Summary of Research Center Project

* Compile in English withinA4 3 pages.

Center name: Advanced Institute for Marine Ecosystem Change (AIMEC)
Host institution 1: Tohoku University
Head of host institution 1: Hideo Ohno, President
Host institution 2: Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
Head of host institution 2: Hiroyuki Yamato, President
Prospective Center director: Toshio Suga, Professor, Tohoku University
Prospective Administrative director: Kentaro Ando, Director, JAMSTEC

(1) Overall Framework of the Center Project

Since the Industrial Revolution, human activities have expanded to the extent that they significantly impact every subsystem that constitutes the Earth system, which manifestations include global warming, ocean acidification, biodiversity loss, and ecosystem collapse. In the face of this crisis, understanding the mechanisms of change in the Earth-Human system and projecting them is the most crucial challenge for the sustainability of human society.

The mission of the WPI-Advanced Institute for Marine Ecosystem Change (AIMEC) is to unravel the primary question, **"What are the response and adaptation mechanisms of marine ecosystems to Earth-Human system dynamics?"** With a specific focus on marine ecosystems, which have lagged significantly behind terrestrial ecosystems in terms of understanding, we aim to create and lead globally a new interdisciplinary academic field called **"Ocean-Ecosystem Change Systematics (OECS)" for sustainability** by integrating marine physics, ecology, and mathematical and data science. Through these efforts, we will significantly deepen our understanding of ***connectivity***, ***stability***, and ***adaptability***, which are indispensable for the sustainability of marine ecosystems, achieve projective modeling of marine ecosystem changes, including both positive and negative feedback that affects **"ecosystem services"**, and contribute to proactive restoration and recovery of the ocean and ecosystems.

The WPI-AIMEC fosters an environment that pursues scientific understanding of the relationships among data of different natures from the stage of creating fundamental datasets for integrated research. Leveraging Japan's geographical location and research accumulation, we plan to focus first on the **Northwestern Pacific**, a region with significant spatiotemporal variations in the marine environment and globally high biodiversity. Subsequently, we will incorporate options for global deployment into the data integration products generated, and promote international data utilization beyond the scope of the main target region.

Under the strong institutional collaboration between Tohoku University, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and the University of Hawai'i at Mānoa, AIMEC will bring together approximately 90 world-class researchers and outstanding young scientists. By linking (i) **Tohoku University**'s academic strengths and higher education functions, (ii) **JAMSTEC**'s marine research and computational platforms, and (iii) the **University of Hawai'i**'s environmental observation capabilities, we will establish the WPI alliance that focuses on the Northwestern Pacific as a priority region for interdisciplinary research, effective international brain circulation and higher education (**Fig. A**). Furthermore, we will leverage the international networks to enhance the level of integrated research and higher education, and strongly promote the public relations, outreach, and digital transformation (DX) capabilities to provide beneficial information to UNs' agencies, policymakers, and the general public. Through these efforts, we will maximize the synergy generated by this WPI alliance and contribute to **"Planetary Stewardship" for sustainability**.

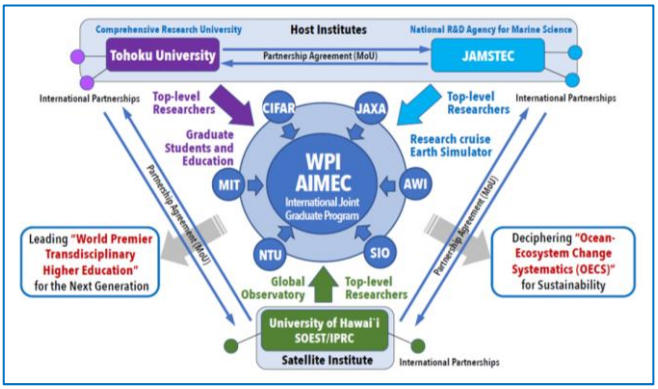

Fig. A. Conceptual diagram of the WPI-AIMEC .

(2) World-Leading Scientific Excellence and Recognition

1) Research content

As one of the key transdisciplinary and integrative research targets constituting the response and adaptation mechanisms of marine ecosystems to environmental changes, we focus on the mystery of **"regime shifts,"** which are widespread and rapid large-scale transformations in climate and ecosystems. Deepening our understanding of regime shifts will expand our understanding of the "tipping points" associated with global warming. Here, we describe the summary of research themes (I-III) that form the axis of the WPI-AIMEC's integrated research:

I. Deciphering Climate-Ocean-Ecosystem Interactions and Regime Shift: The decadal-scale variations in the stability of the Kuroshio Current, which are linked to the Pacific Decadal Oscillation, affect short-period variations

such as seasonal cycles and daily fluctuations, as well as medium-scale variations such as front waves and ocean eddies. Over the past 30 years, multiple observation projects have been conducted to comprehensively understand the Northwest Pacific, making it one of the most advanced regions in the world for understanding environmental field variations from decadal to seasonal scales. Combining this knowledge with the latest autonomous platform (Argo floats, ocean gliders, etc.) and seafloor cable observation data will enable us to understand variability across a wide range of spatiotemporal scales. Furthermore, the detailed information on environmental variability can be effectively integrated with environmental genome (eDNA) information, biogeochemical data, genomic-level plasticity, and adaptive evolutionary process data. Through statistical methods and machine learning, we will hierarchically extract temporal and spatial patterns of variations in marine environmental disciplines and lower trophic level ecosystems, ranging from coastal to open ocean, surface to mesopelagic depths, and from daily to decadal changes, revealing the interconnections among different time and variable scales.

