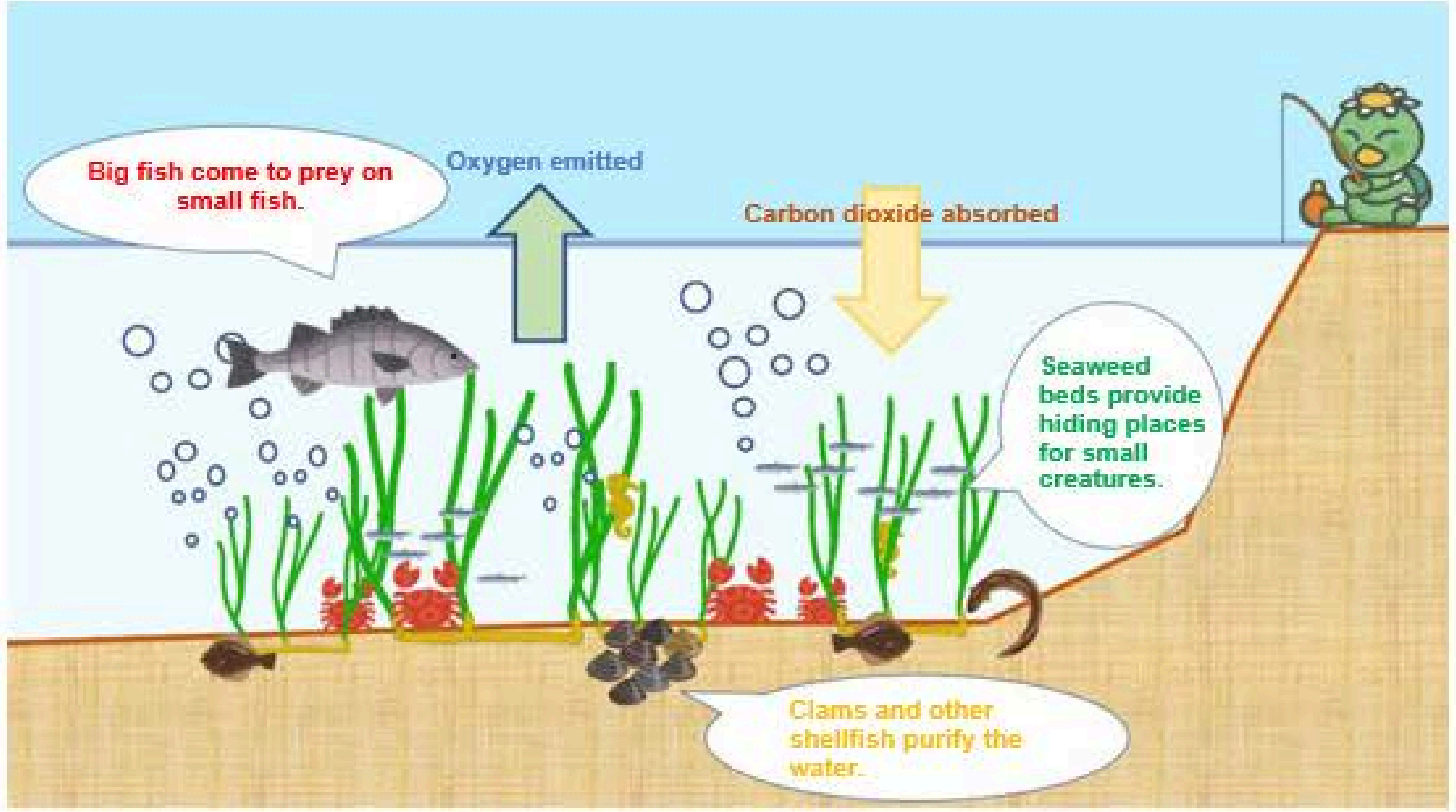
Plastic waste and a sea turtle

Human factors are causing degradation of 66% of ocean ecosystems. More than 85% of wetlands have disappeared. About half of the coral has been lost since the 1870s, and recent climate change has accelerated the decline. Biodiversity is under serious threat from invasive alien species.

https://www.env.go.jp/policy/hakusyo/r02/html/hj20010103.html

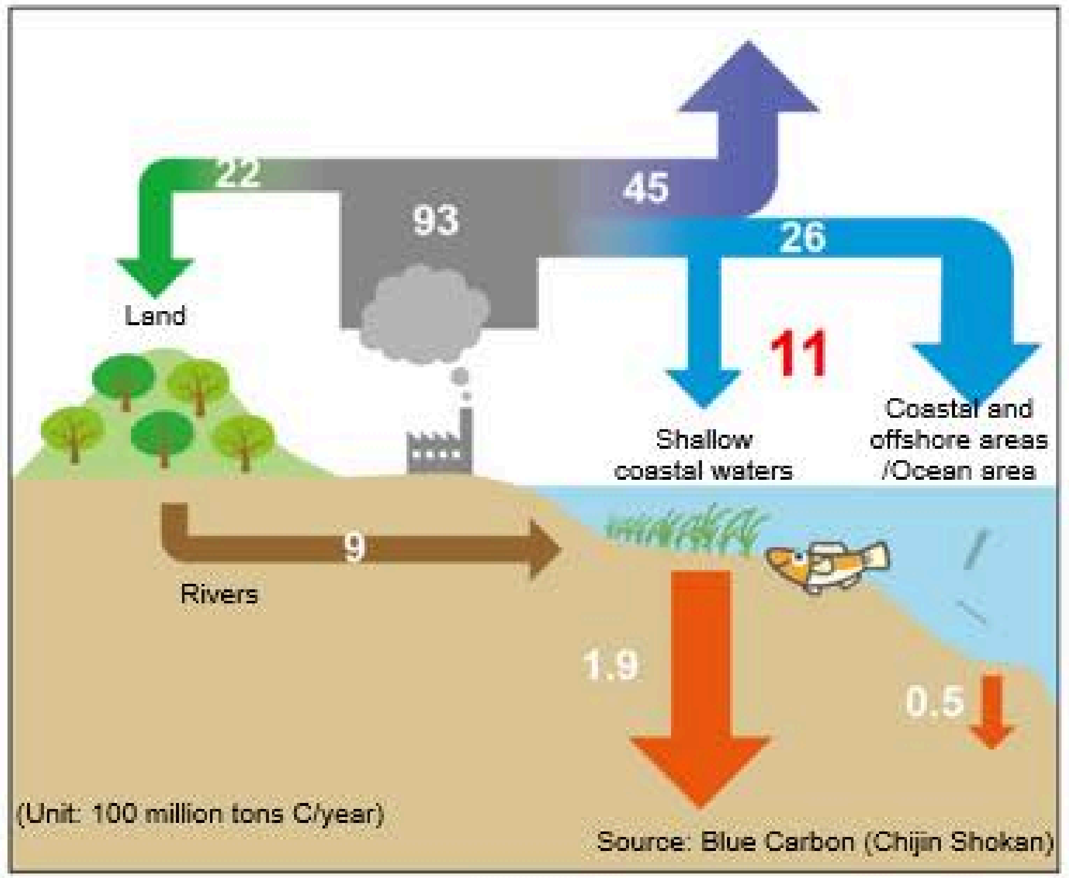
Current status and future of marine environmental issues


Eelgrass bed (Photo provided by Katsumi Iwai)



Rendered image of carbon cycling

- Blue Carbon: Carbon that is taken up into marine ecosystems and stored in their biomass and the underlying soils. Blue Carbon was defined in the 2009 United Nations Environment Programme report and has attracted worldwide attention as a new option for carbon dioxide sink measures.
- The main sinks for Blue Carbon are seaweed beds (seagrass and algae), salt marshes such as tidal flats, and mangrove forests, which are known as "Blue Carbon ecosystems."



Of the carbon dioxide emitted, a portion is absorbed by land (2.2 billion tC/year) and oceans (2.6 billion tC/year).

https://www.pref.aichi.jp/soshiki/mizutaiki/bluecarbon2.html

Source: Japan Blue Economy Association

Marine Environment Conservation Commitment to SDG 14

14-1: Prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including **marine debris and nutrient pollution**.

14-2: Sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for **their restoration** in order to achieve healthy and productive oceans.

14-3: **Minimize and address the impacts of ocean acidification**, including through enhanced scientific cooperation at all levels.

14-4: Restore fish and shellfish and other **marine resources** in the shortest time feasible to a level where they can be fished without reducing overall numbers.

14-5: Conserve at least 10 per cent of the world's **coastal areas** (consisting of lands and seas across coast lines) and **marine areas**, consistent with national and international law and based on the best available scientific information.

14-6: Prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing.

14-7: Increase the economic benefits to small island developing states and least developed countries from the sustainable use of marine resources, including through **sustainable management** of fisheries, aquaculture and tourism.

Reference: Japan Committee for UNICEF (https://www.unicef.or.jp/kodomo/sdgs/17goals/14-sea/). Wording partially modified.

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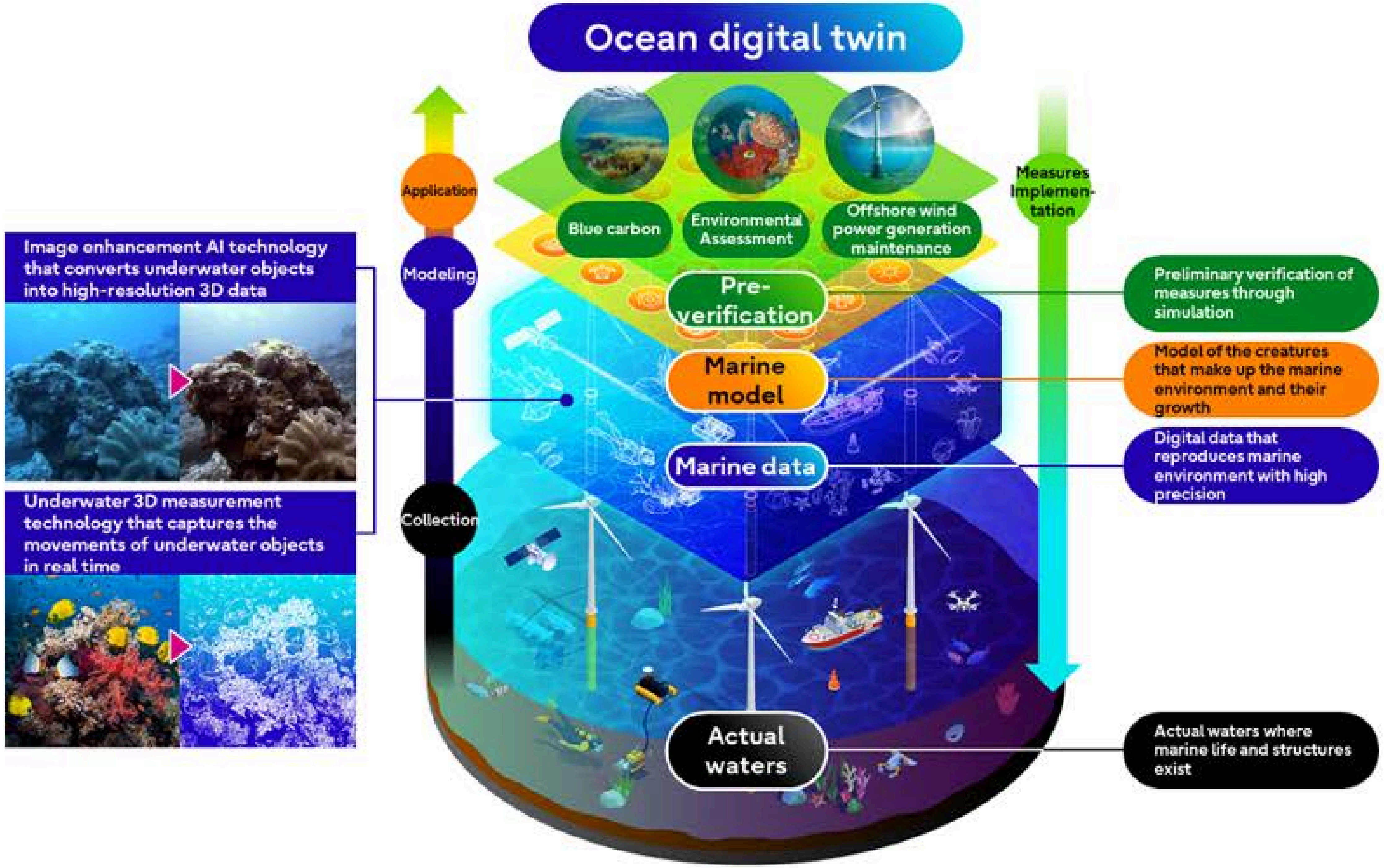
Ocean Digital Twin Development at Kobe University

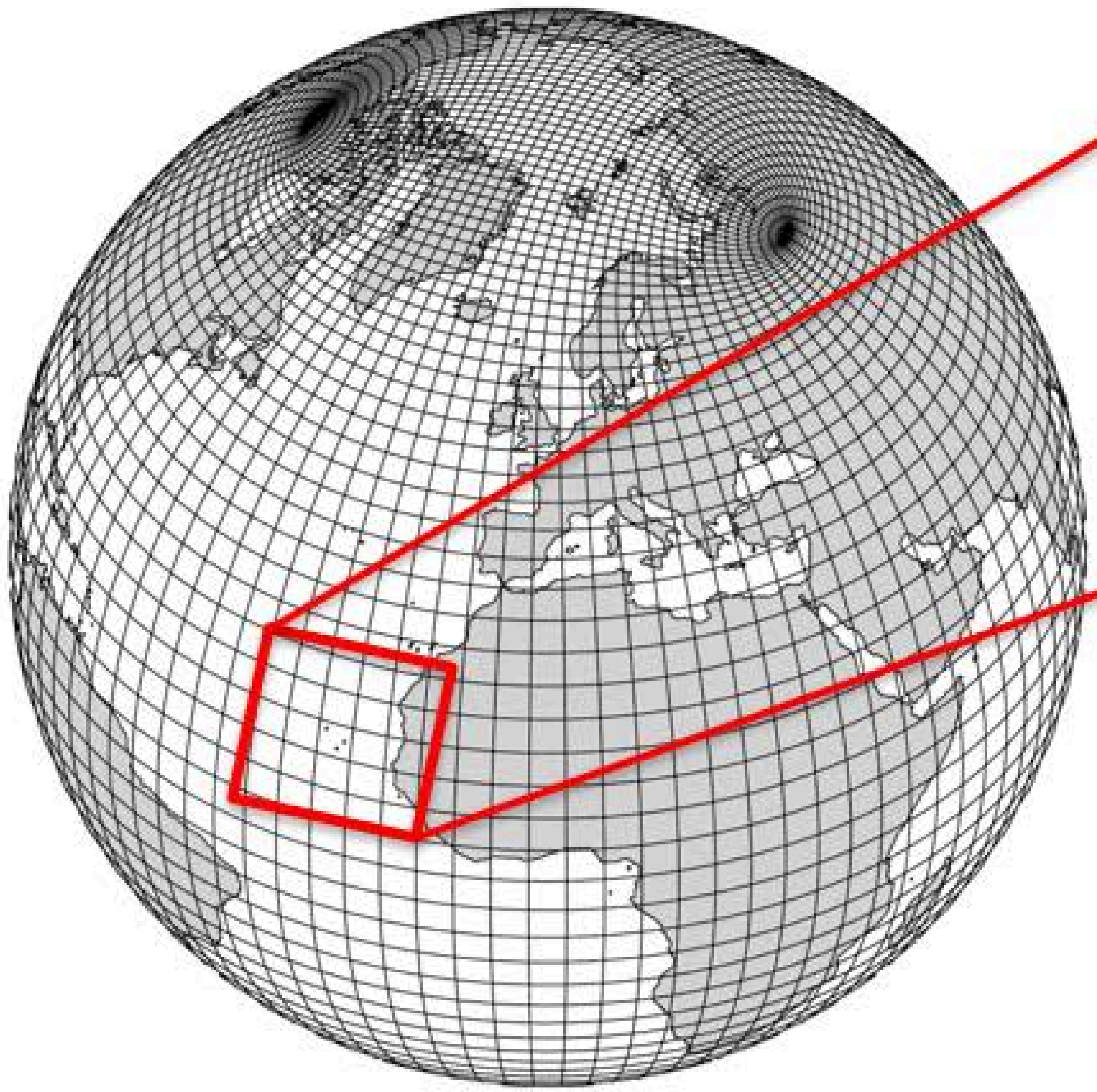
- By reproducing ocean currents and the transport of pollutants in three-dimensional space on a computer, it becomes possible to conduct research and make predictions under the same conditions as in reality.
- Various physical, chemical, and other equations that describe natural phenomena are used to calculate changes in flow, heat, and the like over time using a computer.
- By integrating actual observational data and making corrections, the accuracy of reproduction and prediction can be improved. (This is known as data assimilation; the use of AI is also advancing.)



Rendered image of ocean digital twin
https://www.fujitsu.com/global/about/resources/news/press-releases/2024/0326-01.html

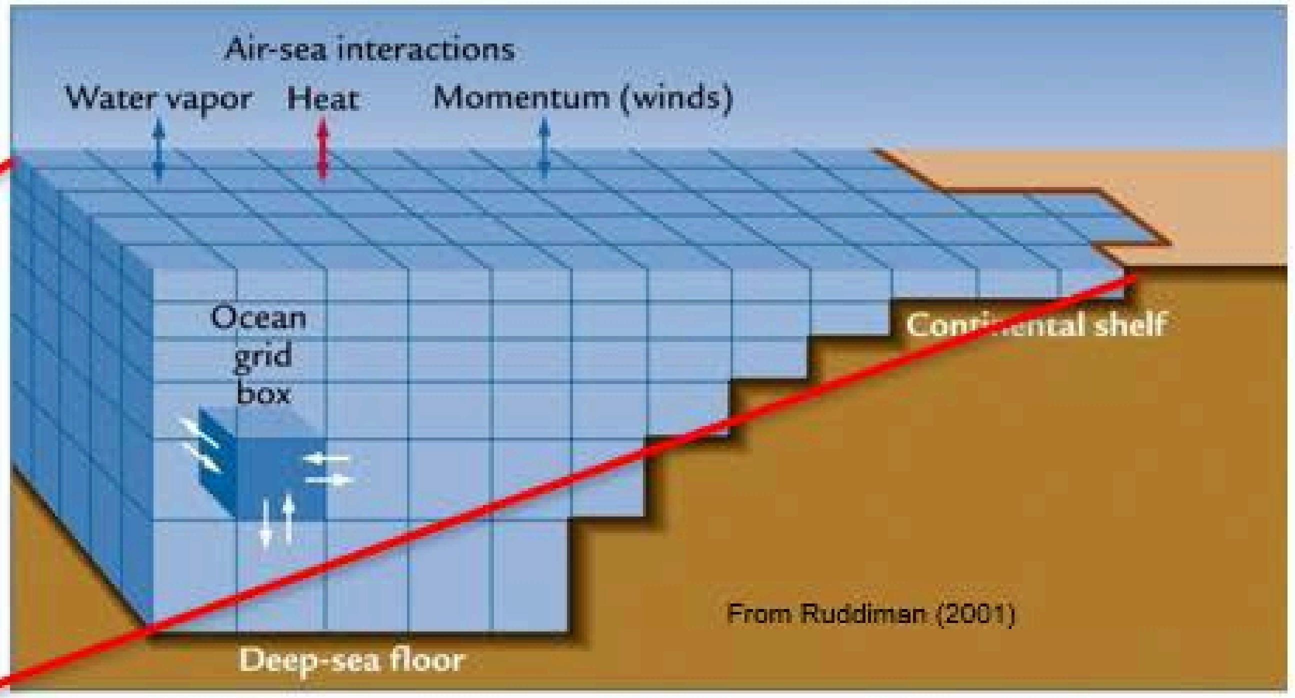
Ocean Digital Twin Development at Kobe University

- To make it easier for computers to handle, the ocean is represented by a fine, regularly arranged grid, and values such as pressure, temperature, and flow velocity are determined at each grid point, and their evolution over time is calculated.
- An approximate governing equation is used. To improve accuracy, make the grid spacing as small as possible. → Requires a supercomputer