II. Ecosystem Response, Adaptation, and Evolution Mechanisms to Environmental Changes: To understand the response and adaptation mechanisms of marine ecosystems, it is essential to comprehensively understand biological responses from the individual and population to the community level. Marine microbial ecosystems support primary production in surface waters and directly influence the diversity, abundance, and movement of higher trophic-level organisms in the food web. Ecological theory suggests that changes in species interactions occur on much shorter timescales than intergenerational scales and that the accumulation of these change impacts ecosystem dynamics at the large-scale community level. To understand non-equilibrium and nonlinear species interactions with dynamic stability indicators of ecosystems, the WPI-AIMEC will maximize opportunities provided by JAMSTEC and the University of Hawai‘i’s observation stations, marine surveys, and *in situ* eDNA/RNA surveys with new sampling and analytical devices to expand the application of spatiotemporal eDNA analysis to the Northwestern Pacific region. We will also use “culturomics” approaches, including *in situ* and *in vitro* experiments with environmental stressors, to elucidate the potential responses, adaptability, and limits of marine ecosystems to periodic behavior modes of physical environments, at the gene expression-, isotopic fractionation-, and metabolite-levels.

III. Projection of Marine Ecosystem Changes: To quantitatively capture the relationship between environmental changes and productivity for future projections, it is necessary to understand and accurately reproduce the mechanisms by which disturbances in the physical environment affect the marine ecosystem and lead to the maintenance or changes of productivity. The ocean general circulation model developed by JAMSTEC has a horizontal resolution of approximately 10 km and reproduces the marine physical environment, covering the entire ocean and representing medium-scale eddies to some extent. The marine ecosystem modules, which parameterizes and incorporates the connectivity among variables in I and the response and adaptability at the gene expression and metabolic levels in II, are installed in the model to validate and improve the marine ecosystem modules by assimilating observed data. In addition, we will develop methods to convert biological distributions into functions for material cycling and climate formation. Furthermore, we will leverage machine learning and AI-based approaches to improve our understanding and projecting of changes and their feedback mechanisms on the marine environment and human activities.

2) Interdisciplinary research

To elucidate the ecological response and adaptation mechanisms, including the mystery of “regime shifts”, observations of a wide range of physical and biological phenomena with high spatiotemporal resolutions and numerical modeling to reproduce them are essential. By utilizing satellite, advanced biogeochemical Argo float, and submarine cable observation networks, we will conduct high spatiotemporal resolution observations in the dynamic Kuroshio region and coastal areas in Theme I. By integrating these observation data with the numerical models of III, we will achieve a comprehensive understanding and reproduction of the phenomena with high spatiotemporal resolution. Furthermore, through mathematical and data sciences that incorporate machine learning and AI, we will analyze the correlations between the short-term variability patterns revealed in Theme I and the dynamic stability indicators of biodiversity and functionality elucidated in Theme II to achieve both high-resolution comprehensions of spatiotemporal dynamics and high-resolution understanding of biological response processes. This will allow us to holistically elucidate the stability and adaptability of marine ecosystems and potential feedback mechanisms from the ecosystem to the Earth’s environment. Combining the results of Themes I, II, and III and assimilating observation and experimental data, the system can be validated by reproducing environmental fields in the context of real decadal-scale marine environmental and ecosystem changes. In addition, our efforts will be made to project variables related to human activities, such as fishing, to achieve dynamic predictions of systems in which the environment and humanity mutually interact with each other. We will compile a database of the results and intermediate products of themes I-III and their fusion research, create a prototype of a generative AI for marine ecosystems based on the database, and utilize it in further interdisciplinary research, aiming to build a generative AI that can be made available to the public in 10 years.

(3) Global Research Environment and System Reform

1) International research environment

Approximately 4,000 m^2 of common space owned by Tohoku University will be used to launch the WPI-AIMEC.

Within 3 years, a new building will be established to serve as the main base of this center, creating an "under one roof" fusion research environment. The main base will provide advanced laboratory spaces for PIs and other researchers and facilitate an open laboratory space to promote international brain circulation. Tohoku University established the "International Support Center" in 2022, which functions as a research reception center with staff who provide high-quality support in English, regarding their accommodation, daily lives, and research collaboration, as established based on the expertise of the WPI-Academy AIMR. JAMSTEC also has long-term experience accepting many foreign scientists since establishing the Frontier Research System. In addition, the international "JAMSTEC Young Research Fellowship Program" has been started since 2014, and a total of 40 early-carrier scientists have spent their research lives in JAMSTEC. Through the infrastructure of Tohoku University, JAMSTEC, University of Hawai'i at Mānoa, and other international partners, this WPI alliance will have an international research environment that maximizes human interactions and joint trans-dimensional research activities from the center's launch. In addition, by participating in international programs and projects related to marine ecosystems, such as Decade Action Programme/Projects of UN Decade of Ocean Science for Sustainable Development, in cooperation with the United States, Europe, and other major institutions around the world, we will build mutually beneficial relationships with these institutions.

2) Center management and system reform

The prospective AIMEC Director will oversee and supervise the entire research organization and be responsible for all decision-making regarding this center's operation. The prospective Administrative Director will elevate international brain circulation to the highest level in the world. English will be the working language. Dedicated University Research Administrators, International Coordinators, and Science Communicators will be appointed. The Fusion Research Division will consist of approximately 110 scientists and support staffs, and the Administrative Division around 40, resulting in a total of approximately 150 staff members, with a commitment to maintaining a foreign and female representation ratio of over 30% each. The International Science Advisory Board (SAB), composed of eminent scientists and experts, will be established to provide advice scientific and operational advice.

The WPI-AIMEC will be positioned within the "Research Innovation System" as the top layer of the "Advanced Research Institutes" under "Tohoku University Global Gateway Strategy" and will collaborate with the "Frontier Research Institute for Interdisciplinary Sciences (FRIS)" and other research facilities. JAMSTEC will also establish a new research system that utilizes advanced oceanographic research and computational capabilities, aiming to enhance the integrated and flexible operation of the WPI-AIMEC in tight collaboration with Tohoku University.

(4) Values for the Future

1) Generating and disseminating the societal value of basic research

Following the adoption of the SDGs in 2015, initiatives related to "Carbon Neutrality" and "Nature Positive" have been progressing, including the IPCC and UN Decade of Ocean Science for Sustainable Development since 2021. At the COP15 in 2022, countries shared their efforts toward the long-term goal of achieving a "Harmonious World with Nature" by 2050. In March 2023, the G-Science Committee proposed **"Regeneration and Restoration of the Ocean and its Ecosystems"** as a key theme. Very recently, the G7 Science and Technology Ministerial Meeting declared the strengthening of marine ecosystem observation. However, there is a significant gap between time-series studies of mobile ecosystems and physical studies of their habitats, hindering the accurate projection of marine ecosystem change. AIMEC aims to address such bottlenecks in fundamental science and achieve more accurate projection of marine ecosystem dynamics. With 41% of the world's ocean area impacted by human activities such as shipping and fishing, many countries, including Japan, benefit from marine ecosystems (i.e., ecosystem services). Therefore, our interdisciplinary evidence-based information will provide scientific guidance to stakeholders such as marine industries and policymakers, contributing to improving human well-being and prosperity. The research results and the integrated findings obtained from the research will be disseminated in an effective and timely manner to diverse stakeholders through regular roundtable meetings with the general public and policy makers, information dissemination via SNS and websites, and the establishment of our own video distribution channel, while making maximum use of relevant organizations and international programs, such as the United Nations.

2) Fostering next-generation human resources linked with higher education

The WPI-AIMEC will establish an environment where young researchers can actively participate in doctoral programs in relevant departments and receive guidance from world-class researchers at institutions such as JAMSTEC. Through international open recruitment, young researchers will be actively employed, with 6 postdoctoral fellows in the first year and 18 per year thereafter. Support will be provided to over 54 postdoctoral fellows over a period of 10 years. Outstanding young researchers who achieve excellent results will be designated as **"Rising STAR Researchers."** To foster international and interdisciplinary graduate students, Tohoku University has collaborated with the University of Hawaii at Manoa through the International Joint Graduate Program, producing 5 joint-degree recipients since 2018. In addition to this program, AIMEC will establish the new **"WPI-AIMEC International Joint Graduate Program"** in close collaboration with Tohoku University, JAMSTEC, and the University of Hawai'i, expanding its scope and implementing a robust higher education program in which world-class researchers from AIMEC will be involved in the education and training of graduate students. Students will take cross-disciplinary lectures from the second year of master course after learning the basics of each specialized field,

participate in summer schools, etc. at overseas partner institutions, and practice research activities at overseas partner institutions for six months or more during the doctoral course. In addition, we will promote overseas participation in this program by utilizing the mechanisms for accepting international students at each graduate school. As a result, this program will employ 33 doctoral students annually, with a goal of producing more than 120 PhD recipients in 10 years.

3) Self-sufficient and sustainable center development

The "Tohoku University Global Gateway Strategy" under the 4th Medium-Term Plan aims to establish and expand research and support systems of the highest international standards, and promote system reforms to strengthen its independent and strategic management. Tohoku University has pledged its commitment to providing utmost support to continue the WPI-AIMEC with JAMSTEC beyond the 10-year funding period (see form5). The AIMEC's decadal plan includes the establishment of a robust collaborative framework in research and administrative aspects, including personnel, administrative structure, research and support system, and joint guidance in higher education programs. In addition, we will support and clarify career paths for young and mid-career researchers by coordinating with the tenure-track systems at Tohoku University and JAMSTEC. Through such integrated system reforms and collaboration between Tohoku University and JAMSTEC, the WPI-AIMEC will develop into a self-sustaining and sustainable entity even after the 10-year grant period, generating powerful synergies that will enhance academic excellence, international higher education, integrated knowledge co-production and mobilization, and sustainability.

August 2024 revised

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Head of host institution 2: Hiroyuki Yamato, President

Prospective center director: Toshio Suga, Professor, Department of Geophysics, Tohoku University
Appendix 1: "Biographical Sketch of Prospective Center Director" (to be attached)
Appendix 2: "Reference (recommendation) for prospective center director by world's distinguished researcher(s) in the center's target field" (to be attached)

Prospective administrative director: Kentaro Ando, Director, JAMSTEC
Appendix 3: "Biographical Sketch of Prospective Administrative Director" (to be attached)

1) Overall Framework of the Center Project

* Cleary and concisely describe your center's mission statement as a WPI center, its identity, and its goals toward achieving the objectives of the WPI program.

The mission of this institute is to answer the primary question:

What are the response and adaptation mechanisms of marine ecosystems to Earth-Human system dynamics?

In the **WPI Advanced Institute for Marine Ecosystem Change (AIMEC)**, we will focus on marine ecosystems, which are poorly understood compared to terrestrial ecosystems, and create and globally lead **"Ocean-Ecosystem Change Systematics (OECS)"** as a new academic field that integrates marine physics, ecology, and mathematical and data science. This will enable a much deeper understanding of ***stability***, ***connectivity***, and ***adaptability*** of marine ecosystems, an endeavor that is essential for establishing sustainability and projecting change. By doing so, we will contribute from the fundamental science standpoint toward realizing the **"regeneration and restoration of the oceans and ecosystems".**

In the current Earth-Human system, humanity has expanded to the point where it significantly impacts all subsystems. Consequently, the effects of global warming, ocean acidification, loss of biodiversity, and collapse of ecosystem functions have already been tangible (see ref. 1 in Appendix 4). As a result, understanding the mechanisms of and predicting change in the Earth-Human system is the most crucial issue for the sustainability of human society and out planet. So far, research and development have progressed to measure and evaluate the current conditions of the various Earth's subsystems in a snapshot manner. Individual and regional studies have also been conducted on how changes in the global environment, including the effects of human activities, affect biodiversity and the functionality of ecosystems. However, **the interlinkages among biotic and abiotic factors and the mechanisms by which bi-directional feedback in changing marine ecosystems alters the global environment and affects human sustainability remain poorly understood**.