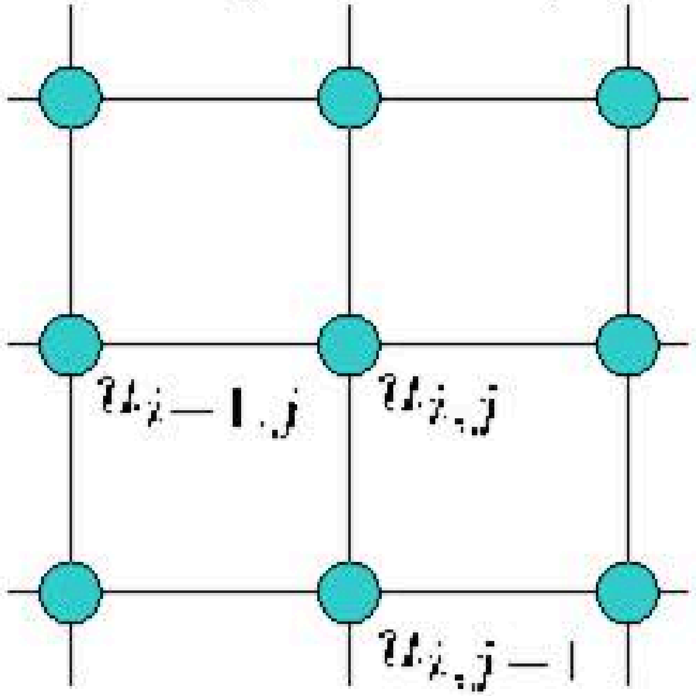
Example of horizontal grid division of a global ocean digital twin

https://www.clivar.org/sites/default/files/documents/wgomd/ws2014/06_highres_bentsen.pdf



Vertical grid division example

Divided grid (2D example)



Governing equation

$$\frac{\partial u}{\partial t} + c\frac{\partial u}{\partial x} = 0$$

↓ Taylor expansion

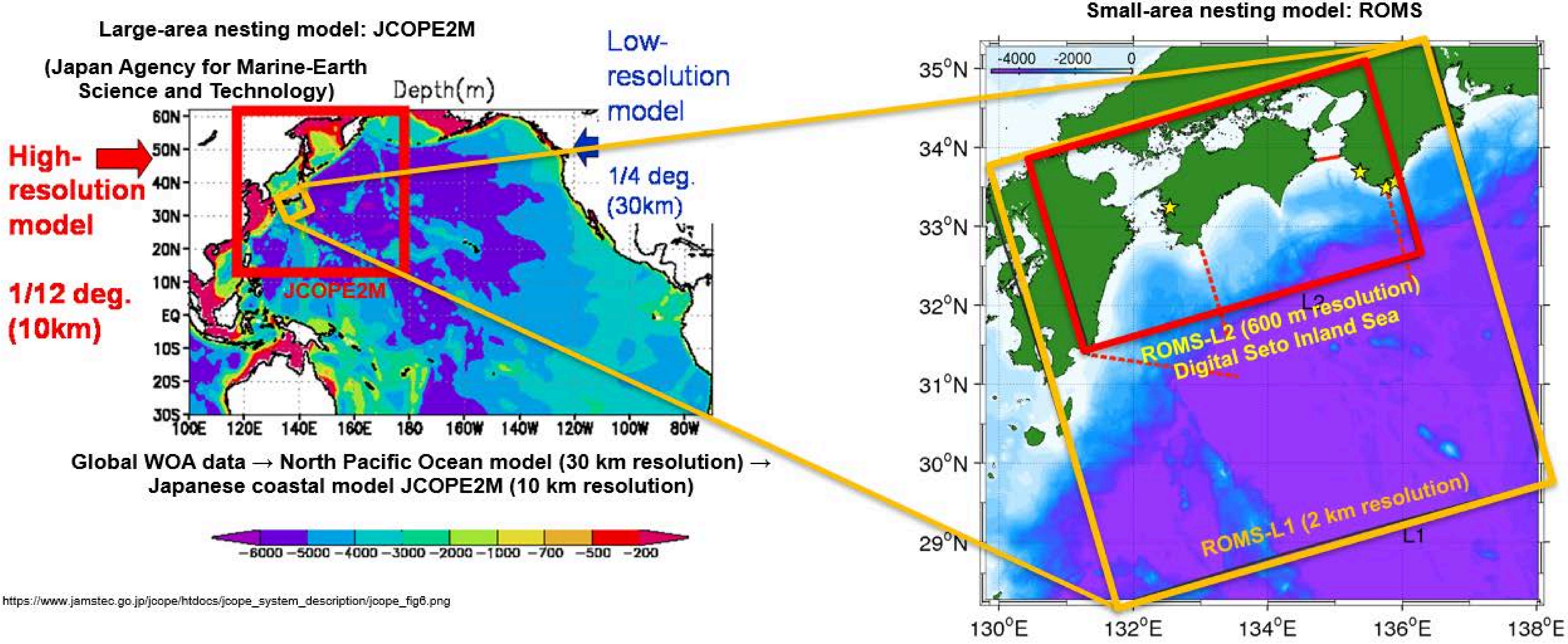
Difference equation

$$\frac{u^{n+1}_{i,j} - u^{n}_{i,j}}{\Delta t} + c\frac{u^{n}_{i-1,j} - u^{n}_{i-1,j}}{2\Delta x} = 0$$

Ocean Digital Twin Development at Kobe University

- Global and regional scales (Seto Inland Sea) are seamlessly combined (known as nesting).
- By nesting a small-area model within a larger one and sequentially exchanging data at the boundaries between the areas, a digital twin of the target sea area is created with gradually improving resolution.

Example of Digital Seto Inland Sea (JCOPE2M-ROMS system)



https://www.jamstec.go.jp/jcope/htdocs/jcope_system_description/jcope_fig6.png

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Background

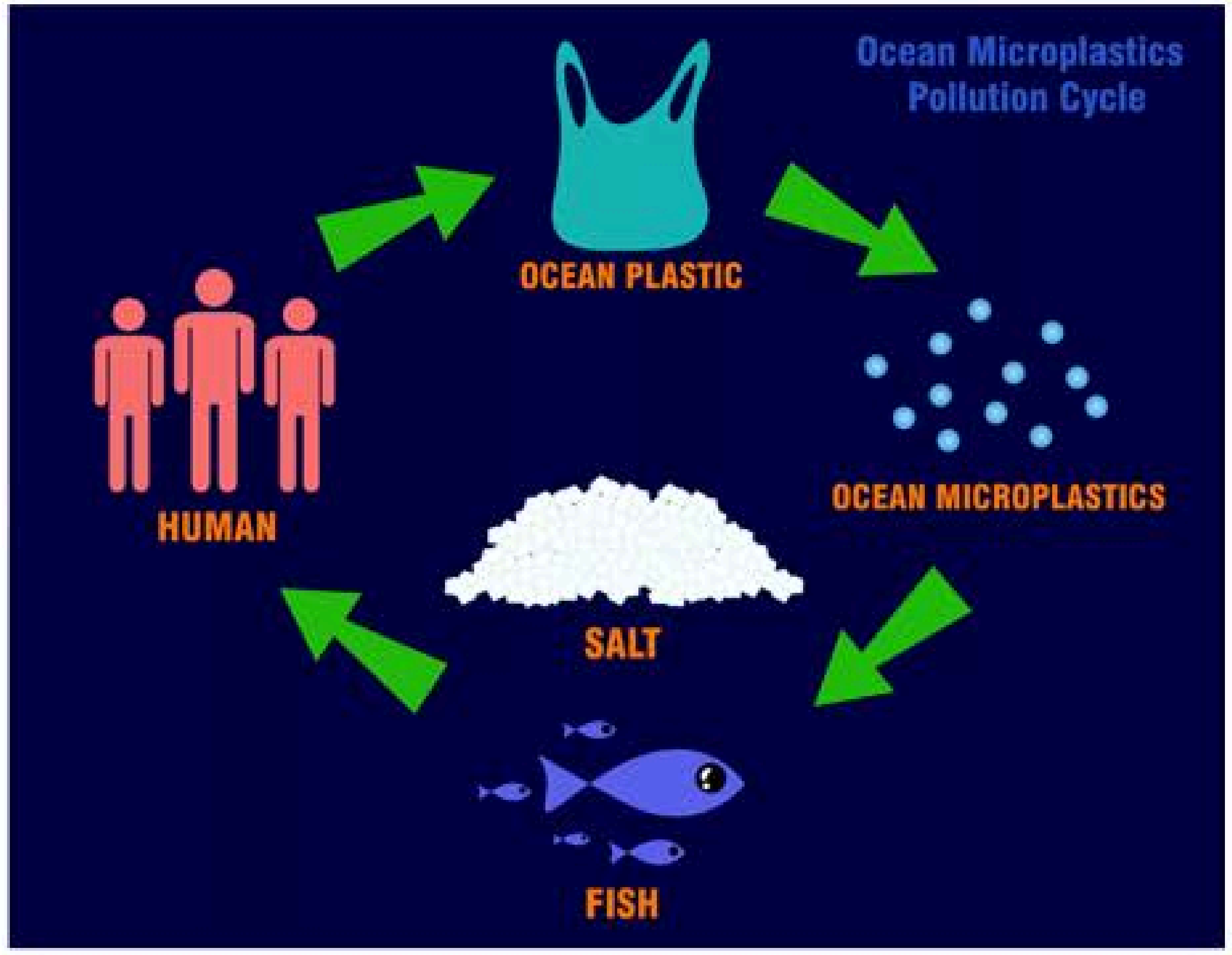
The issue of ocean plastic waste

- In recent years, ocean plastic waste has been taken up as a global environmental issue, as in SDG 14.
- Plastic accounts for 65.8% of marine debris and is predicted to outweigh fish by 2050 (Ellen MacArthur Foundation, 2016).

The issue of microplastic (MP) waste

- Plastic waste on coasts and in the ocean continues to deteriorate and break down.
- Microplastics are those with a diameter of 5 mm or less.
- There are also concerns about the impact on living organisms as they ingest MP that has adsorbed harmful substances.

Goal 14: Life below water



⇦ Cycle of marine MPs through the food chain, including humans

https://www.bluewatergroup.com/news-item/microplastics-everywhere-but-bluewater-offers-solution/

Background

Japan's ocean plastic pollution

- (Japan ranks 30th in the world in terms of plastic waste generation and 11th in terms of population.) (Jambeck et al., 2015)
- It's not just a cross-border waste issue.
  - Percentage of domestic origin waste on beaches
    Approximately 25% on the Sea of Japan side, approximately 70–80% on the Pacific side
    98% of the waste in the Seto Inland Sea is domestic.

⇨ As it is an enclosed sea area, the issue should be resolved through domestic efforts.
(On Plastic Waste, Ministry of the Environment, 2007)

Hiroshima Bay

- Field observations (Fujieda et al., 2011) showed that the density of plastic waste on the coast and in the sea was particularly high in this area compared to other sea areas.
- Efforts are being made through collaboration among local communities and organizations, such as Setouchi Oceans X (https://setouchi-oceansx.jp).

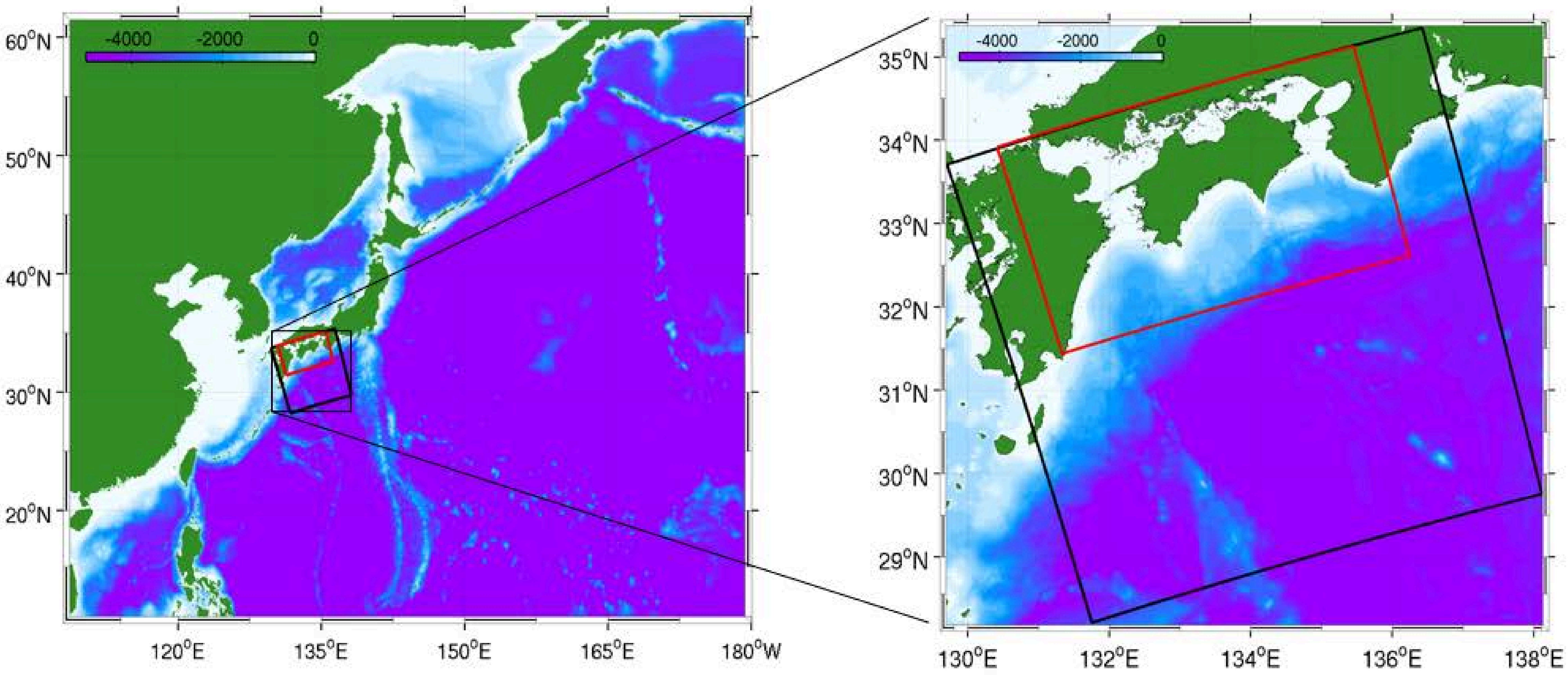
Zushigahama Beach, Hiroshima Bay (photographed November 2022)

(Based on the FY2015 Survey to Grasp the Actual Situation of Drifting Waste in the Seto Inland Sea: Ministry of the Environment, 2015)

Method 1 Digital Seto Inland Sea: a JCOPE2-ROMS two-stage nesting high-resolution 3D flow model of the entire Seto Inland Sea

JCOPE2 (horizontal resolution : 1/12°)

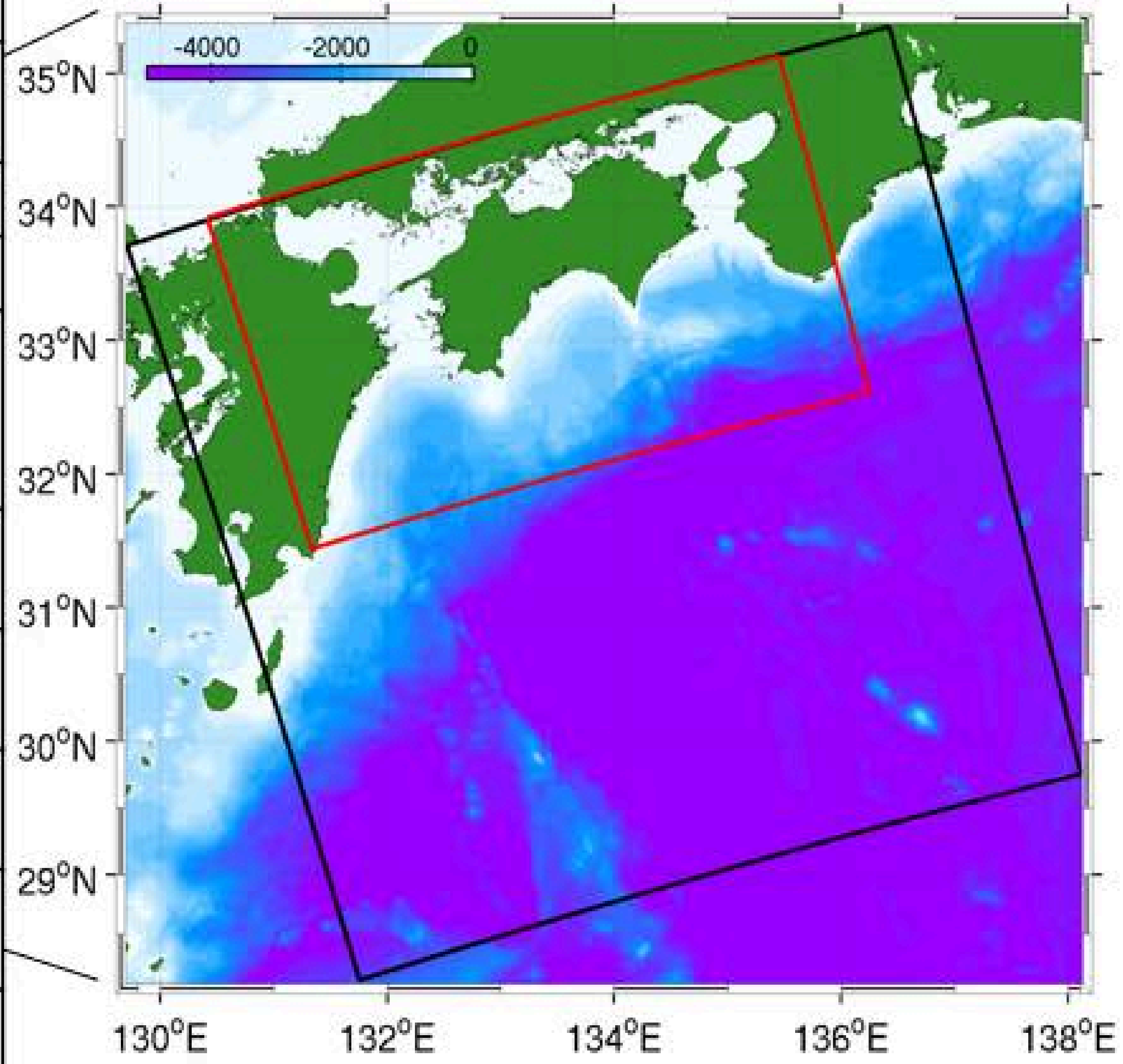
Resolution increased: JCOPE2 (–10 km) → ROMS-L1 (2 km)→ ROMS-L2 (600 m)



Method 1 Digital Seto Inland Sea: a JCOPE2-ROMS two-stage nesting high-resolution 3D flow model of the entire Seto Inland Sea

	ROMS-L1	ROMS-L2
Computational period	Jan, 1, 2004–Jan, 31, 2014	Nov, 1, 2011–Oct, 31, 2012
Horizontal (Vertical) grids	320 × 320 (× 32 in z)	800 × 480 (× 32 in z)
Horizontal resolution	2 km	600 m
Surface wind stress	JMA GPV-MSM (hourly)	JMA GPV-MSM
Surface fluxes SSS/SST	COADS (monthly climatology) JCOPE2 (daily)	COADS JCOPE2
Tide along perimeter		TPXO7.2 (10 major constituents)
River discharge	29 major rivers (monthly climatology)	27 major rivers
Boundary/Initial conditions	JCOPE2 (daily)	ROMS-L1 (daily)
T-S nudging(1/20day^{-1})	JCOPE2 (10 day-averaged)	
Topography	JEGG500, SRTM30	JEGG500, SRTM30

Resolution increased: JCOPE2 (~10 km) → ROMS-L1 (2 km)→ ROMS-L2 (600 m)

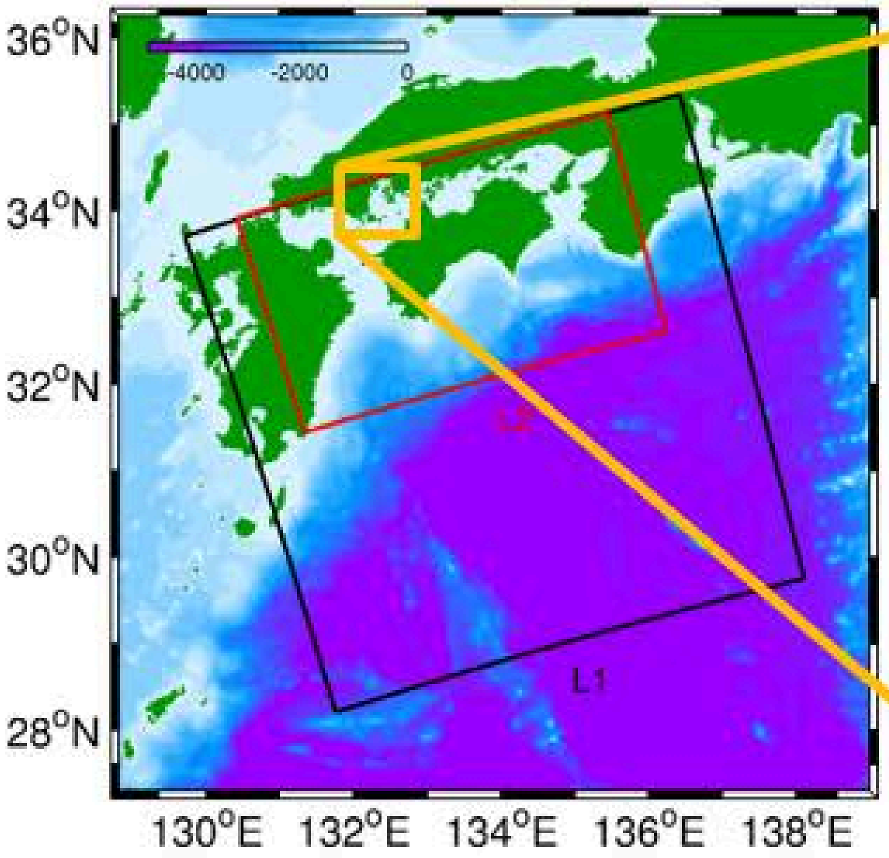


[References]