To address these globally significant issues, our strategy proposes the utilization of existing big data from satellite and *in-situ* observation networks coupled with the acquisition of new (meta)data corresponding to environmental DNA/RNA (eDNA/RNA), isotope (bio)geochemistry, *ex situ* "culturomics" towards integration and centralization of these data into a repository equipped with a graphical user interface (GUI) permitting users to conduct base-line and predictive assessments using an Artificial Intelligence (AI)-guided search engine and model builder developed by our team. The WPI-AIMEC will bring together leading researchers in the fields of climate physics, ocean physics, ecology, biology, microbiology, isotope (bio)geochemistry, and mathematical and data science, who have been brought together **"under one roof"** to collaborate from the stage of creating basic data sets for integrated research, and to develop scientific interactions on the relationships among data of different natures. At the center's start, taking full advantage of Japan's geographical location, we will focus on the **Northwest Pacific**, which has the greatest temporal and spatial variability in the marine environment and the richest biodiversity worldwide, to conduct effective fusion research. At the same time, by incorporating the option of global deployment into the data integration products created as our research progresses, we will promote international data utilization that transcends the boundaries of the target area and build a WPI alliance that will have a global impact.

To pursue our challenging mission, we will gather *~100* world-class researchers and excellent early carrier researchers under the strong inter-institutional collaboration between **Tohoku University**, **Japan Agency for Marine-Earth Science and Technology (JAMSTEC)** and **the University of Hawai'i at Mānoa** (**Fig. 1**). By linking (1) Tohoku University's basic academic strengths and higher education functions, (2) JAMSTEC's oceanographic research and computing platform functions, and (3) the University of Hawai'i's environmental observation functions, the WPI-AIMEC will effectively implement interdisciplinary research by utilizing the shared open laboratories, international vigorous scientific and educational exchanges. The proposed WPI alliance is unprecedented worldwide as a flexible international marine research center that strategically defines the Northwest Pacific region as a priority ocean area and has a global human resource development function. AIMEC will also collaborate with world-leading researchers from Japan Aerospace Exploration Agency (JAXA), the Scripps Institution of Oceanography (SIO), Massachusetts Institute of Technology (MIT), Alfred Wegener Institute for Polar and Marine Research (AWI), and Nanyang Technological University of Singapore (NTU), and we will also establish a partnership with the Canadian-based global research organization CIFAR to advance fusion research and higher education (**Fig. 1**). Furthermore, the domestic and international public relations, outreach, and digital transformation (DX) functions will be enhanced to provide information to relevant UN agencies and disseminate information to the public in a continuous and effective manner. Through these efforts, we will maximize the synergies created by this international WPI alliance while contributing to **"Planetary Stewardship"**, which will lead the Earth-Human system towards sustainability.

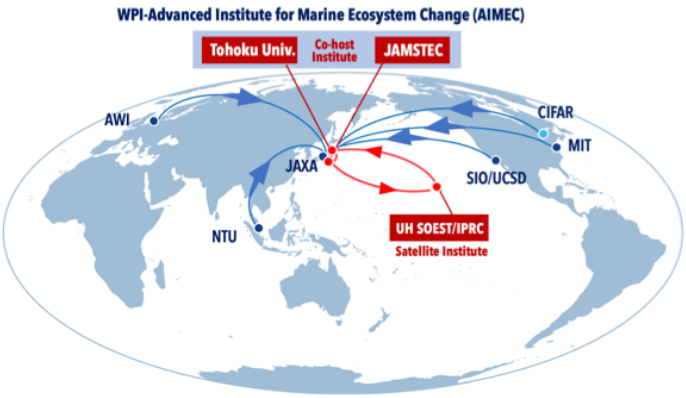


Fig. 1. International networks and partnerships of WPI-AIMEC.

2) World-Leading Scientific Excellence and Recognition

2) -1 Research fields

* Write in your target research field(s)
* Describe the importance of the target research field(s), including the domestic and international R&D trends in that research domain and neighboring field(s), and describe the scientific and/or social significance of the field(s).
* Describe the value of carrying out research in the field(s) as a WPI center (e.g., Japan's advantages in the subject fields, the project's international appeal as an initiative that challenges world-level science issues, and the future prospects of the research)
* List up to 5 centers either in Japan or overseas that are advancing research in fields similar to the center's field(s), and evaluate research levels between your center and those centers.
* Appendix 4: "Up to 10 English-written papers (review papers are also acceptable) closely related to the center's project and their list" (to be attached)

Elucidating and predicting the mechanisms of change in the Earth-Human system, arguably the most critical issue for the sustainability of human society, has been the subject of much research and development, both domestically and internationally. However, measuring and evaluating the current status of the various subsystem elements that make up the Earth-Human system have thus far proceeded in a piecemeal and snapshot fashion, separately rather than in integrated manner. Individual and regional studies have investigated how changes in the global environment, including those stemming from human activities, affect ecosystem diversity and functionality. Nevertheless, our understanding remains limited and partial as to **how macroscopic global environmental changes alter ecosystems through interactions among subsystem elements, including microscopic processes**, and **how ecosystem changes alter the global environment and affect human sustainability**.