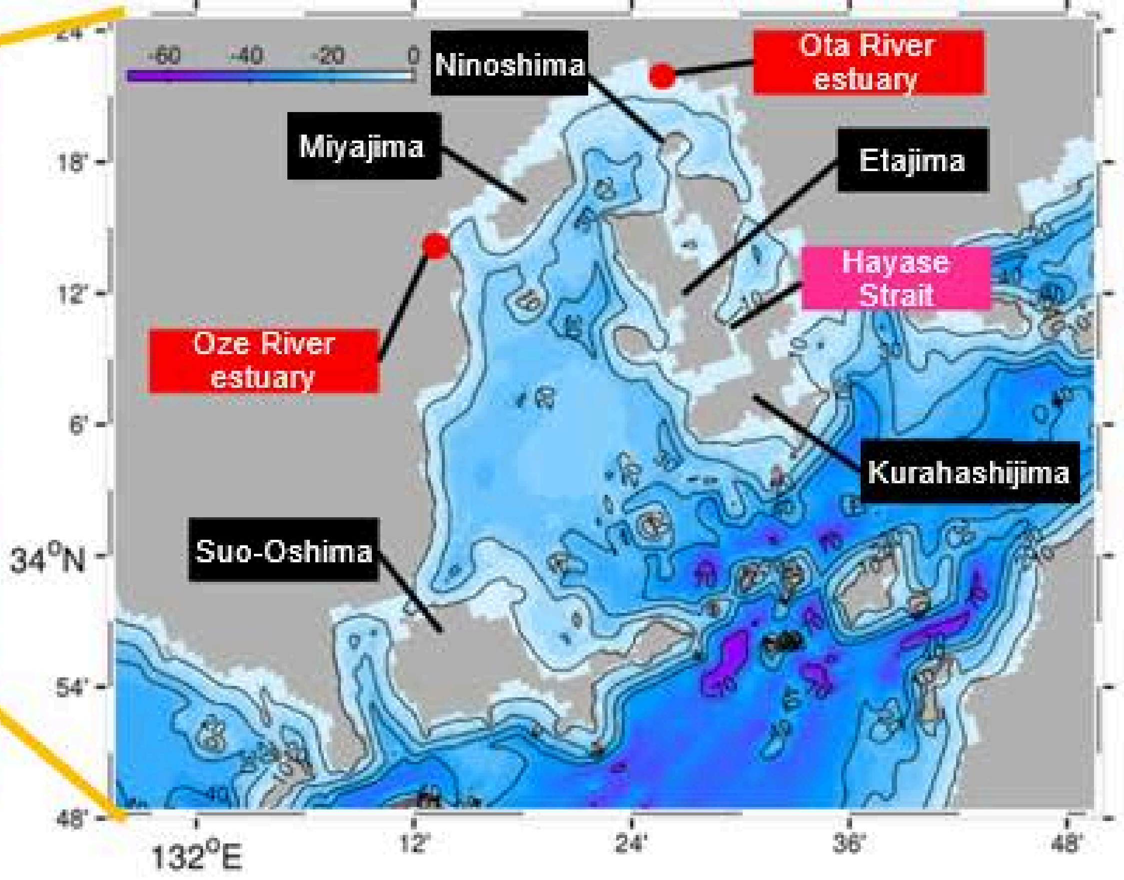
- JCOPE2-ROMS system: Uchiyama, Y., Kanki, R., Takano, A. et al., *Atmos.-Ocean*, 2018
- High-resolution Seto Inland Sea model: Uchiyama, Y., Zhang, X., Suzue, Y., Kosako, T. et al., *Mar. Pollut.*, 2018
- Lagrangian particle tracking modeling: Uchiyama, Y., Odani, S., Kashima, M., Kamidaira, Y. and Mitarai, S. *J. Geophys. Res. Oceans*, 2018.

Method 2 Lagrangian 3D neutral particle tracking (virtual microplastics)

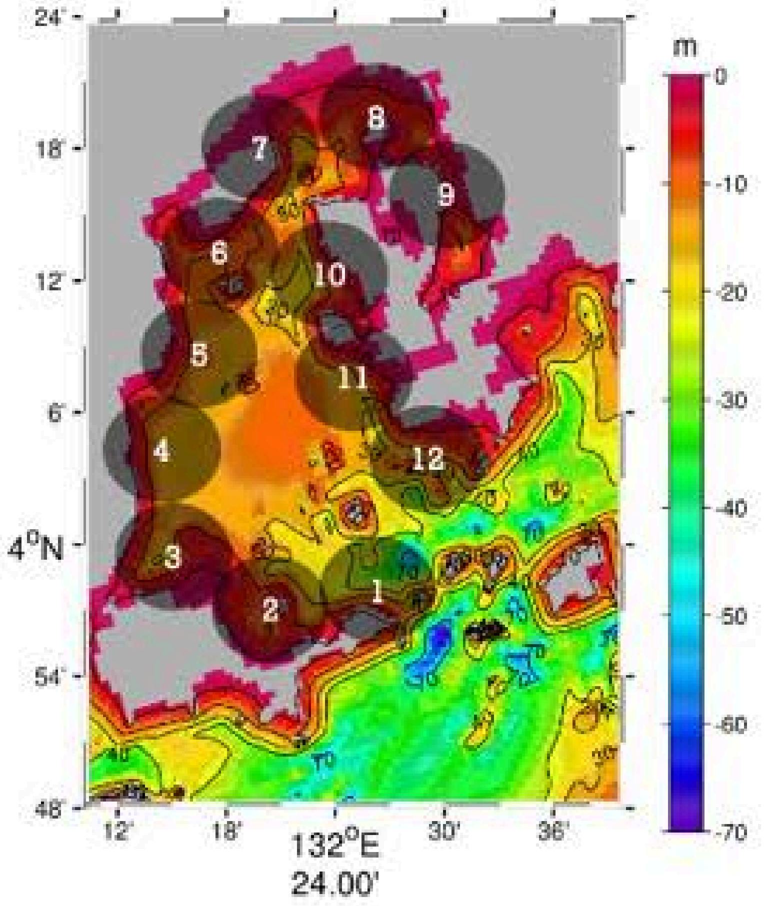
JCOPE2-ROMS area



Enlarged map of Hiroshima Bay and place names



Distribution of particle discharge sites



Lagrange's equations of motion

$$\frac{\partial}{\partial \tau}\mathbf{X}_n(\tau, \mathbf{a}) = \mathbf{U}_n(\tau, \mathbf{a})$$

$$\mathbf{U}_n(\tau, \mathbf{a}) = u[\mathbf{X}_n(\tau, \mathbf{a}), t_n + \tau]$$

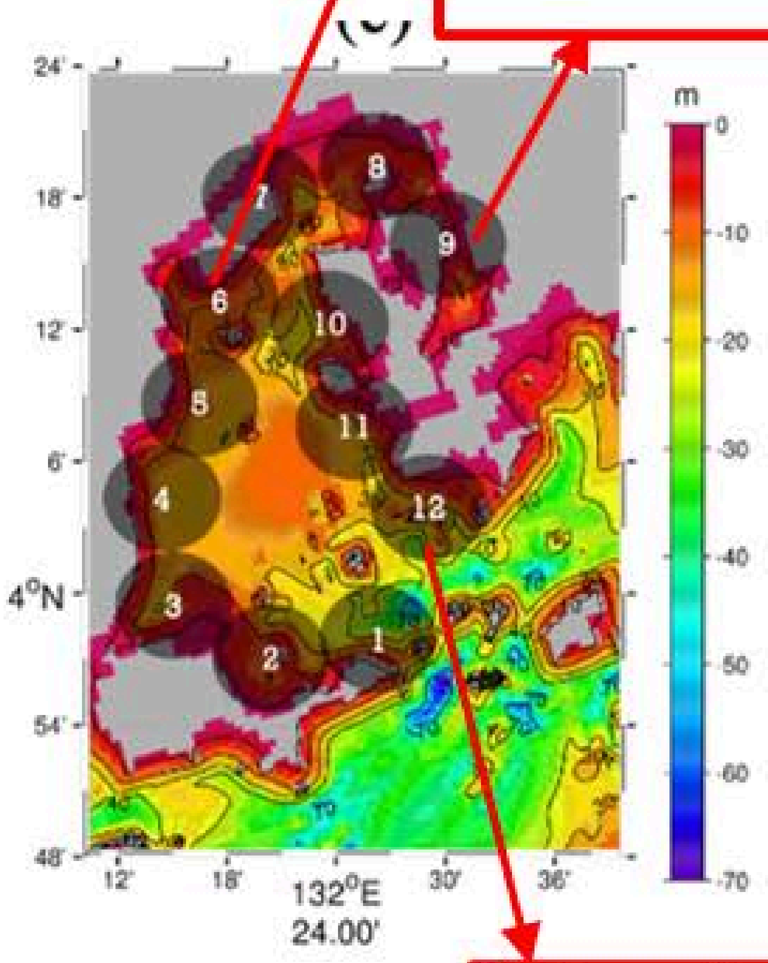
$\mathbf{a}$: initial location, τ: advection time (elapsed time), $\mathbf{X}_n(\tau, \mathbf{a})$, $\mathbf{U}_n(\tau, \mathbf{a})$: position vector and Lagrangian velocity of the nth particle, $\mathbf{u}$ (x, τ): Euler flow velocity from ROMS.

Radius of site	5 km	Discharge depth	2 m
Center of site	away from the coast 5 km	Discharge interval	12 h
Center interval of sites	10 km	Number of released particles	Approximately 900 pieces per time
Total number of sites	12		(per site)

Particle release period (tracking for 28 days after release)
Summer: June 1 to June 30, 2012
Winter: December 1 to December 31, 2011

Results (summer)

Time evolution of the virtual MP particle Lagrangian PDF **during summer**

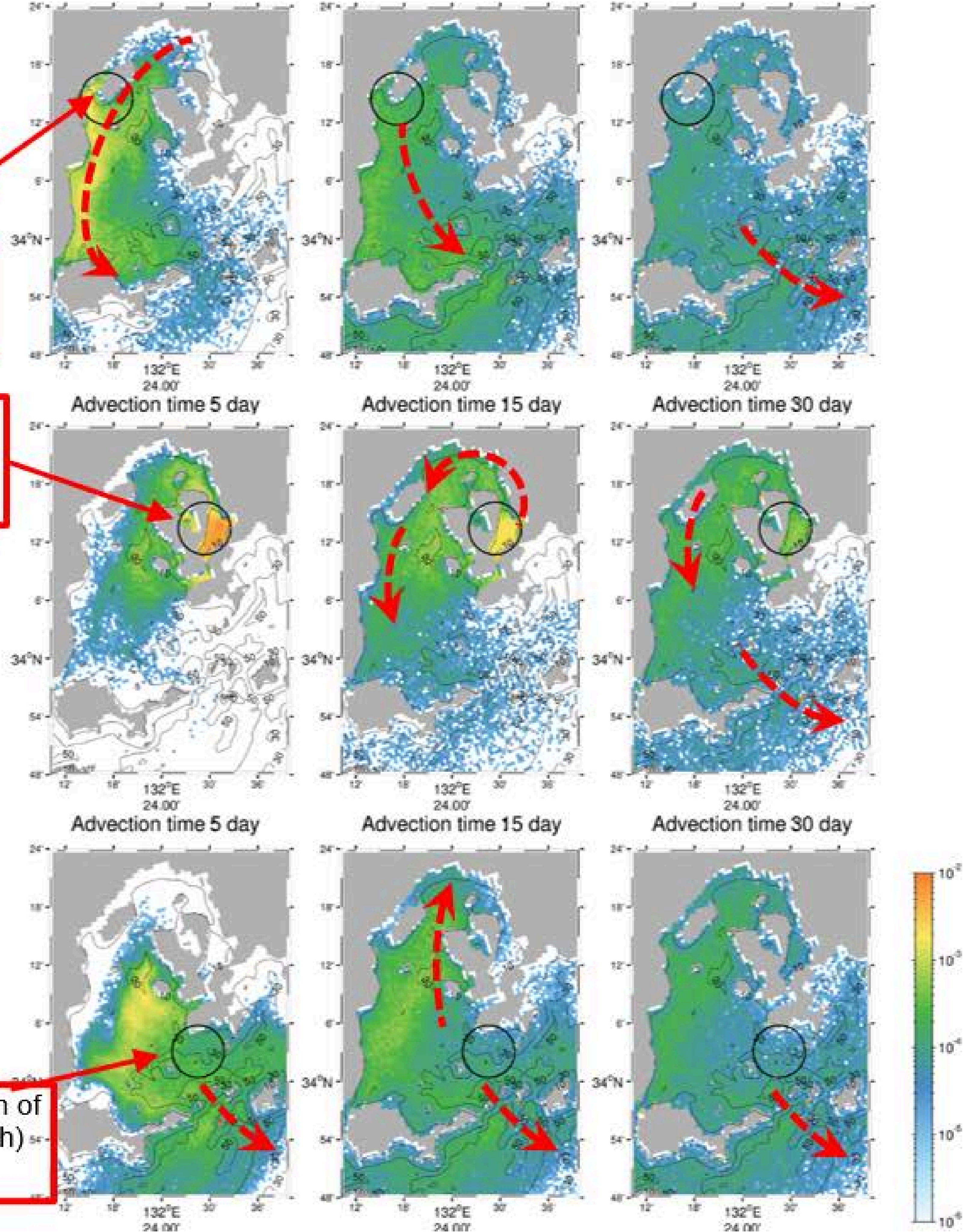


Release site: 6 (waters to the south of Miyajima, west coast of Hiroshima Bay)

Release site: 9 (waters around Etajima, inner Hiroshima Bay)

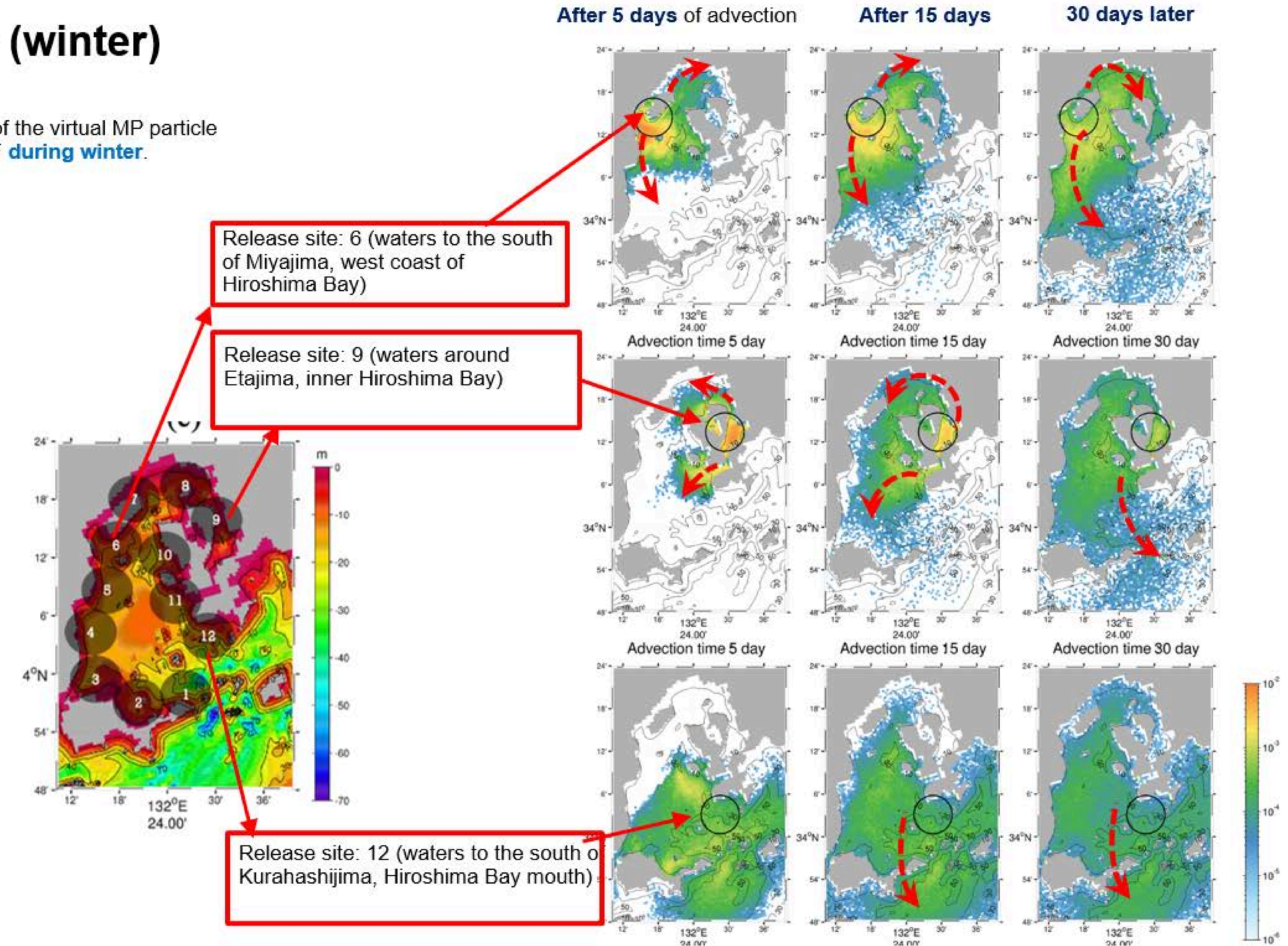
Release site: 12 (waters to the south of Kurahashijima, Hiroshima Bay mouth)

After 5 days of advection | **After 15 days** | **30 days later**



Results (winter)

Time evolution of the virtual MP particle Lagrangian PDF **during winter**.



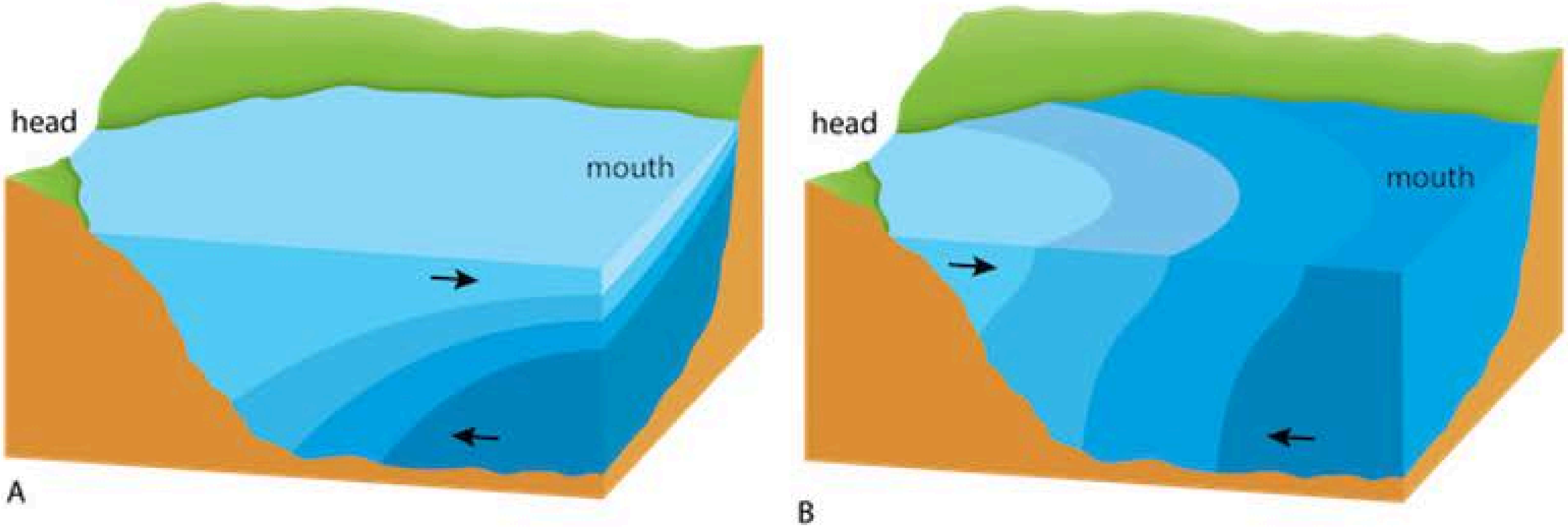
Mechanism of MP transport: Seasonal differences in the currents in Hiroshima Bay

Summer
Heating from the surface + Increase in freshwater (low density water) from rivers

→ Development of surface flow due to weak mixing

Winter
Surface cooling + Reduced river flow

→ Development of full-layer flow due to strong mixing

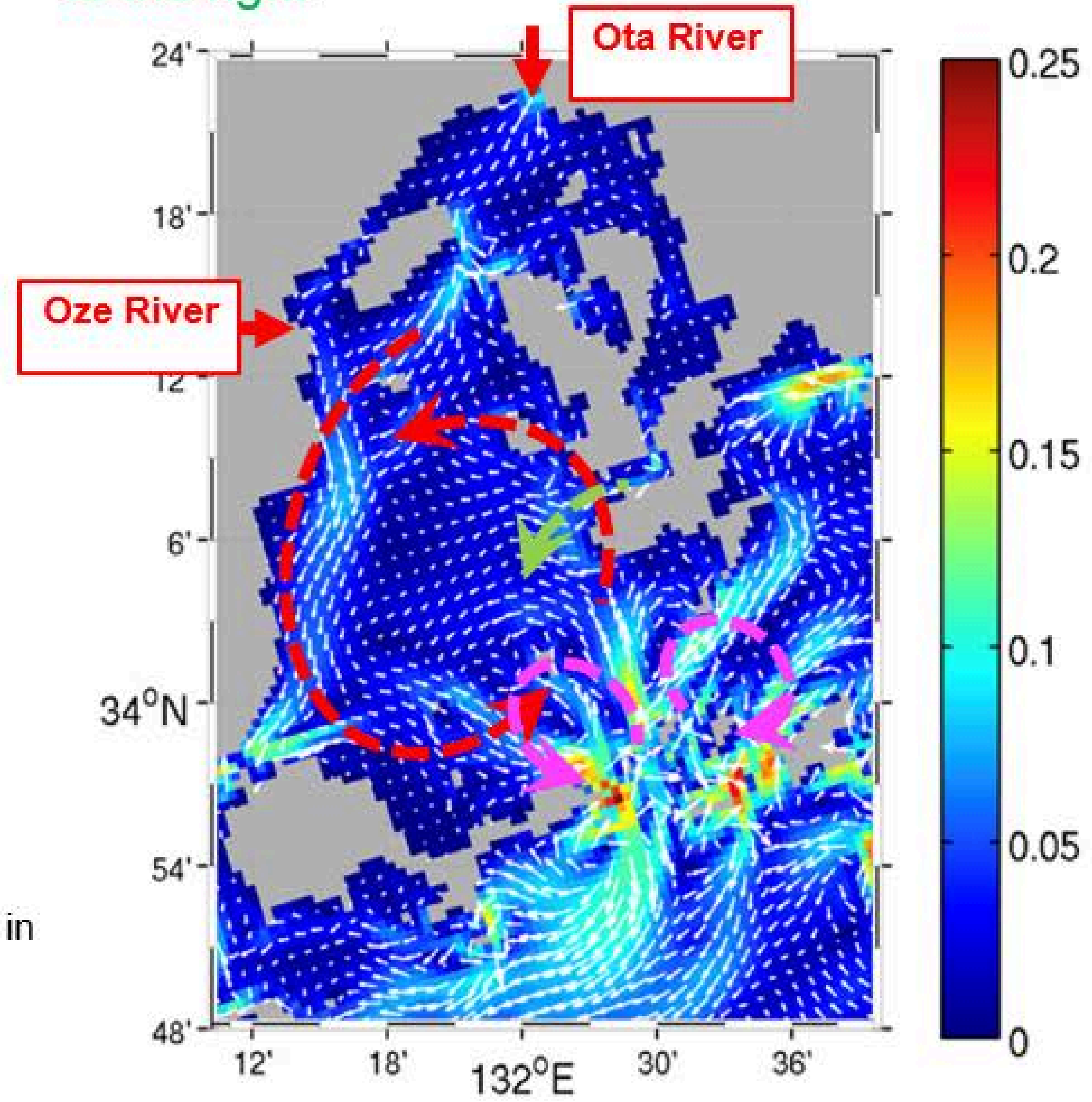


https://manoa.hawaii.edu/exploringourfluidearth/physical/density-effects/circulation-marginal-seas-and-estuaries

Estuary circulation

- Freshwater from rivers mixes with seawater and is transported from the inner bay (north) to the mouth (south).
- Due to the effect of the Earth's rotation (Coriolis force), the flow in the Northern Hemisphere shifts to the right.

Mean surface flow (m/s) in Hiroshima Bay in summer in Digital Seto Inland Sea →



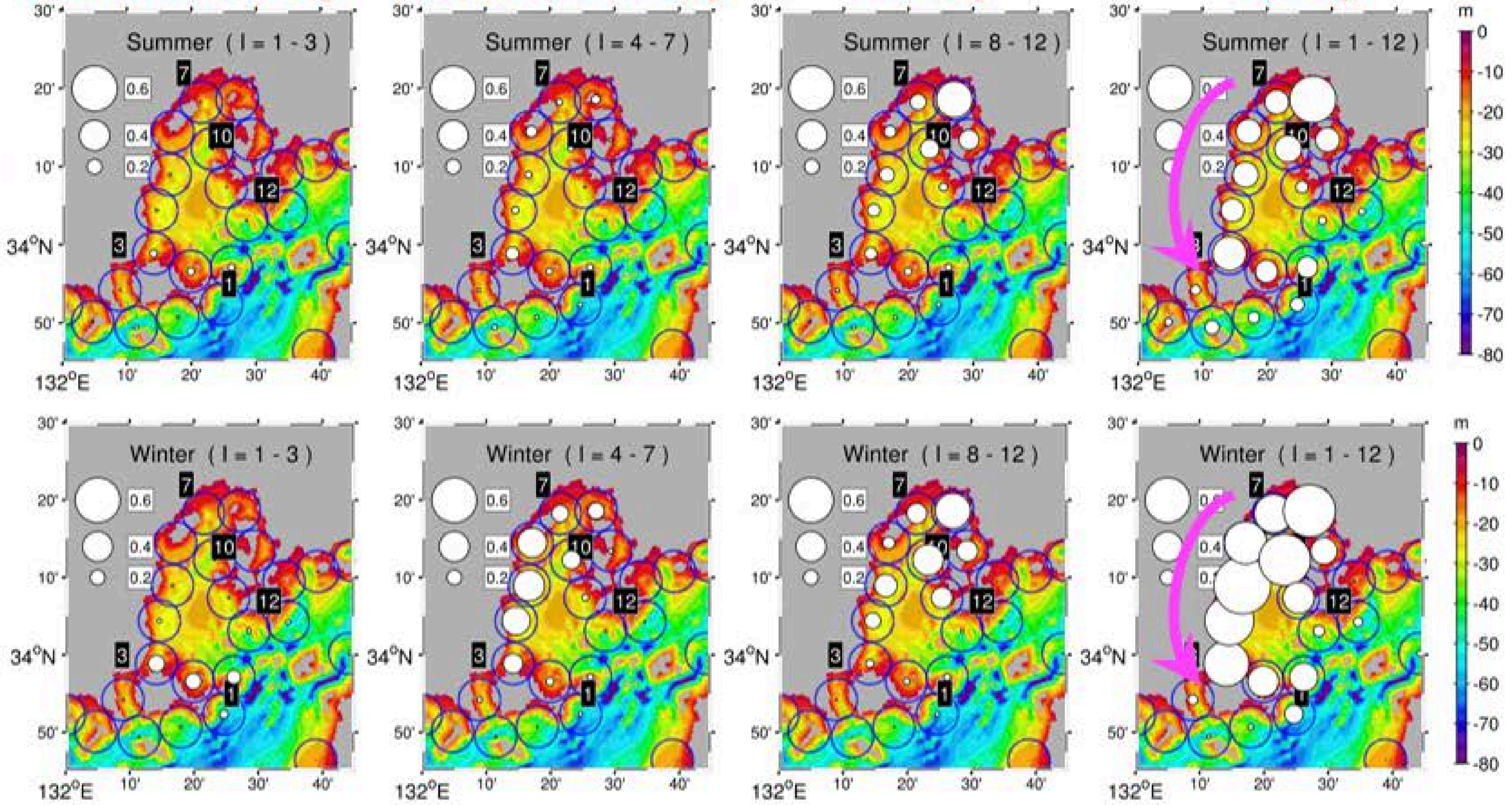
Discussion: Spatial structure of the quantities of MP particles washed ashore

Destination strength D_i (probability that a particle from source set I reaches sink i)

Released from the southwest of the bay | Released from the west coast of the bay | Released from the inner bay | Released from all over the bay

Summer

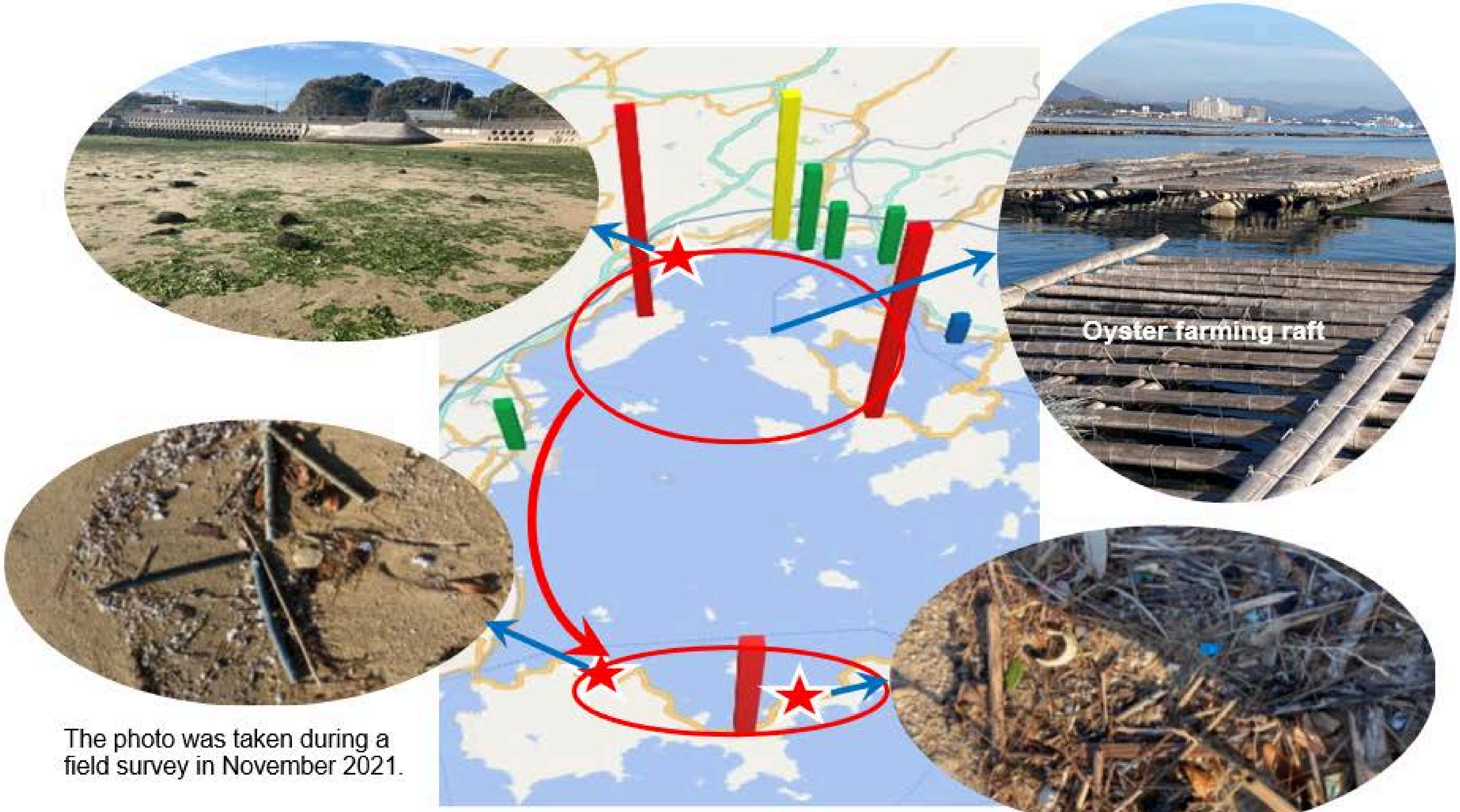
Winter



- Approximately 10% of the MP particles released from the southwest of the bay (sites 1–3) washed ashore in the bay in summer and approximately 20% in winter.
- Particles from the west coast of the bay (sites 4–7) tended to be transported widely across the west coast of the bay in summer and remained near the discharge source in winter.
- Particles released from the inner bay (sites 8–12) clearly remained in large quantities near the release source both in summer and winter.
- Throughout the bay: Although particles were washed ashore less in summer than in winter, the pattern is similar, with particles being washed ashore starting from the inner bay and drifting and being washed ashore along the west coast before exiting the bay.

Discussion: Toward formulating conservation strategies based on the current state of local coastlines

- MPs were detected at multiple locations on the coast, sea surface, and seafloor of Hiroshima Bay (Sagawa et al., 2018).
- Is this due to the deterioration and fine granulation of foam plastic (FPS) originating from buoys used in the active aquaculture industry that is mainly pursued in the inner part of Hiroshima Bay?
- Digital Seto Inland Sea to set discharge sources and predict areas where particles are washed ashore → Utilizing it for generation volume management, outflow prevention measures, and collection efficiency improvement



Numerous pieces of foam plastic, cable ties, and pipes were found throughout Hiroshima Bay, especially on Suo-Oshima (in the southern part of the bay).

Bar graph: Results of a field survey of waste washed ashore along the coast of Hiroshima Bay (created from Yamaguchi Prefecture, 2019). It can be assumed that 90% of the waste washed ashore in Hiroshima Bay is plastics and related to the amount of MPs washed up on the coast.

The photo was taken during a field survey in November 2021.

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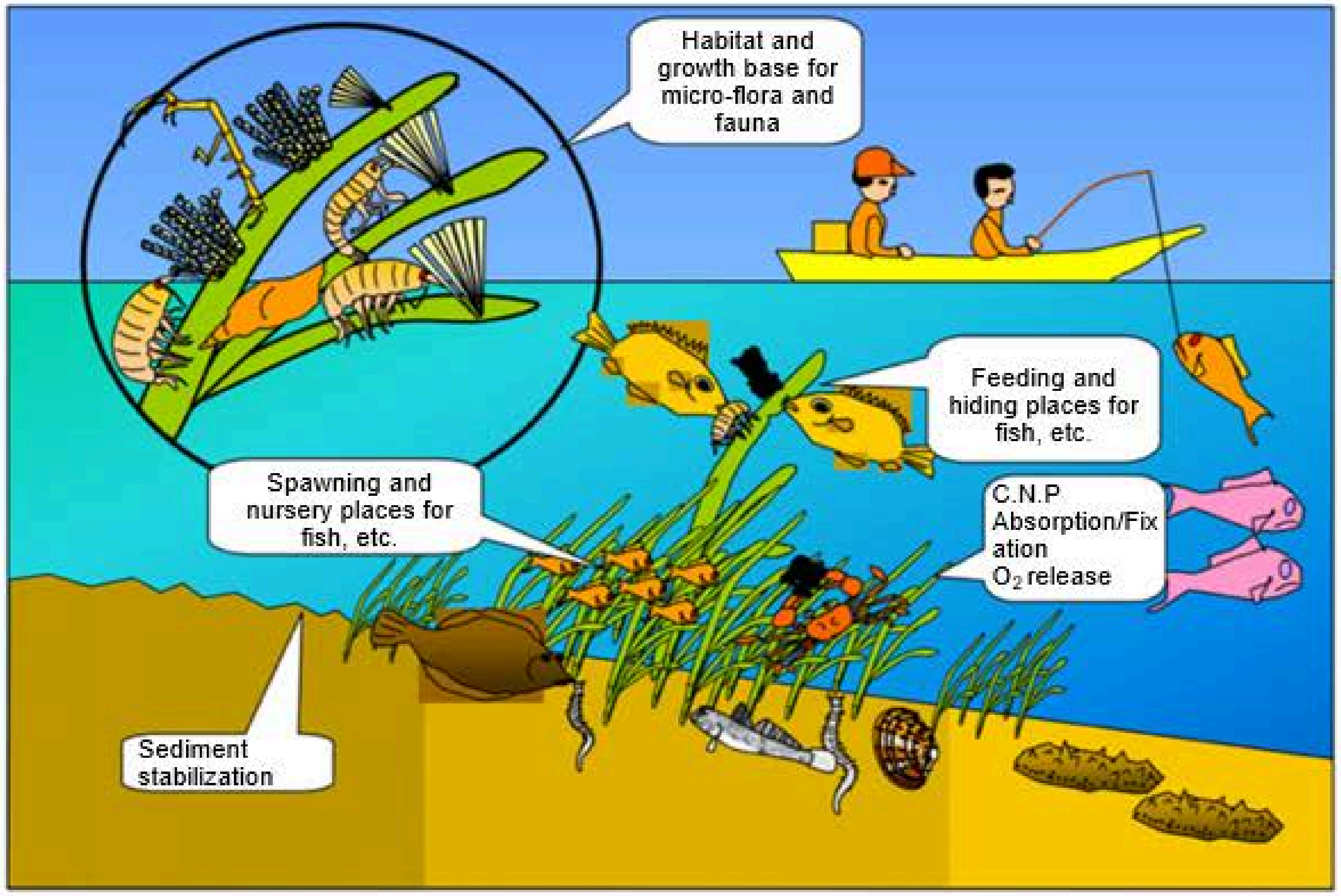
Background

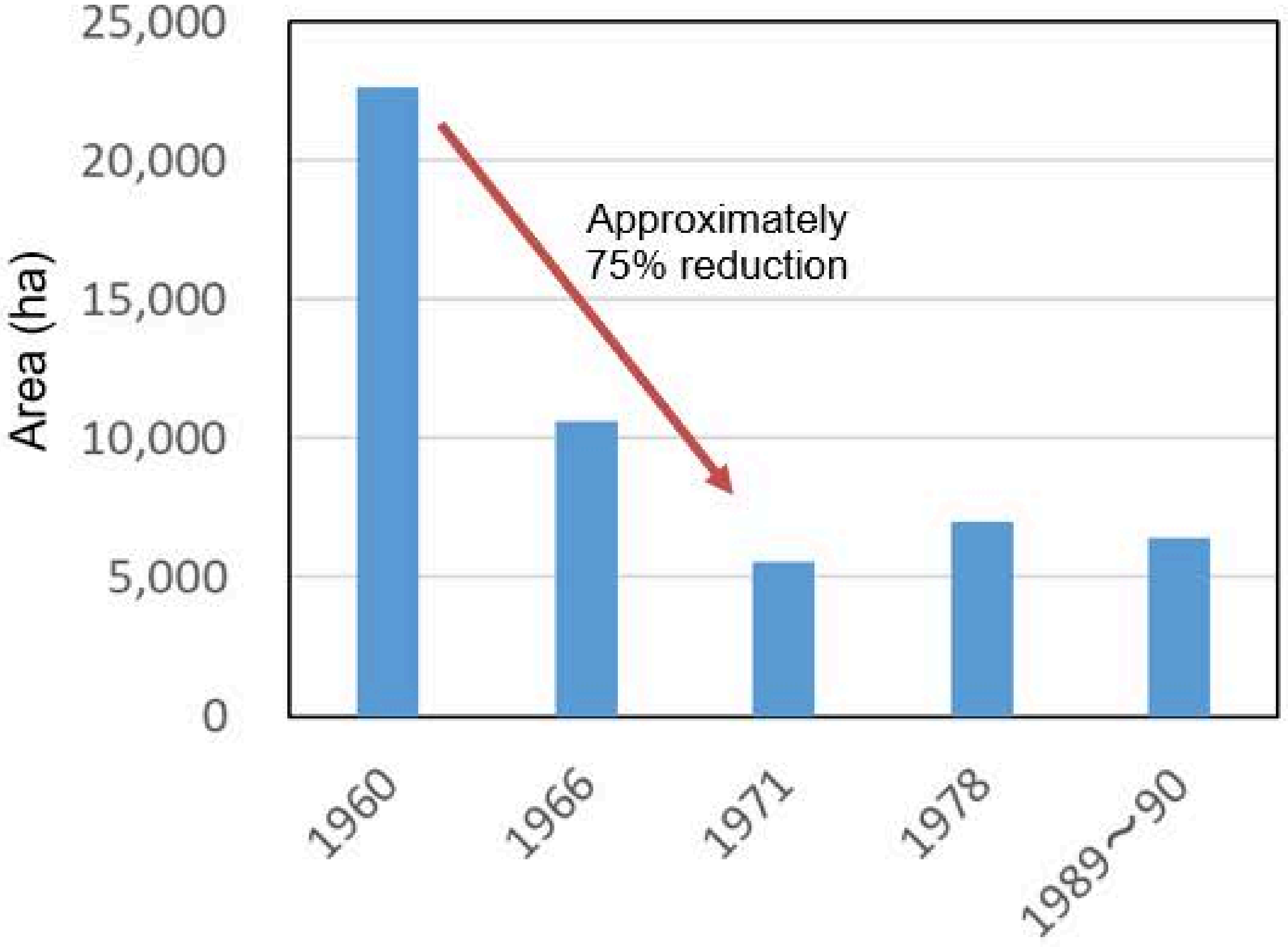
- **Eelgrass beds**: Important coastal ecosystems that enhance biodiversity and protect coastal environments. They have been reported to be in decline worldwide since the 1930s.
- **In the Seto Inland Sea**, approximately **75% of eelgrass beds disappeared** between 1960 and 1971 due to coastal development and other factors (e.g., Komatsu et al., 1997).