The WPI-AIMEC will accelerate our efforts to address these issues by focusing on marine ecosystems, which are overwhelmingly poorly understood compared to terrestrial ecosystems, even though they are responsible for about half of global primary production (i.e., photosynthesis) and their products feed about 80% of all animal life on Earth. Over the past 30 years, the focus area **Northwest Pacific** has become the most advanced region in the world in terms of understanding the actual conditions and mechanisms of changes in the physical environment due to the accumulation of scientific data

and results from several large international joint research projects and, in particular, the World Ocean Circulation Experiment (WOCE), in which Japan has played a significant role. By transdimensionally designating this focus area, we can effectively and efficiently combine data on eDNA/RNA information, isotope (bio)geochemistry, gene expression-level plasticity, and adaptive evolutionary processes, all increasingly being used, with information and intelligence elucidating marine environmental change processes. Our efforts will culminate in the establishment of a new academic field, **"Ocean-Ecosystem Change Systematics (OECS)"**, based on the fusion of cutting-edge marine physics, ecology, and mathematics and data science (but not limited to), and will lead the field worldwide while fostering global human resources.

Major overseas research institutes on marine ecosystem change include the University of Hawai'i at Mãnoa, SIO, MIT, AWI, Earth Observatory of Singapore (EOS) at NTU, and world-reading researchers from these institutes are existing contributors on this WPI-AIMEC initiative. Other choice institutes relevant to this scope include; e.g., the Woods Hole Oceanographic Institution (WHOI), French National Institute for Ocean Science (IFREMER), Helmholtz Centre for Ocean Research Kiel (GEOMAR), Australian Institute of Marine Science (AIMS), and Atmosphere and Ocean Research Institute of the University of Tokyo (AORI), with which we have solid cooperative relationships for enhanced collaborations. These institutes are generally comparable in their respective marine ecology or physics disciplines, despite differences specific to individual research subjects. However, in promoting the transdimensional fusion research centered on the Northwest Pacific to the global environment, **the AIMEC's WPI alliance initiative surpasses other individual research institutes in terms of its collective capacity to conduct leading-edge research and distinguishes itself by establishing an environment to foster systematic fusion research cooperatively, reflecting the scientific excellence of the solid international framework comprising two hosts and a satellite institution.**

2) -2 Research objectives and plans

* Describe in a clear and easy-to-understand manner by the general public the research objectives that your project seeks to achieve by the end of its grant period (in 10 years). In that process, describe what world-level scientific and/or technological issues are sought to be solved, and what will be the expected impact of the scientific advances you aim to achieve on society in the future.
* Describe concretely your research plan to achieve these objectives and any past achievements related to your application.

Theme I: Deciphering Climate-Ocean-Ecosystem Interactions and Regime Shift

Climate phenomena cover a wide range of time scales. Climate fluctuates around its mean in a self-excited oscillations over time scales from a few days to several decades (climate variability). Contrarily, and due to external forcing of the climate system, the mean state itself is also changing on time scales longer than a few decades to astronomical time scales associated with Milankovitch cycles (climate change). Global warming due to human activities is not only associated with climate change but also alters climate variability, and both combined drive the on-going ecosystem degradation and biodiversity crisis (Appendix 4, ref. 1). Accordingly, an insightful grasp of how marine ecosystems respond to global warming is required to forecast and mitigate this crisis.

What is the nature of the present climate-ocean-ecosystem complex and how is the complex integrally linked and driven?

Oceans moderate global warming effects on ecosystems in many ways. Oceans are major determinants of climate variability and climate change, and of their interlinkages. Oceans have a heat capacity of about *1, 000* times greater than that of the atmosphere and store about *50* times more carbon than is present in the atmosphere and, thus, constitute major sinks of anthropogenically released greenhouse gases. In addition, changes in marine ecosystems feed back into the atmosphere and terrestrial ecosystems through material circulation, radiative processes, and changes in food webs and elemental cycling (**Fig. 2**). We tackle these issues by combining advanced monitoring with state-of-the-art data-driven modeling and hypothesis-driven empirical and experimental research in the fields of ocean and climate physics, ecology, (micro)biology (bio)geochemistry, and mathematical and data sciences. **The resulting holistic interpretation will facilitate forecasting and mitigation of latent ecosystem degradation due to global warming and human activities.**

As a critical target of transdisciplinary and integrated research on the response and adaptation mechanisms of marine ecosystems to environmental change, we specifically focus on **"regime shifts"**, which are broad, abrupt, and extensive structural shifts in climate and ecosystems. Currently, detailed mechanisms underlying the regime shifts remain unclear; however, studies suggest that they are considered to result from the linkage between different spatiotemporal scales of variability in the marine environment and the strong non-linear nature of interactions and ecosystem responses.

Understanding the mechanisms of marine ecosystem change through the elucidation of regime shifts is expected to lead to a breakthrough of the understanding of tipping points in Earth-Human system, including global warming, ocean acidification, and anthropogenic nutrient inputs. We believe that a key to understanding global warming impacts on ecosystems and achieving a sustainable Earth-Human system lies in understanding how oceans, climate, and ecosystems, including human societies, are linked at different spatiotemporal scales.

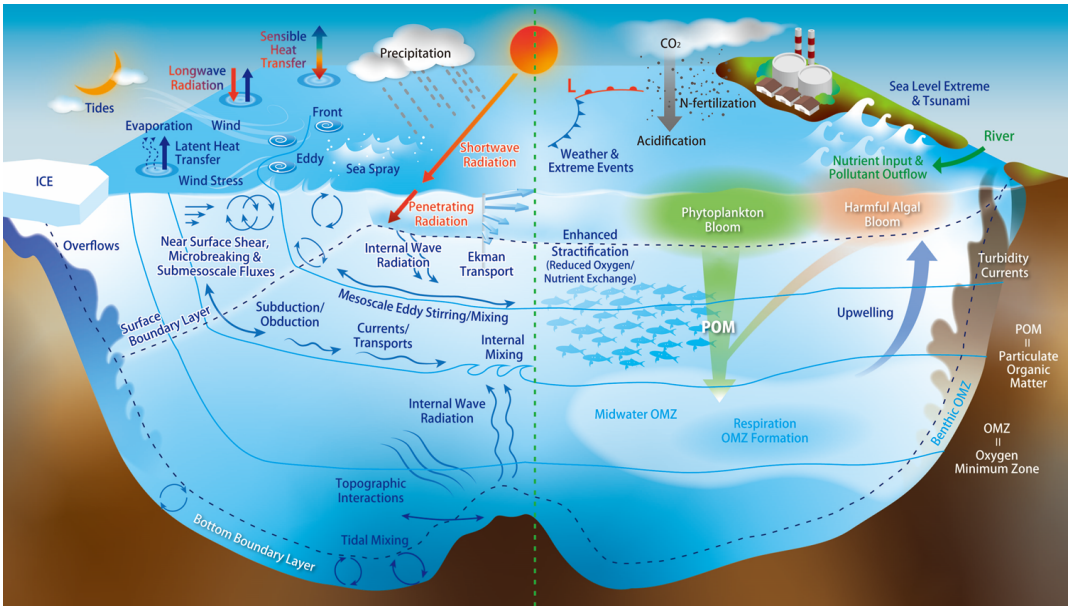


Fig. 2. Climate-ocean physical processes at various scales (left) and marine biogeochemical and ecological processes that are shaped by physical processes and interact with the human societies (right).

I-1. Connectivity and non-linear interactions across spatiotemporal scales of variability

The physical and chemical environments interact with the ocean ecosystem through property distribution and fluxes (**Fig. 2**). A cursory look at snapshots or time series of Northwest Pacific sea-surface temperature or biological variability, for example, chlorophyll measured by the National Aeronautics and Space Administration (NASA)'s MODIS (Moderate Resolution Imaging Spectroradiometer) satellite, reveals variations on a multitude of time and space scales, including the seasonal cycle, the ocean circulation and eddy field, and indications of spatially heterogeneous vertical fluxes. These are forced by the atmosphere and internal ocean dynamics, coupled by non-linear processes, and stirred and mixed by ocean motions. Important time scales are the mean and seasonal cycle, interannual and decadal variations associated with climate models, such as El Niño, the Pacific Decadal Oscillation (PDO), and global change. The underlying physical processes depend on time and spatial scales from basin-wide gyres with strong and narrow western boundary currents, such as the Kuroshio current, ocean mesoscale eddies and fronts, and the submesoscale, ocean waves, and horizontal and three-dimensional turbulence (refs. 1-3 in Appendix 4).

The characterization of the Northwest Pacific physical environment at basin scales has dramatically progressed in recent decades, with great strides made in understanding large-scale and low-frequency variations of the physical environment, including the distribution of upper ocean water masses (Oka & Qiu, J. Oceanogr., 2012; Sugimoto et al, Nature, 2017), El Niño (Timmermann et al., Nature, 2018) and decadal variations such as PDO (ref. 2 in Appendix 4). The current Pacific observing system and advances in coverage and technology expected in the decadal WPI-AIMEC's research activity will enable investigations of processes on eddy scales that have been challenging for decades, interacting with the coupling to the atmosphere in the extratropics, and the coupling of geophysics and biogeochemistry. New satellite missions, long-term station time series, and expansion and new developments of robotic platforms will reveal processes at unprecedented scales and cover new variables. These include proposed concurrent satellite observations of surface currents, winds, air-sea fluxes of heat, and *in situ* observations from fixed and drifting platforms such as the Kuroshio Extension Observatory (Cronin et al., IEEE Systems J., 2008), the Hawai'i Ocean Time Series (HOT; Karl et al., Nat. Rev. Microbiol., 2014), biogeochemical variables of extended Argo array, and observations of eDNA/RNA *in situ* and *ex situ* (see Theme II). The vast and disparate data set will be challenging to characterize, understand and interpret, and an opportunity for deep interdisciplinary collaborations that AIMEC seeks to embrace. We proposed to jointly analyze these unprecedented observations with theory

and high-resolution advanced Earth System Model simulations (ESMs; see Theme III) to investigate Northwest Pacific ecosystem dynamics, considering various processes and spatiotemporal scales (**Fig. 3**). To this end, we will bring to bear the latest insights through our team of experts in ocean physics, ecosystem, and computational approaches.

Coupled physical-ecosystem dynamics combine the complexities of each subsystem. The proposed analyses commence with the basic statistical descriptions, such as linear covariance structure, spectra, and coherences in time and space, then expand to consider nonlinear processes. Two dynamical endpoints are linear responses to stochastic forcing due to the chaotic evolution of atmospheric weather, ocean eddies, and multiple steady states that enable rapid regime shifts, with stochastic, nonlinear processes in between (**Fig. 2**). For example, interannual and decadal variability result from the ocean-atmosphere interactions in different regions coupled by oceanic and atmospheric Rossby waves. Tropical areas, especially the Pacific El Niño phenomenon, take center stage due to the strong coupling of ocean and atmosphere. This process is usefully described to leading order by the ocean and coupled ocean-atmosphere system responses to stochastic forcing and remote forcing associated with El Niño/Southern Oscillation in the low latitude Pacific (Schneider & Cornuelle, J. Climate, 2005). This linear stochastic framework is then expanded to consider nonlinearity. For example, El Niño shows a pronounced seasonal phase locking, with peak variance in boreal winter. This effect is explained by the non-linear interaction between the seasonal cycle and the inter-annual variability (Stuecker et al., PNAS, 2015). The underlying theoretical framework is widely applicable to other such couplings, such as prominent seasonal variations of the Northwest Pacific mixed layer depth and their impacts on variance and spectra of sea surface temperatures and upper ocean biogeochemistry. On a smaller scale, ocean eddies result from instabilities of ocean thermal stratification and current shear, in turn resulting from large-scale forcing by the atmosphere. Variance spreads across scales via non-linear energy and entropy cascades. Through associated sea surface temperature and surface current fields, these ocean eddies and fronts impact the winds resulting in a coupled ocean-atmosphere process. This coupling revealed from satellite-borne scatterometers (Chelton et al., Science, 2004), has been investigated using numerical models and non-local statistics, such as transfer and impulse response functions. These revealed the underlying dynamics as inertial lee wave interacting with sea surface temperature-induced modulation of atmospheric boundary layer vertical mixing and hydrostatic pressures (Schneider, J. Atmos. Sci., 2020; also see ref. 3 in Appendix 4).