Conceptual diagram of the ecosystem in eelgrass beds



Source: Guidelines for the Natural Regeneration of Eelgrass (Fisheries Agency and Marino Forum 21)

Changes in the area of eelgrass beds in the Seto Inland Sea (excluding Hibikinada)



Source: 1960, 1966, and 1971 surveys by Nansei Regional Fisheries Research Laboratory, Fisheries Agency
FY1989–FY1990: 4th National Survey on the Natural Environment (Ministry of the Environment)

Sexual reproduction of eelgrass : Transport of **reproductive shoots** (flower branches and seeds floating on the sea surface) (drifting from June to August)

→ Up to **about 30 days** (Källström et al., 2008; Sugimatsu et al., 2015)
Drifting over 100 km (Orth et al., 1994; Erftemeijer et al., 2008)

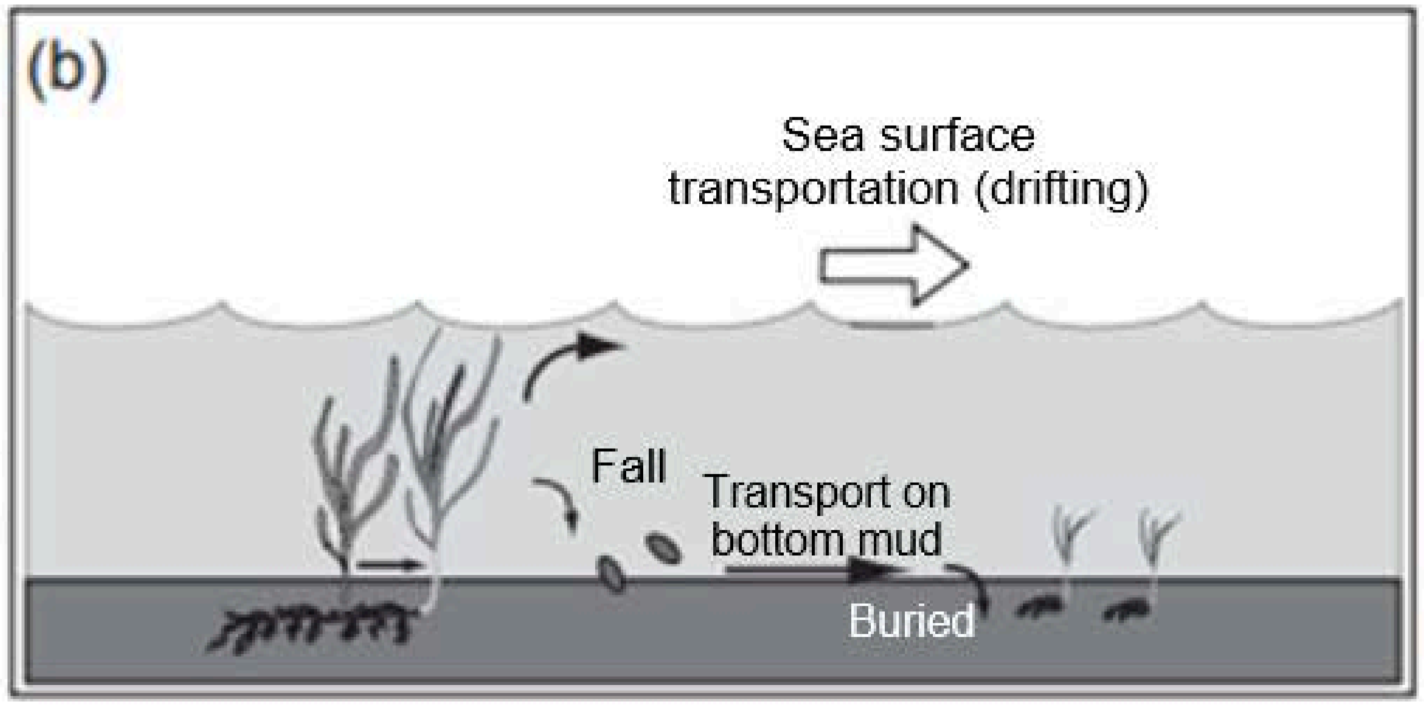
The flow field has a significant impact **on the genetic exchange** and **distribution area expansion** of eelgrass populations.

Previous research on eelgrass in the Seto Inland Sea

- Genetic analysis in Hinase, Okayama Prefecture (Hori et al., 2021), and Hiroshima Bay (Omichi et al., 2014)
  → The genetic structure of eelgrass beds is formed by sexual reproduction via shoots.
- **The influence of ocean flow fields** and **the connectivity (network structure) between multiple eelgrass beds are unknown.**

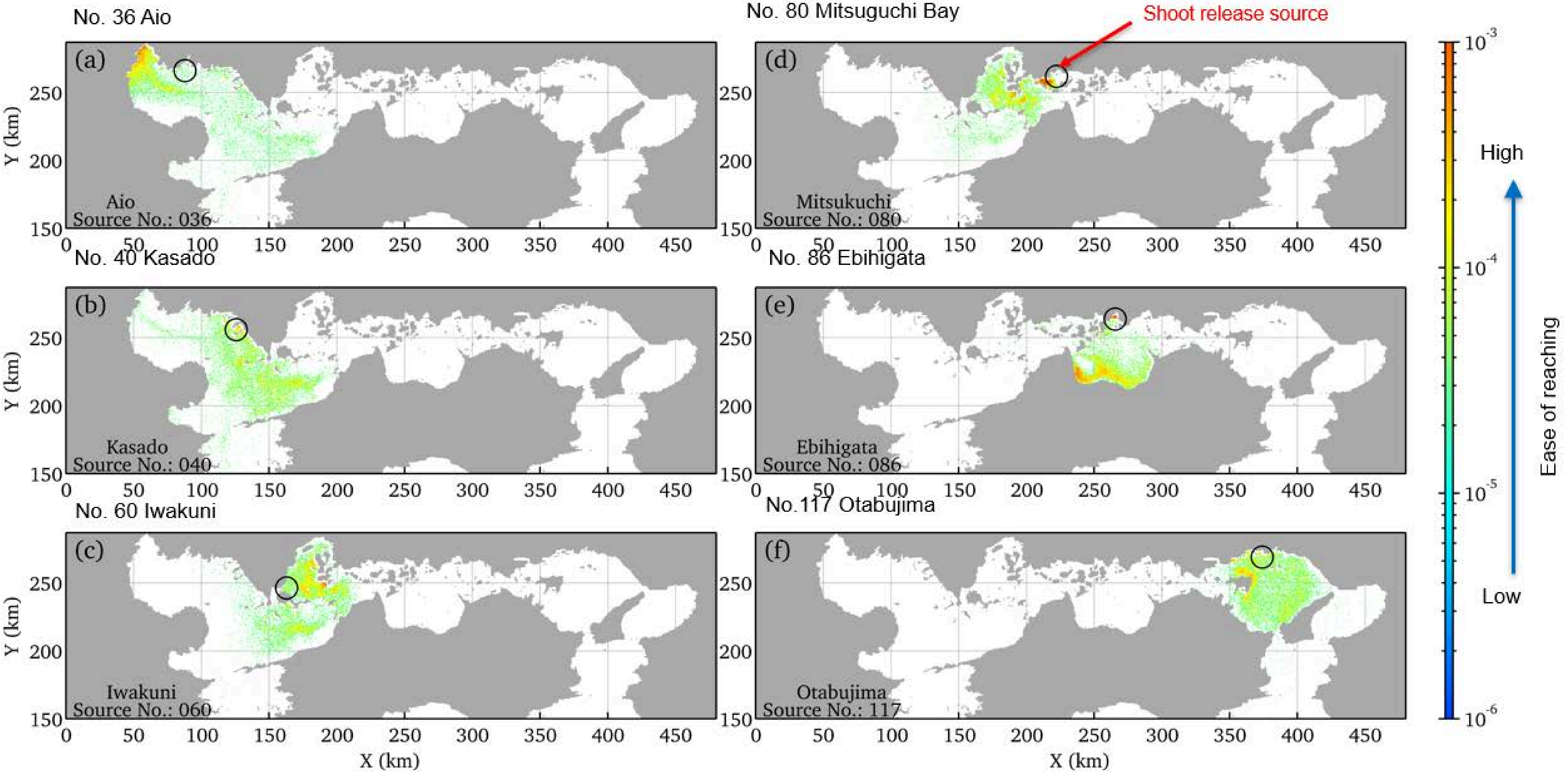
Eelgrass vegetative shoots collected in Hinase, Okayama Prefecture (Photo taken on December 2, 2022)

Form of eelgrass seed transportation



Source: Hosokawa (2017, Port and Airport Research Institute data)

Example of spatial distribution of surface-floating virtual eelgrass shoots 30 days after release



[Note] The Lagrangian PDF (probability density function for particle displacement given to advection time) of a particle with an advection time of 30 days is shown.
Summer 2012

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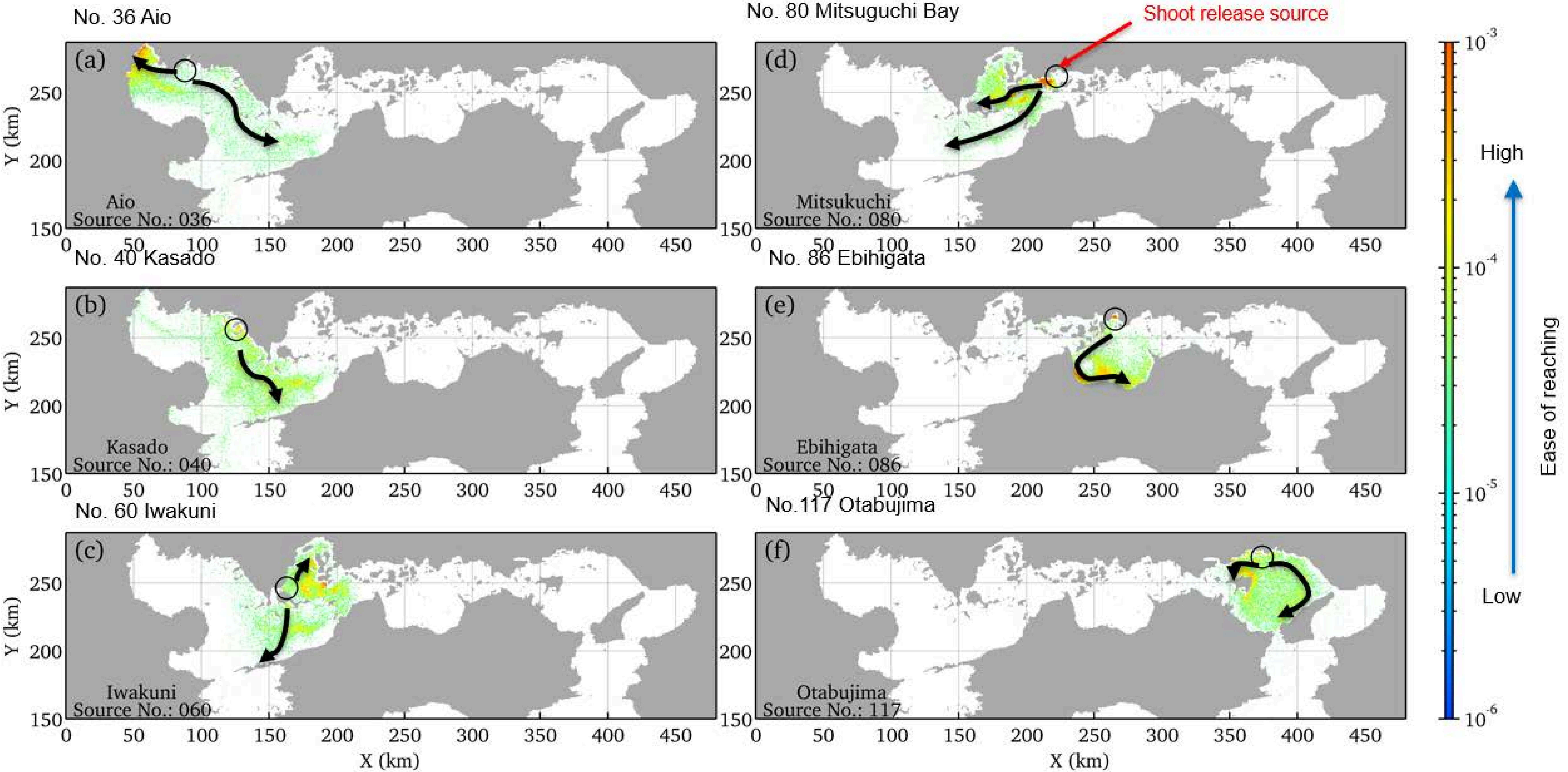
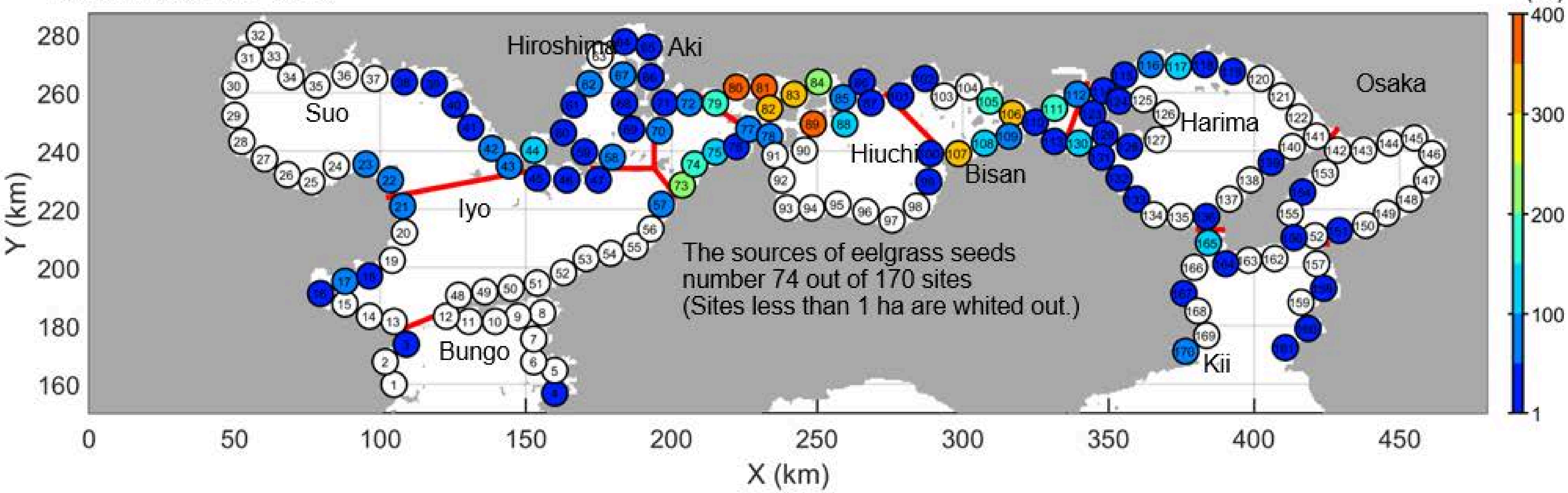
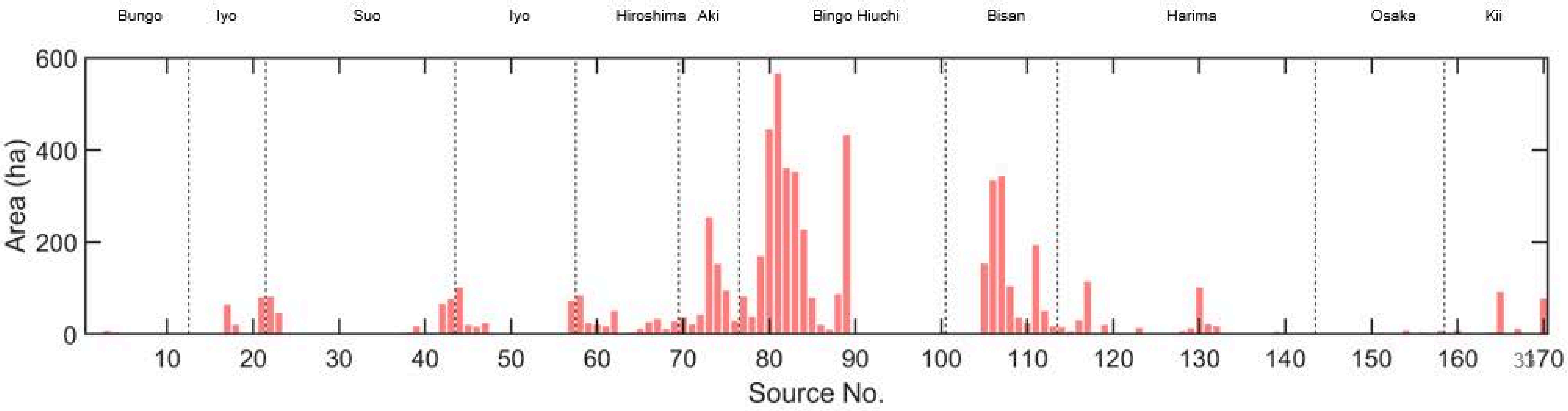


[Note] The Lagrangian PDF (probability density function for particle displacement given to advection time) of a particle with an advection time of 30 days is shown.
Summer 2012

Area of eelgrass beds at the source of release

Area of eelgrass beds (ha) at each discharge source according to the 4th National Survey on the Natural Environment (Ministry of the Environment, 1989–1990)





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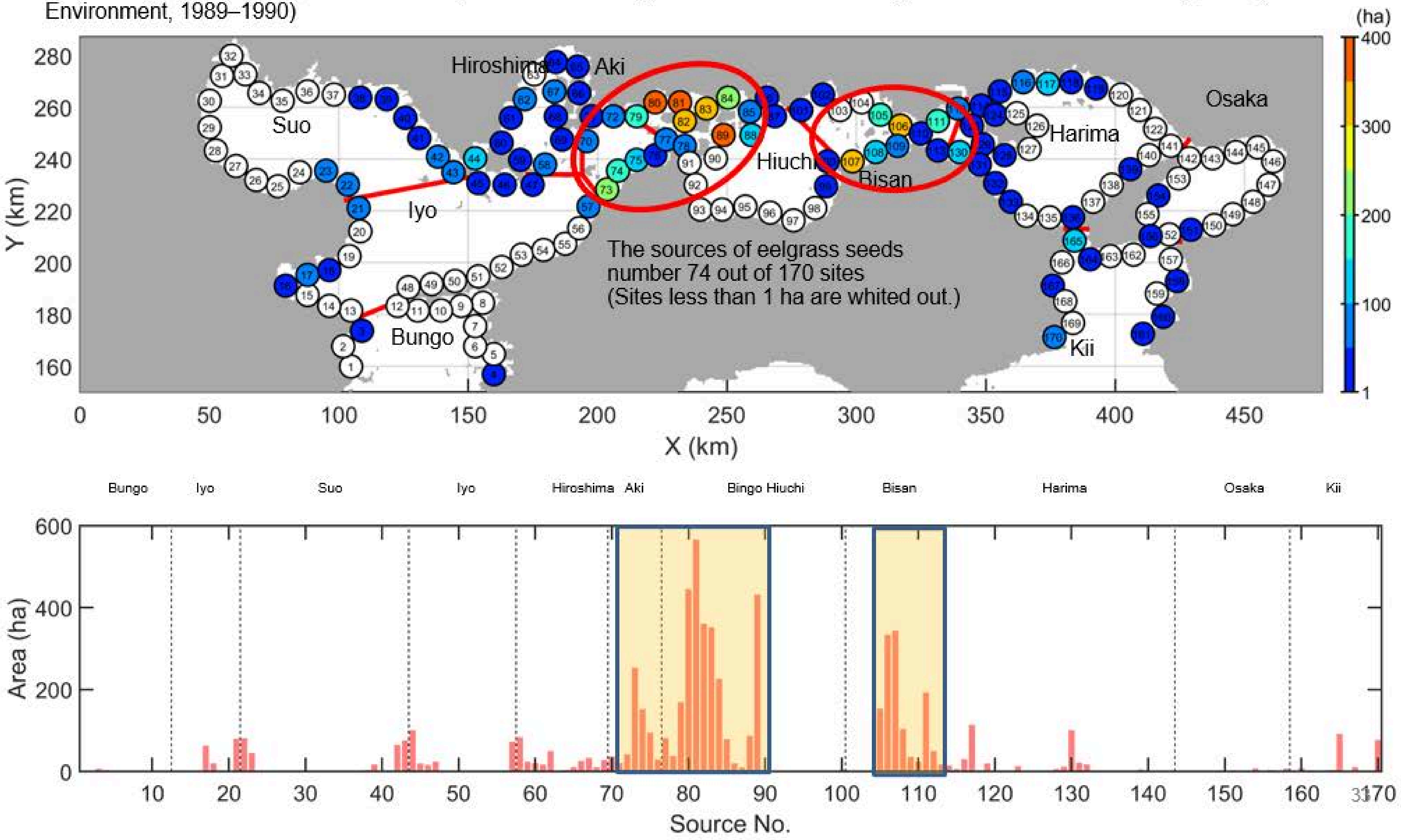
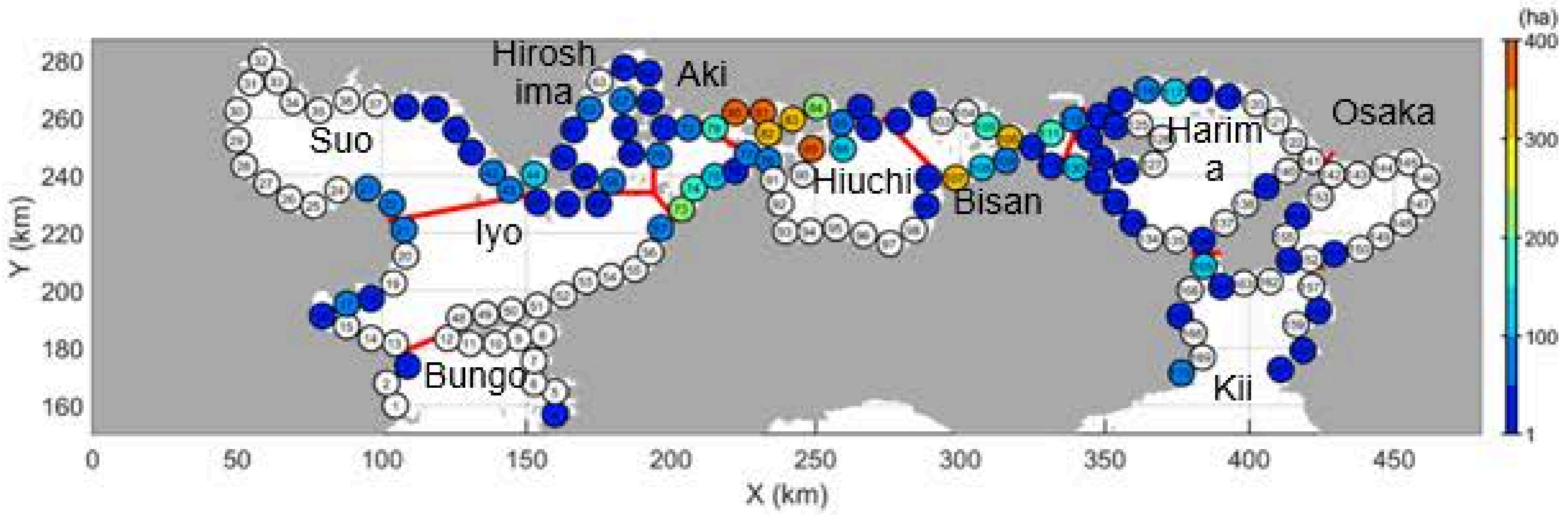


Main Source Areas of Eelgrass Beds in the Seto Inland Sea

Proportion of each source area in eelgrass shoots reaching all coastal sites in the Seto Inland Sea calculated from the joint probability Ca_{ji} of the Lagrangian PDF of particle locations

Source area	(%)
Bungo Channel	0.10
Suonada	1.81
Iyonada	2.39
Hiroshima Bay	3.93
Akinada	5.79
Hiuchinada	56.94
Bisan Seto	21.21
Harimanada	5.32
Osaka Bay	0.36
Kii Channel	2.14

Area of eelgrass beds at each release source (ha)
4th National Survey on the Natural Environment



Main source sea areas: **Hiuchinada and Bisan Seto**

Destination strength : It is possible to evaluate the sites that particles emitted from the source site j **are likely to reach.**

$$D_i(\tau) = \sum_{j \subseteq J} Ca_{ji}(\tau) \quad J = j_1, \ldots, j_N$$

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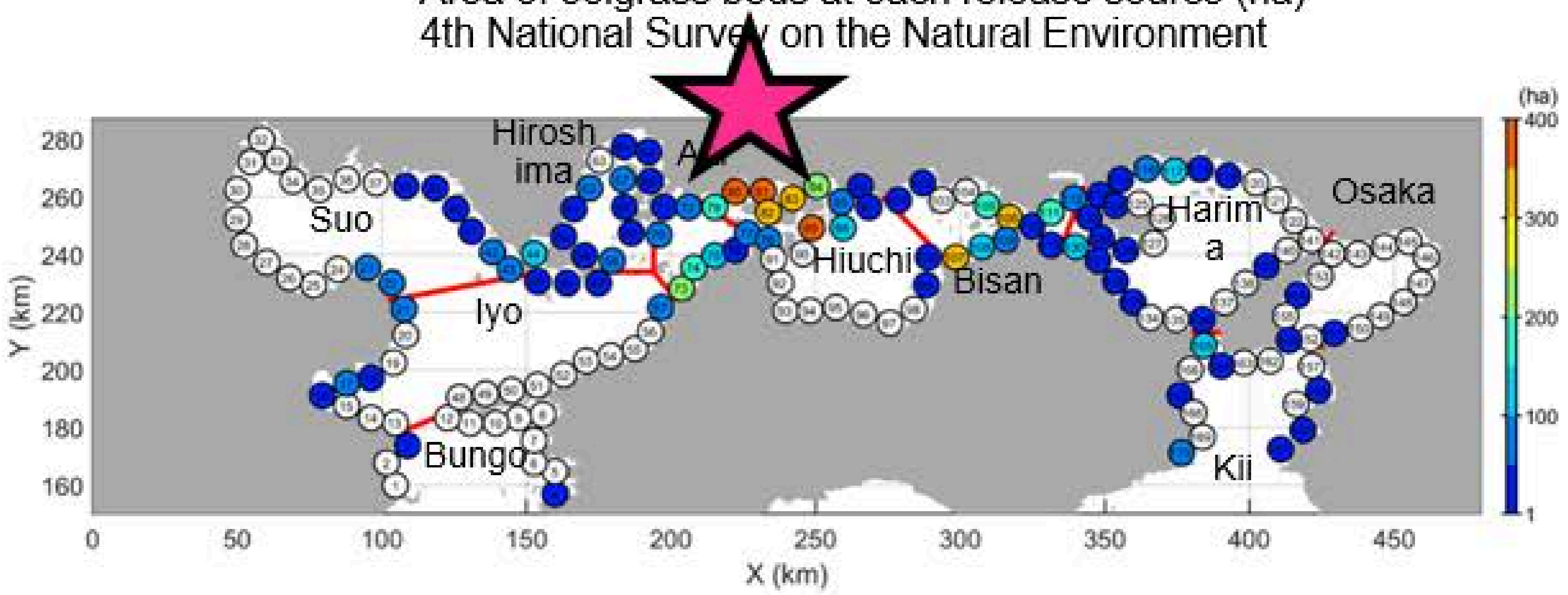

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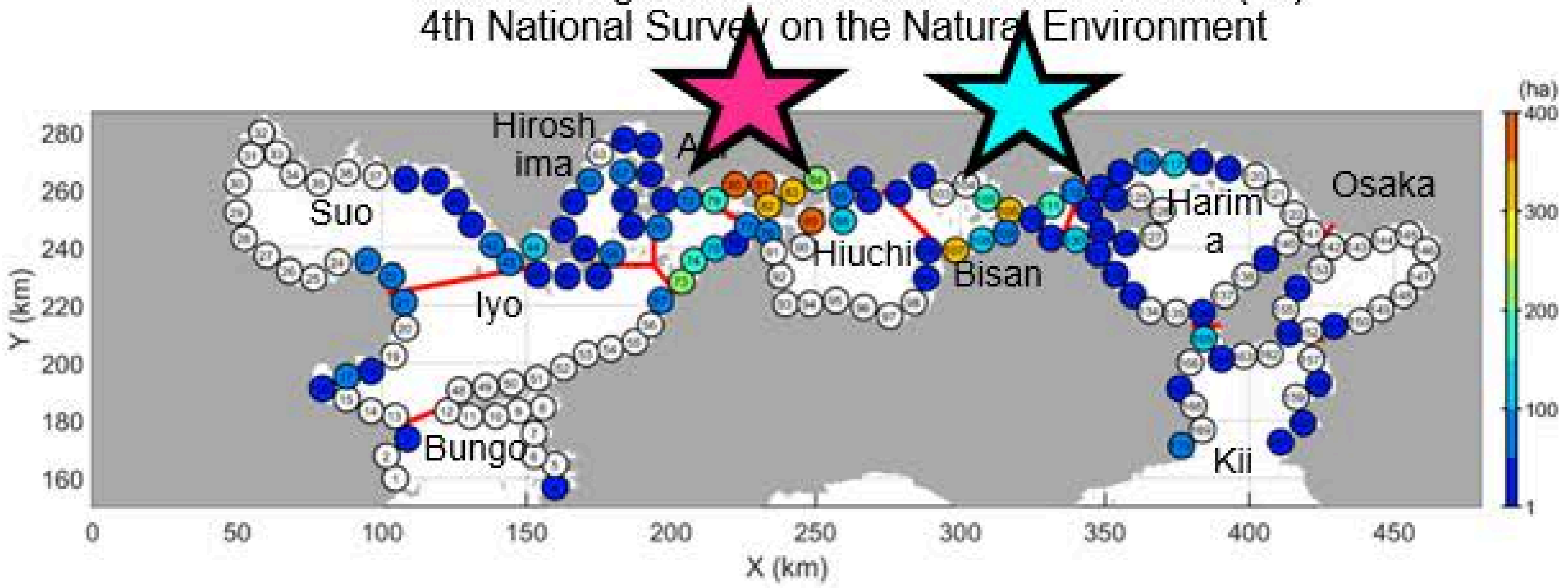
Area of eelgrass beds at each release source (ha)
4th National Survey on the Natural Environment



Main source sea areas: **Hiuchinada and Bisan Seto**

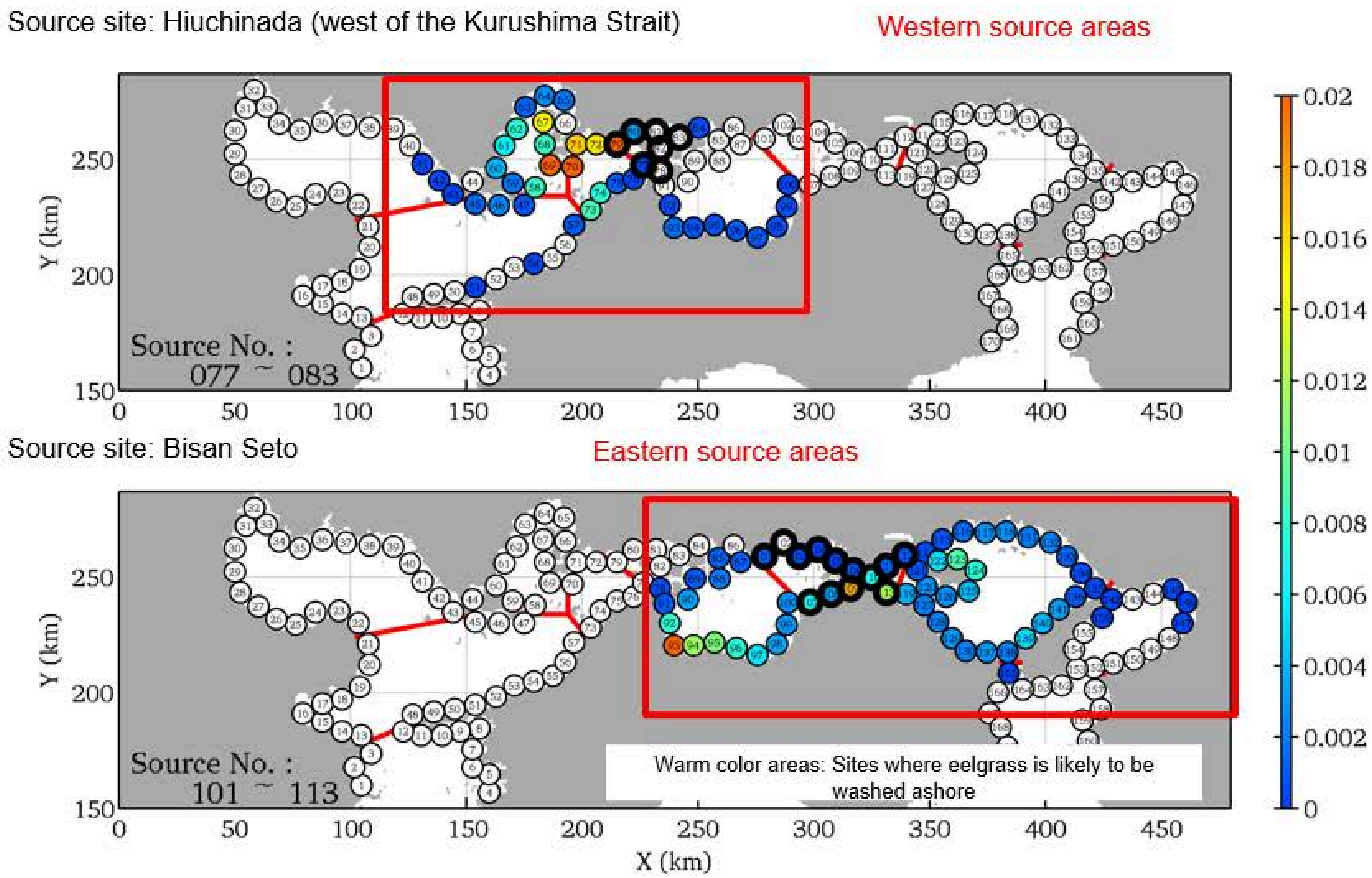
→ To which sea area will eelgrass shoots be transported?

Destination strength : It is possible to evaluate the sites that particles emitted from the source site j **are likely to reach.**

$$D_i(\tau) = \sum_{j \subseteq J} Ca_{ji}(\tau) \quad J = j_1, \ldots, j_N$$

Connectivity between eelgrass beds: Network structure

Spatial distribution of destination strength by source area in 2012



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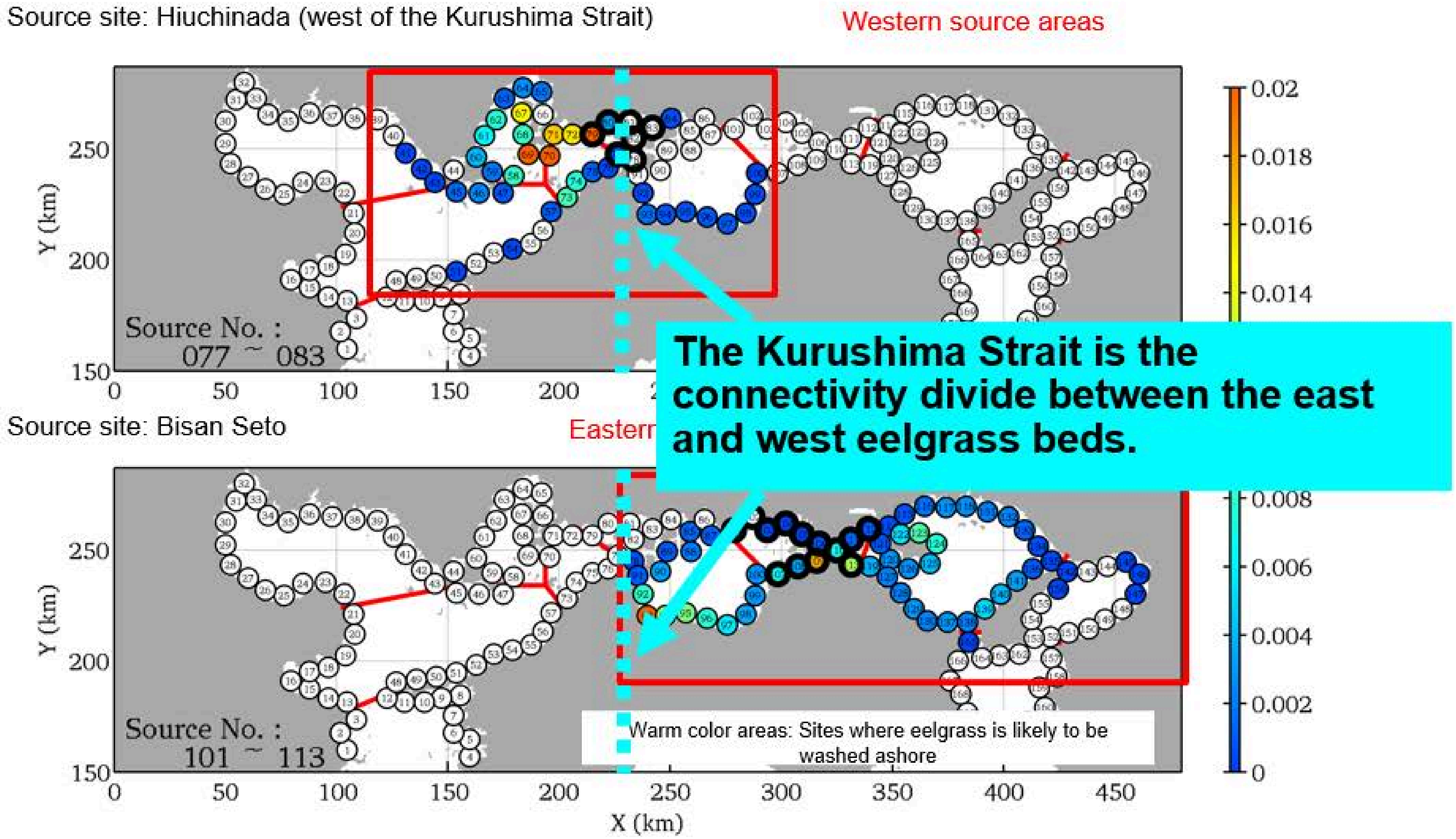
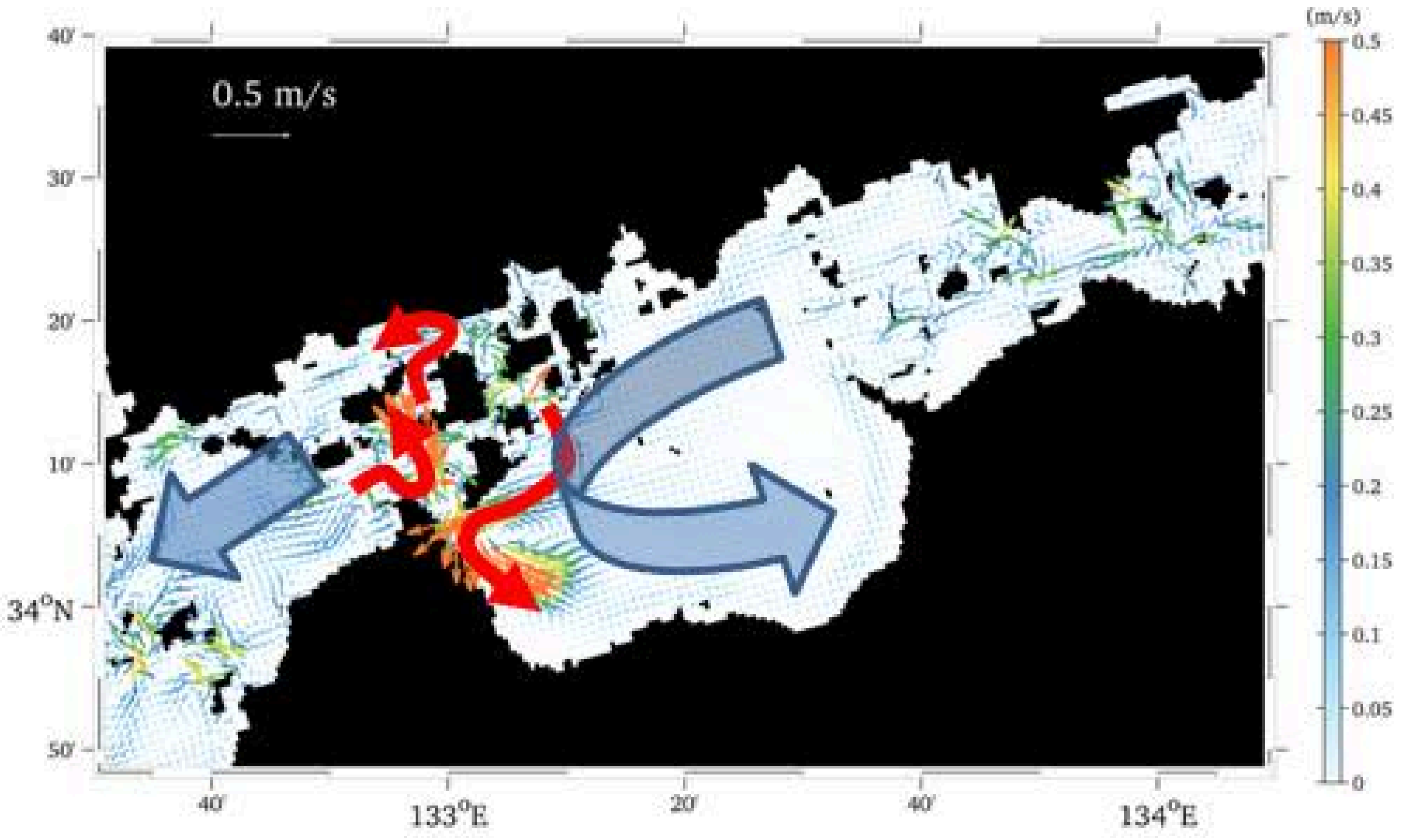