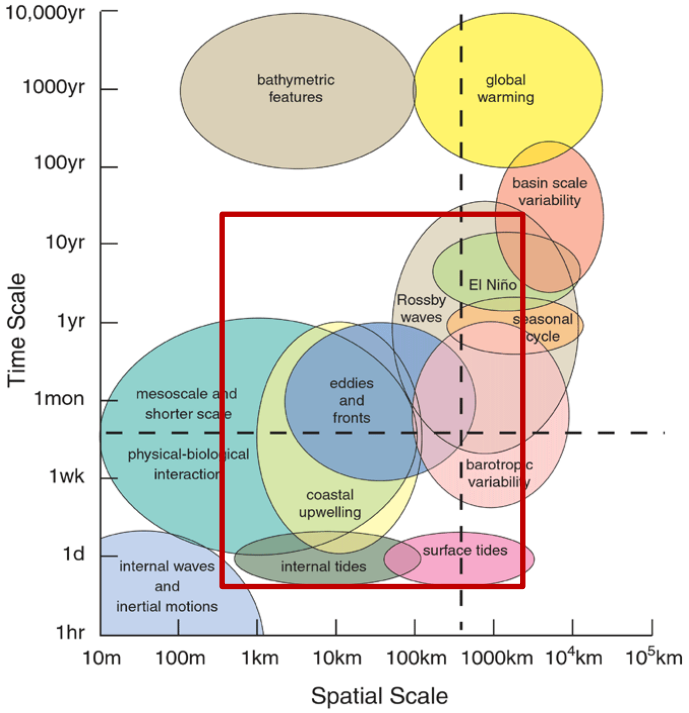


Fig. 3. The multitude of time and space scales of phenomena in the climate system. Time and space scales of oceanic phenomena in the North Pacific, with the red box outlining the approximate scales targeted by the WPI-AIMEC. The simulation of sea surface height (see Fig. 10, Theme III) shows the multitude of spatial scales ranging from entire basins, narrow boundary currents, and fronts to vigorous eddies.

PI Schneider at the University of Hawai‘i has extensively used this suite of analytical techniques which will be employed on existing and new observations of the physical and biogeochemical environment of the Northwest Pacific. We will explore linkages among concurrent satellite observations of ocean color (chlorophyll), sea level (as a measure for surface currents and thermocline depth), sea surface temperature and salinity, and subsurface temperature and salinity observed by the Argo array of drifting buoys. On a larger scale, principal component analysis of ocean color will be used to establish patterns in time and space of the individual variables and across variations. For scales of ocean eddies and fronts, the ocean mesoscale, we will explore linkages through impulse response functions (essentially lagged regressions) in space, and expanded to time lags and relate evolutions of ocean color, temperature and salinity to the ocean eddy field and thermocline depth, as indexed by sea surface height. Conditioning the analysis will identify the dependence on wind speeds, as a measure

for ocean mixing, and start to explore nonlinear modifications. Similar approaches can be used to relate ocean time series of surface fluxes at the Kuroshio Extension Observatory and the Hawai'i Ocean Time (HOT) Series to surrounding sea surface temperature, sea level and surface winds, to explore connections between the ocean mesoscale and the atmosphere. These analyses will be expanded to AI-driven techniques, such as neural nets, applied to new subsurface biogeochemistry observations and compared with the output of advanced Earth System Models (ESM: see Theme III). Formulating hypotheses, selecting techniques, and interpreting will take full advantage of the AIMEC collaborations and exchanges between experts in ocean physics, ecology, and data sciences.

I-2. Exploring the missing link in marine ecosystems through advanced biogeochemical (BGC) Argo and seafloor-cable observations

The Northwest Pacific is one of the most well-studied areas in the world ocean, regarding the upper ocean physical environment and its seasonal to interannual/decadal variability interacting with the atmosphere. For example, in its subtropical gyre and the subtropical-subarctic transition zone, Subtropical Mode Water, Central Mode Water (STMW), and Transition Region Mode Water are dominant upper ocean water masses, which have been well documented in terms of their seasonal evolution and interannual-to-decadal variability (Suga et al., J. Phys. Oceanogr., 2004; Toyama et al, J. Phys. Oeanogr., 2015). These mode waters characterize density stratification between the surface mixed layer and the permanent pycnocline and, therefore, likely control nutrient supply to the euphotic zone (**Fig. 4**: Sukigara et al., J. Oceanogr., 2013).