Causes of the eelgrass network divide at the Kurushima Strait

Effect of tidal currents (tidal residual currents)

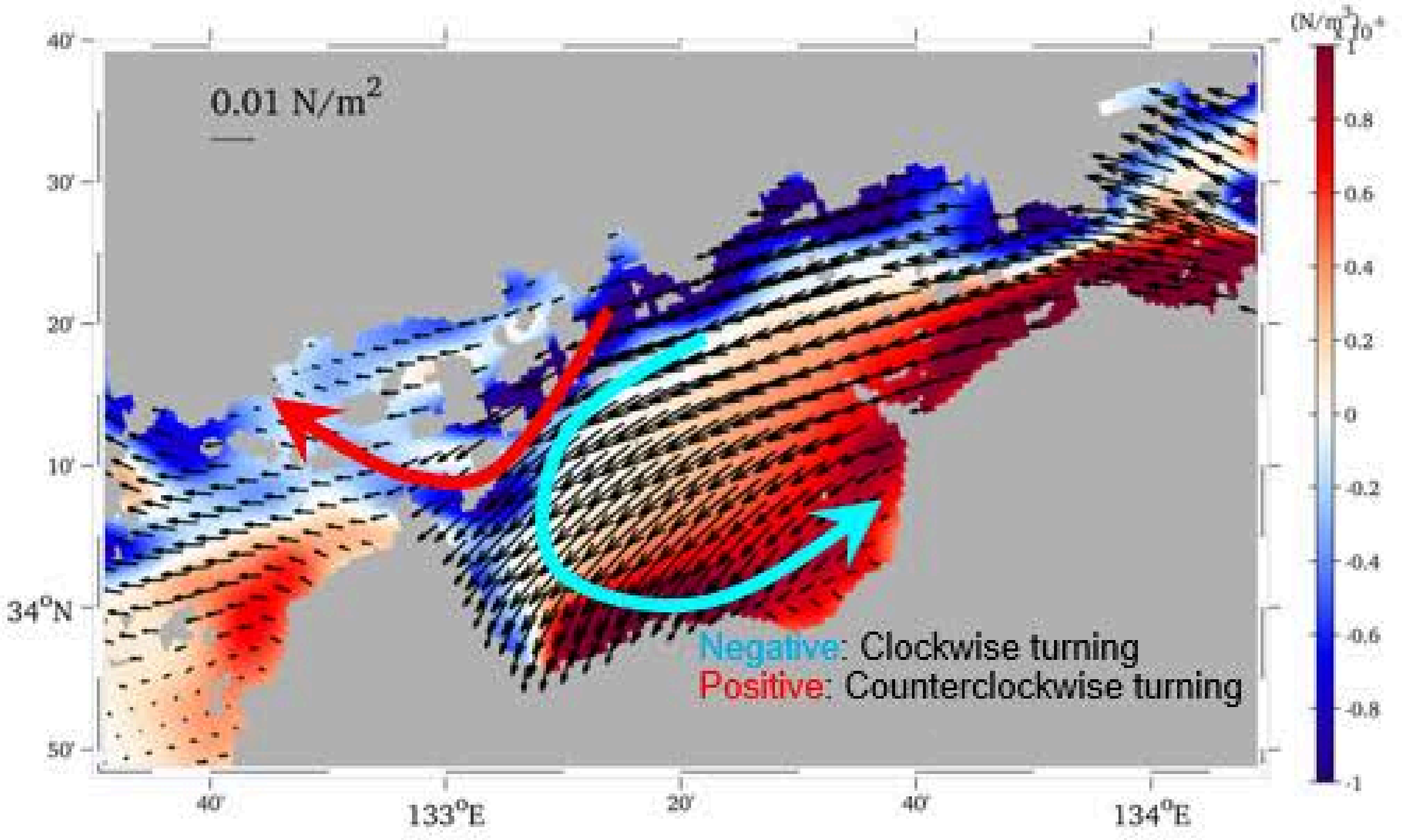
- Mean current velocity vector (m/s) at 0.5 m below the sea surface from June to August 2012



West of the Kurushima Strait: **Westward residual current**
East of the Kurushima Strait: **Eastward residual current**

Effect of marine winds (wind-driven current)

- Mean wind stress vector (Pa) and curl for the same period

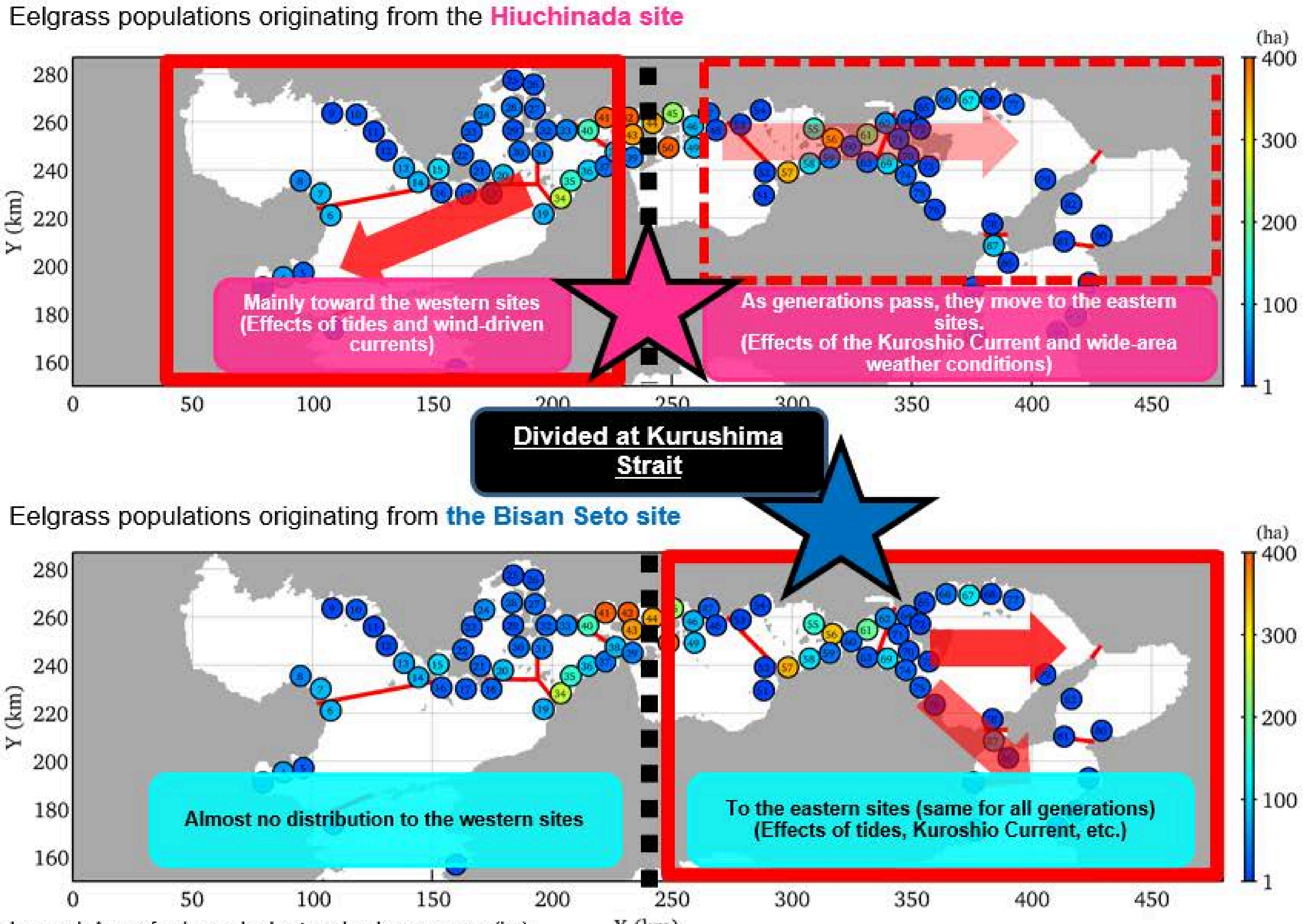


West of the Kurushima Strait: **Westward wind-driven current**
East of the Kurushima Strait: **Eastward wind-driven current**

Residual current and **development of a counterclockwise horizontal gyre** in the vicinity of Hiuchinada (presence of cold water at the bottom)
Development of east-west wind-driven currents in the surface layer (existence of marine winds influenced by topography)

→ Kosako et al. (Coastal Eng. Journal, in print)

A conceptual diagram of the network structure of eelgrass beds in the Seto Inland Sea

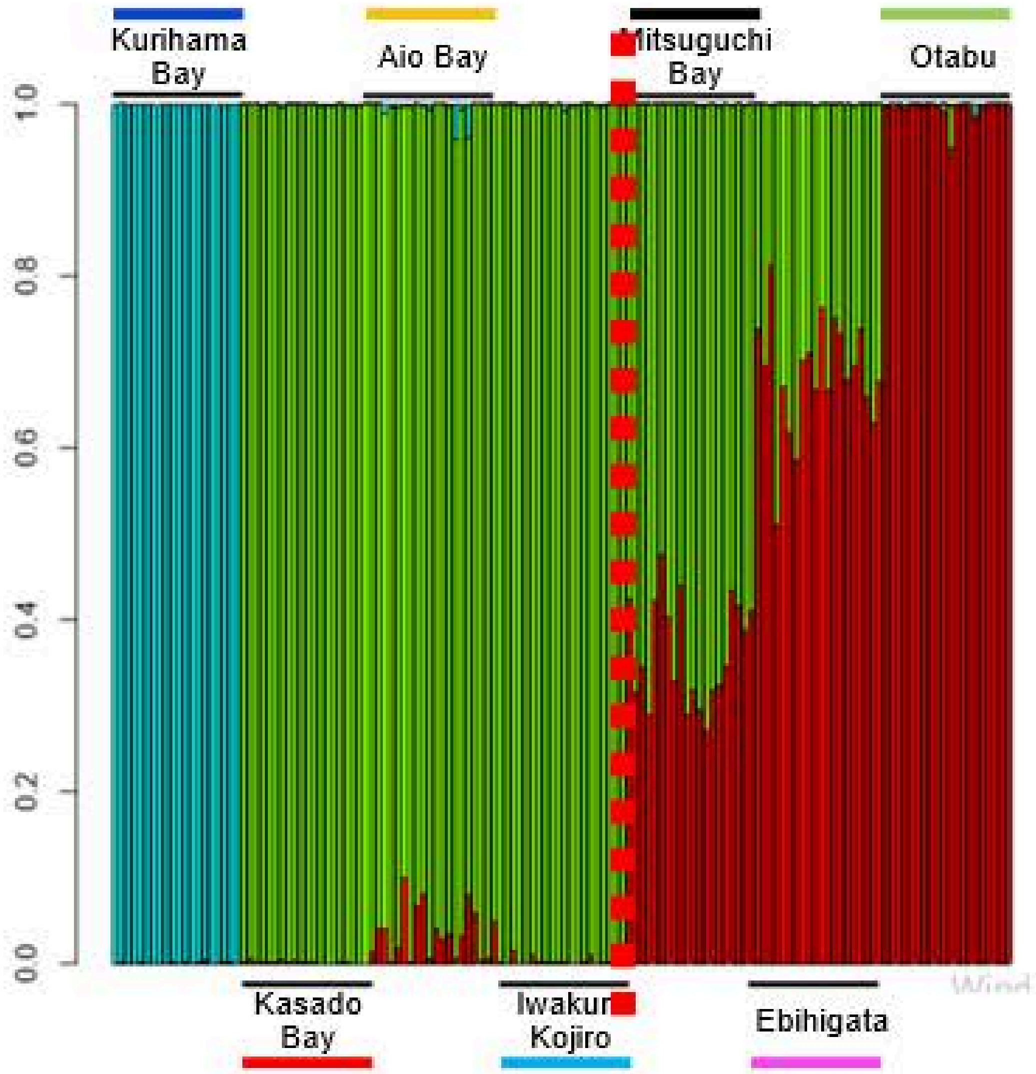


Background: Area of eelgrass beds at each release source (ha)

Validity of digital Seto Inland Sea: Comparison with genetic analysis

- A genetic diversity survey was conducted on eelgrass beds in the Seto Inland Sea in 2019.
- The genetic populations of eelgrass in the Seto Inland Sea **were largely divided into the western part (Iwakuni Kojiro) and the eastern part (Otabu)**. (Hosokawa et al., Port and Airport Research Institute)

Structural analysis results
(Classification of genetic populations into three groups)



Source: FY2019 Chugoku Commissioned Report

Targeted eelgrass beds (6 sites)

[Source: Geospatial Information Authority of Japan Map, http://maps.gsi.go.jp/]

Good agreement with digital twin predictions

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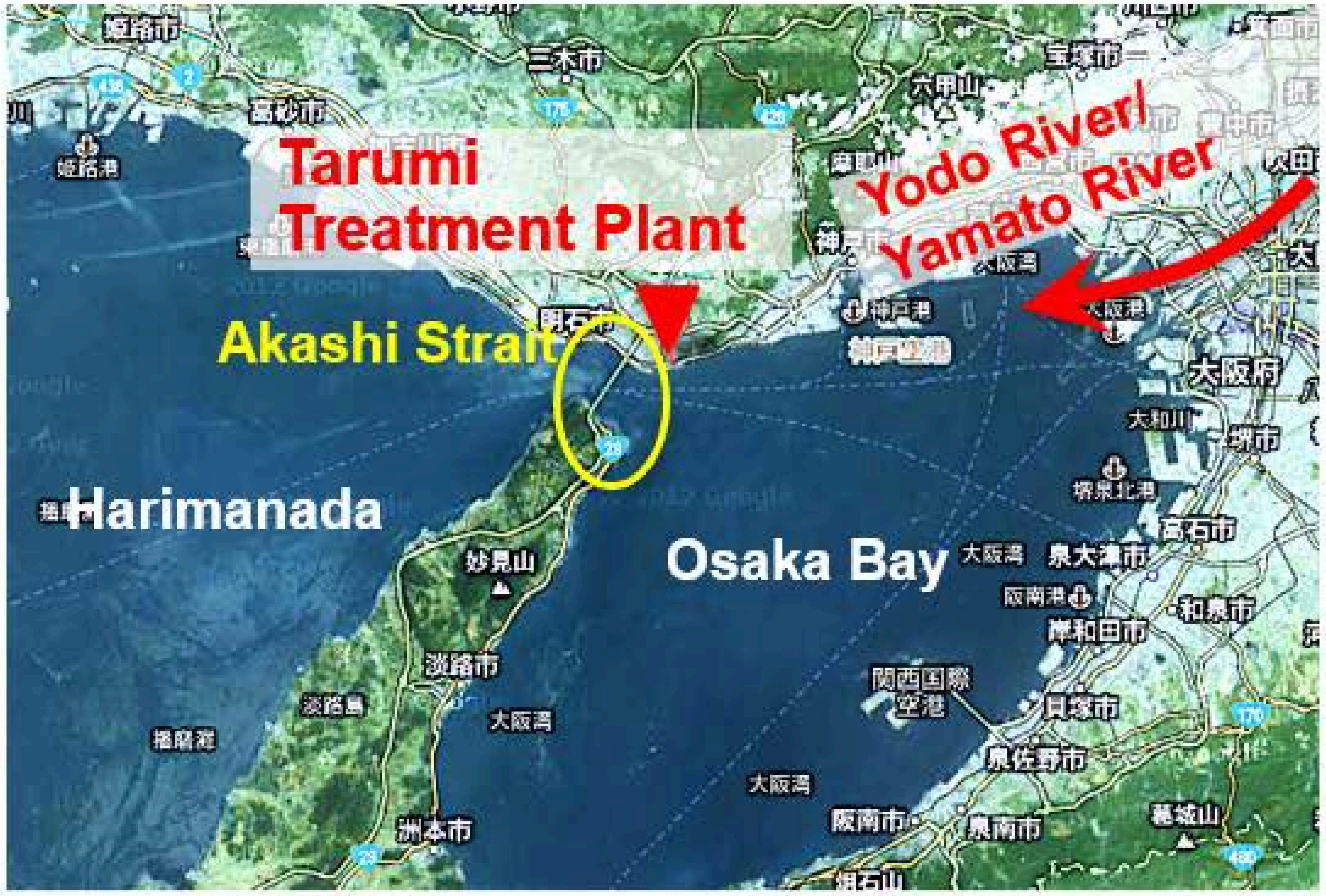
Diffusion of treated sewage water from the Tarumi Treatment Plant in Kobe City: Impact on seaweed farms

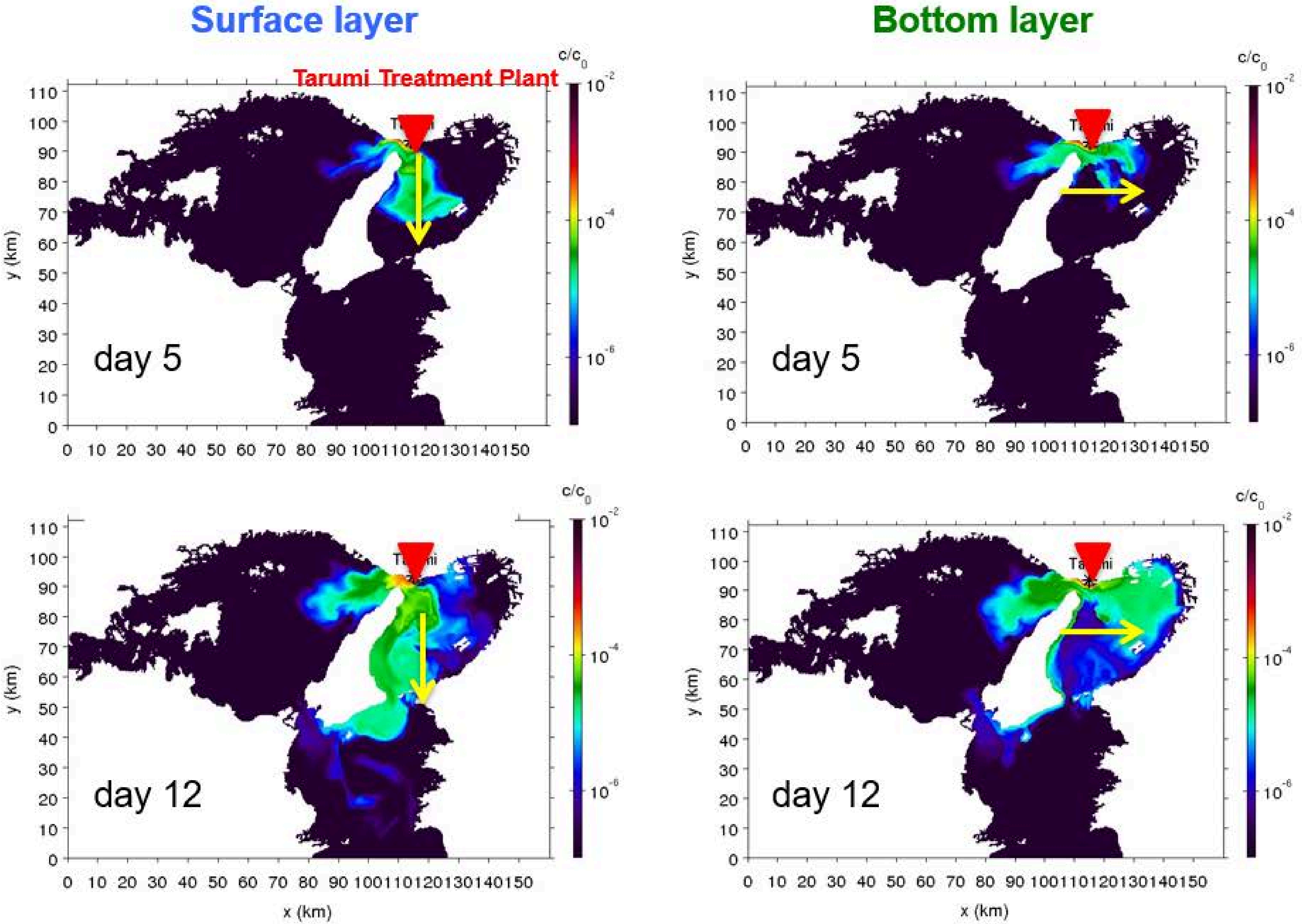
- Mean currents in Osaka Bay and the effects of Akashi Strait and river waters
- Impact on seaweed farming and water quality management



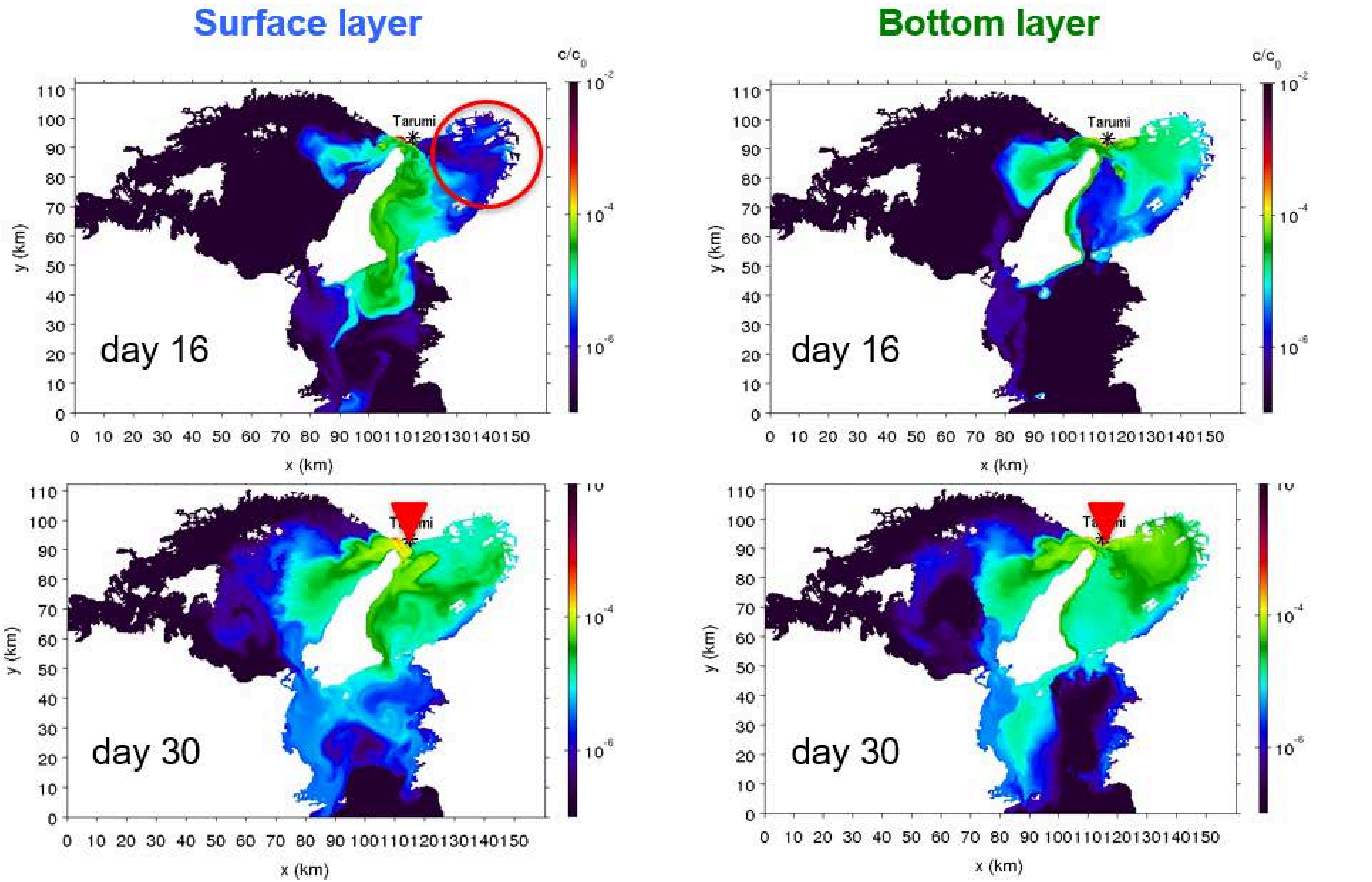
Seaweed farm near the Tarumi Treatment Plant→

Uchiyama, Y., Zhang, X., Suzue, Y., Kosako, T., Miyazawa, Y. and Nakayama, A. (2018): Residual effects of treated effluent diversion on a seaweed farm in a tidal strait using a multi-nested high-resolution 3-D circulation-dispersal model, *Mar. Pollut. Bull.*, Vol. 130, pp.40-54.

Transport and diffusion of treated water to distant areas: Differences in behavior between the surface and bottom layers

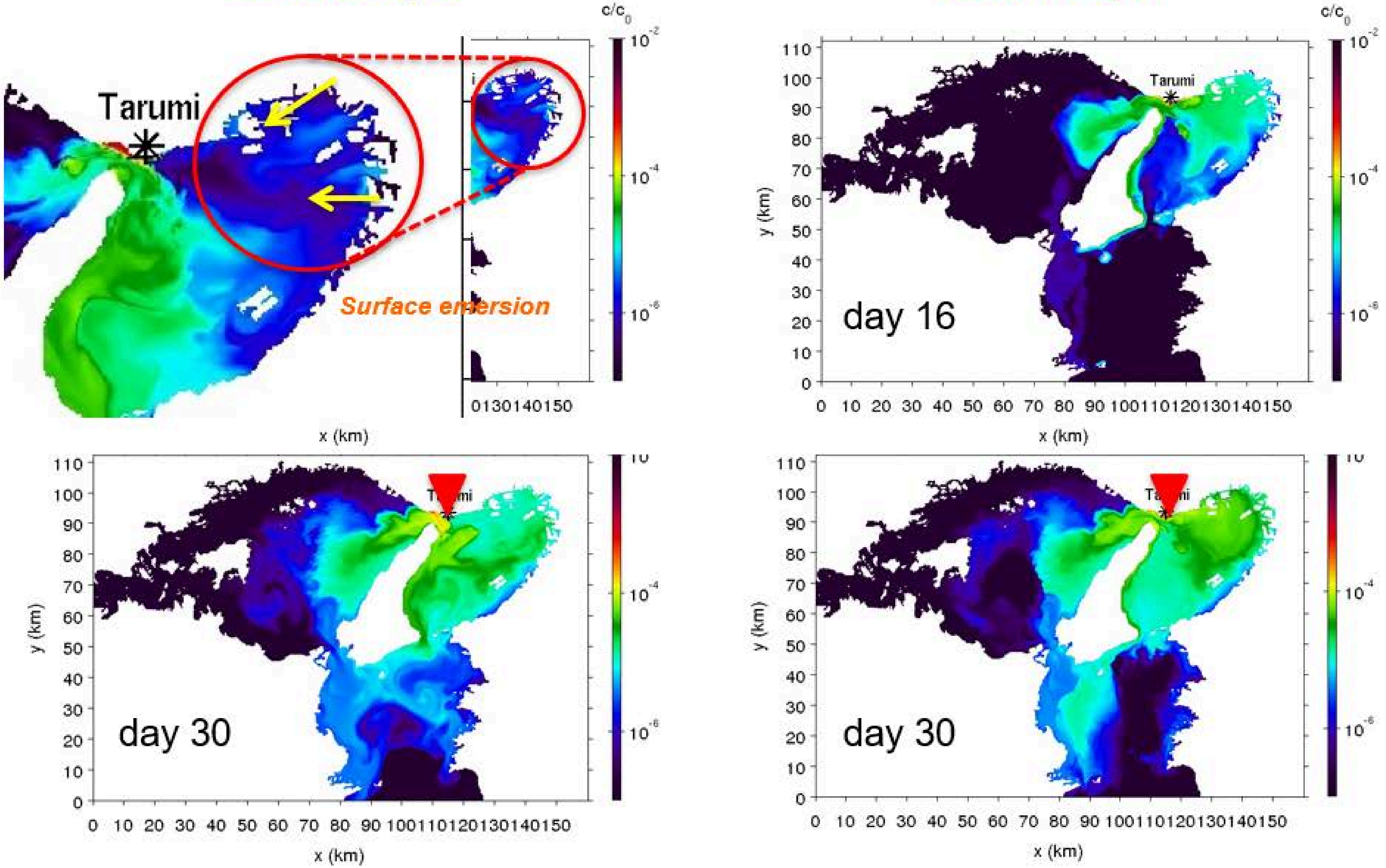


c/c_0 : tracer concentration normalized by the initial concentration c_0



The treated water sinks into the lower layer and is transported toward the mouth of the Yodo River, where it emerges together with the river flow and spreads throughout Osaka Bay. → Sink and sprinkler effect

Surface layer **Bottom layer**



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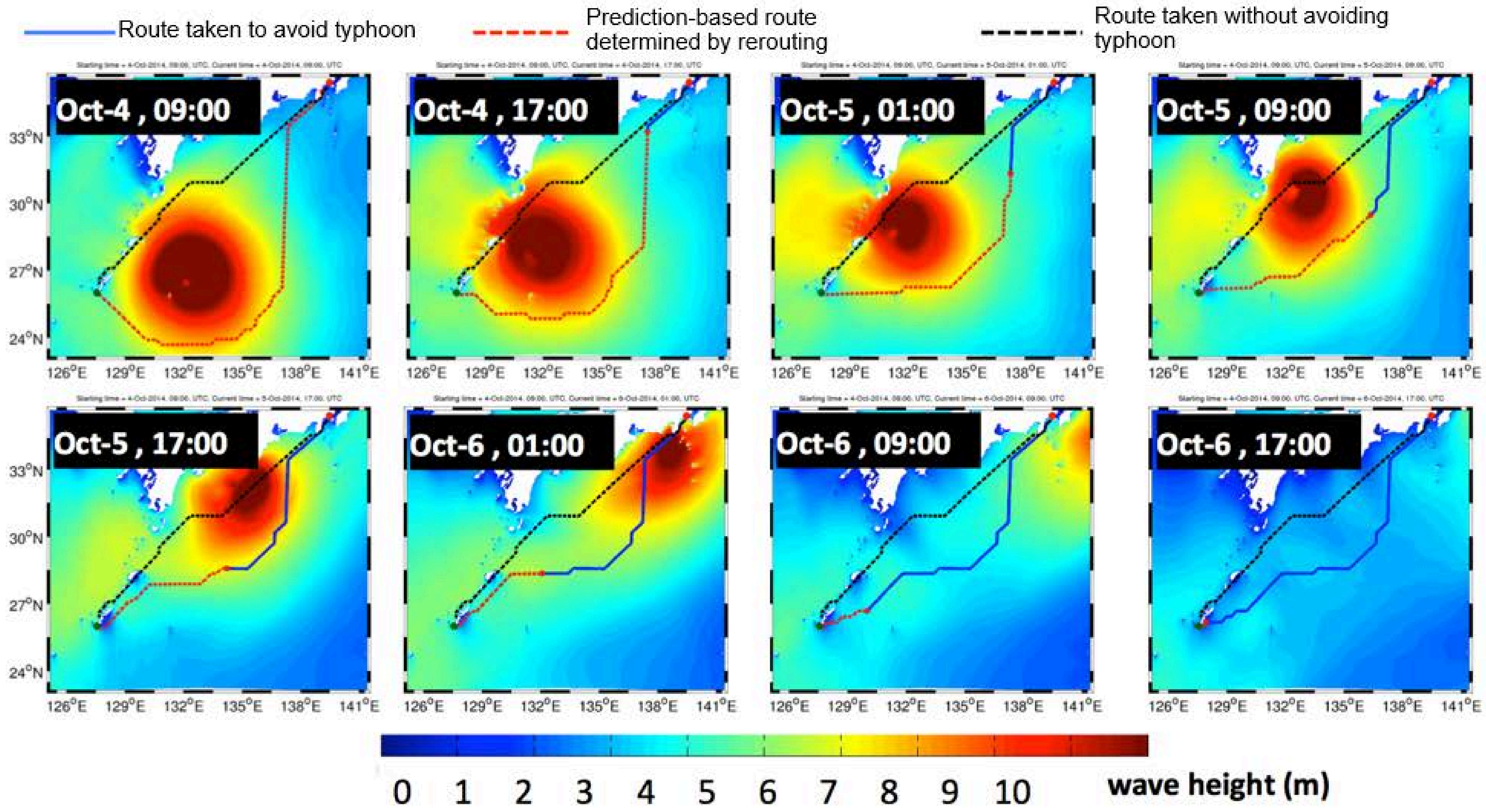
Optimal Ship Route Problem (Weather Routing)

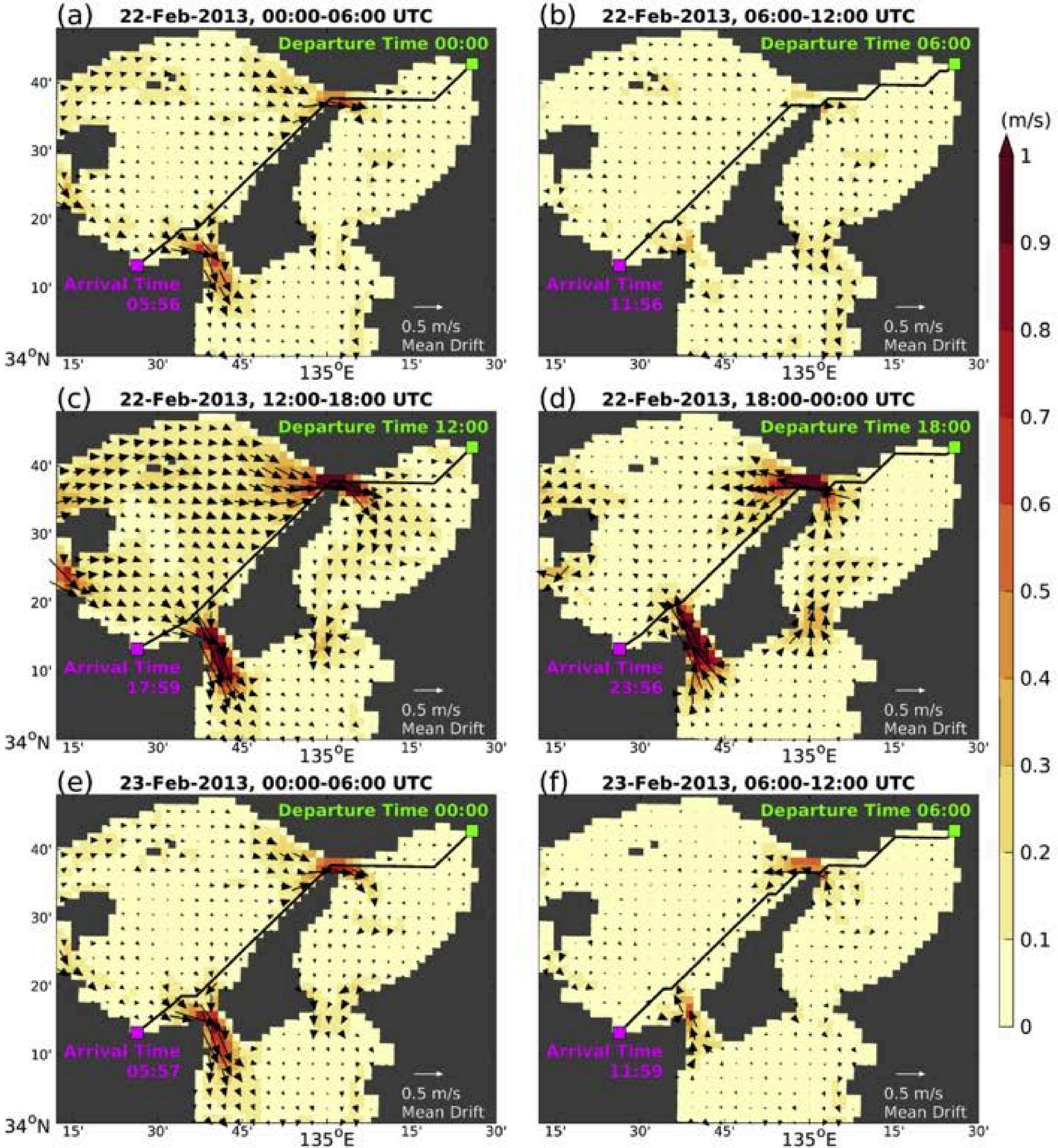
Results of route exploration using the digital twin to reduce fuel consumption and avoid typhoons for ocean-going ships



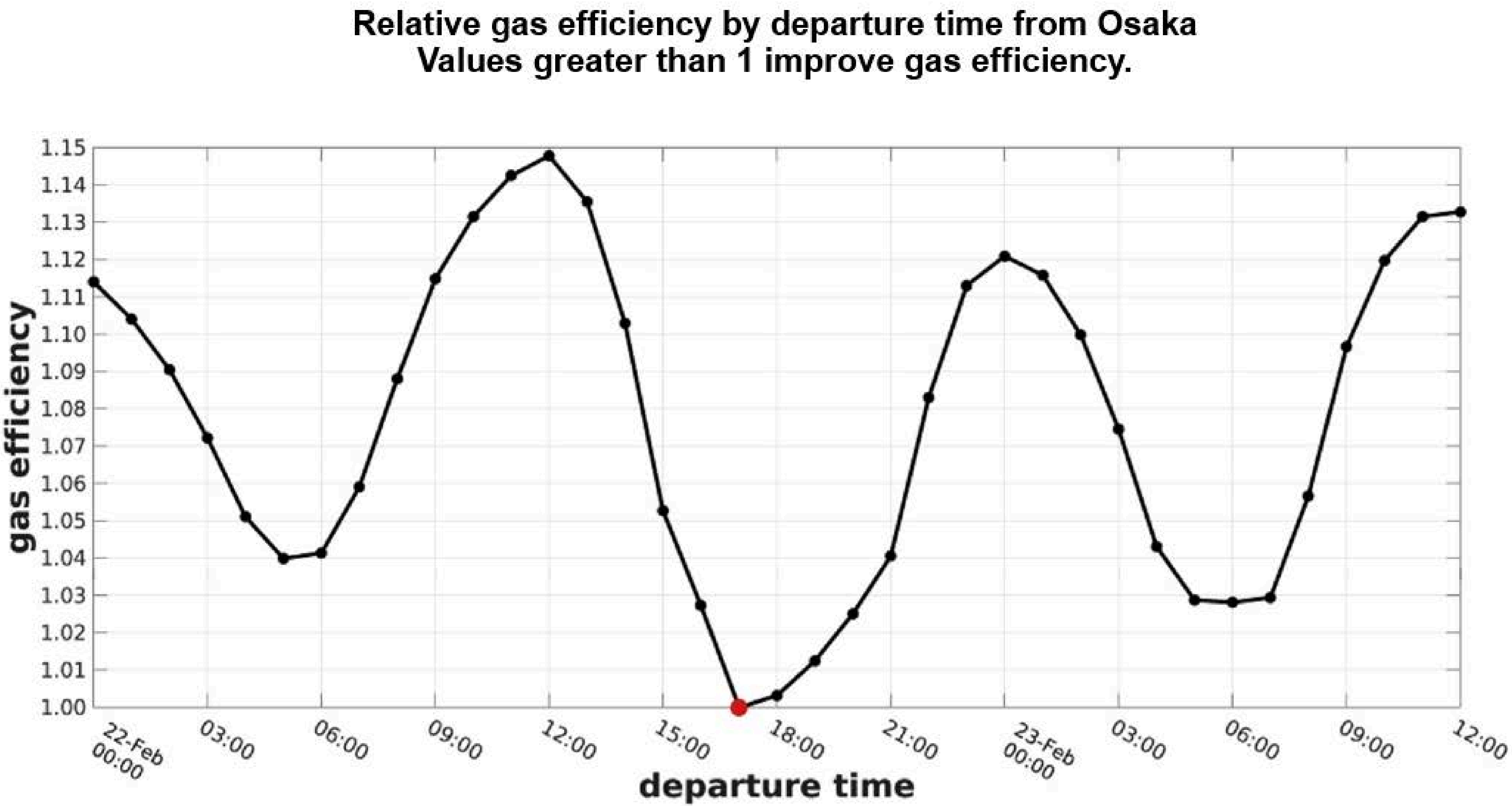
Kurosawa, K., Uchiyama, Y., and Kosako, T. (2020): Development of a numerical marine weather routing system for coastal and marginal seas using regional oceanic and atmospheric simulations, *Ocean Eng.*, Vol. 195, 106706.

Application of weather routing to domestic shipping routes using the digital Seto Inland Sea

Between Osaka and Kagawa
- Optimal route (black line)
- Time required (number)
- Surface current velocity (coloring and arrows)



Application of weather routing to low-carbon shipping



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Website of Uchiyama Laboratory, Kobe University
http://coast.dce.kobe-u.ac.jp

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