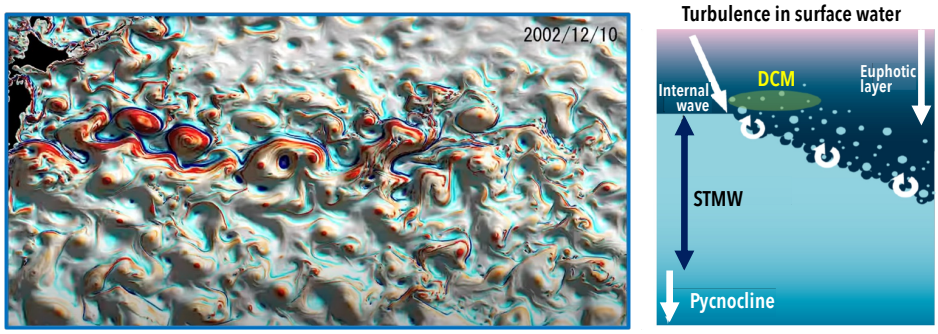


Fig. 4. Ocean eddies in the Kuroshio Extension region reproduced by a high-resolution ocean model by JAMSTEC (left). Eddies modulate mixing processes, which transfer nutrients from the subsurface layer (STMW) to the surface layer (euphotic layer). Wind-induced internal wave energy is a source of vertical mixing, which causes upward nutrient flux and maintains deep chlorophyll maximum (DCM) (right).

We will use a physical basis to conduct super-multiparameter high-frequency time-series measurements at several focused sites representing tropics, subtropics, subpolar, and their transition regions. Temporal variations in biogeochemical and biological parameters will be relatively easy compared to known physical environmental variability. The time-series measurements will accompany additional ad hoc observations, including an underwater vison profiler (UVP: see **Fig. 5**), autonomous underwater vehicle (AUV) or research/commercial vessel-based innovative eDNA/RNA sampling from the sea-surface down to the seafloor sediment. PI Ohta will utilize bottom pressure measurements along sea cables to depict high-resolution ocean flow fields near the coasts that are not resolved by traditional satellite measurements. All the data will be analyzed by a transdisciplinary team with various methods, from traditional time-series/statistical analyses to AI-based innovative techniques with broad-scale observation data by existing *in situ* (including advanced BGC Argo: **Fig. 5**) and satellite observation networks.

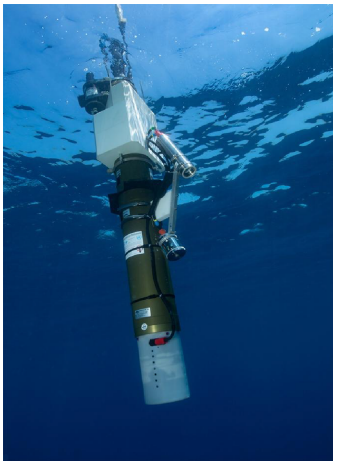


Fig. 5. Biogeochemical (BGC) profiling float with a UVP (underwater vision profiler) measuring vertical profiles of sinking particles and plankton species.

I-3. Understanding of "regime shift" mechanisms

Many complicated and non-linear interactions among the various spatial and temporal time scales and the variables (see **Figs. 2, 3**) can cause an abrupt change from one stable state to another in the climate system, which is called a **"regime shift"** (Lorentz, Qua tern. Res., 1976). The Atlantic Meridional Overturning Circulation, closely related to the global ocean circulation and thus to the global climate, moves back and forth between distinct stable states with the stochastic forcing of freshwater input/transport (Stommel, Tellus, 1961). During the past century, the North Pacific surface temperature has experienced several regime shifts, with a warming in 1945/46 and a cooling in 1976/77 (Yasunaka & Hanawa, JMSJ, 2002). Because ecosystems are more strongly non-linear than physical circulation, regime shifts in the ecosystem are more drastic.

In fact, the fish caught in the North Pacific can be 10 or 100 times larger/smaller depending on the decadal-scale variation in the marine environment (Yatsu, Fisheries Sci., 2019). Furthermore, global warming and human impact would not only act as the forcing to induce the regime shifts but also change the stable states themselves. For example, global warming intensifies ocean stratification and prevents mixing, which results in nutrient depletion near the surface and deoxygenation deeper down (Keeling et al., Annu. Rev. Mar. Sci., 2010; Yasunaka et al., GRL, 2016). However, the explicit mechanisms underlying regime shifts, especially in the biogeochemical states and ecosystems, remains unclear. Equally unresolved are the linkages among climate, physical circulation, and ecosystems also remain elusive.

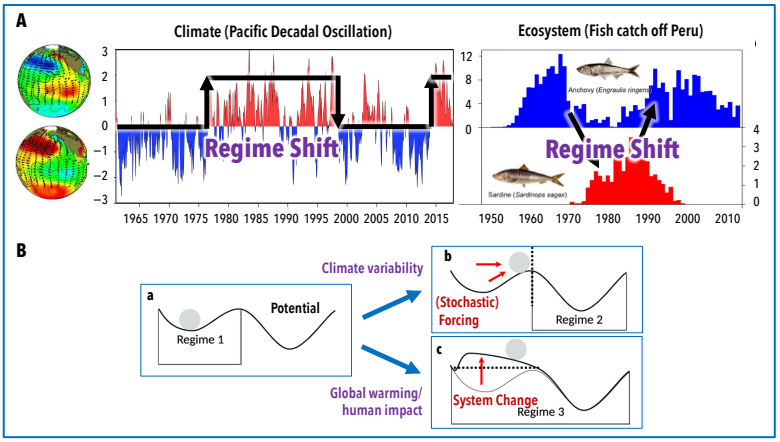


Fig. 6. Examples of "regime shifts" in climate systems and ecosystems (**A**) and their mechanisms (**B**). Each regime is considered stable at the minimum of the potential field. Stochastic climate forcing can shift the state to another regime centered on another minimum (**a→b**). Climate change/human impact may change the potential field, creating a new regime and forcing the state into another regime (**a→c**).

WPI-AIMEC aims to achieve an integrated understanding of climate, physical and biogeochemical ocean environment, and marine ecosystem regime shifts to contribute to the **"regeneration and recovery of oceans and ecosystems"**. By integrating data obtained by the innovative observation technologies, such as advanced BGC-Argo floats, super high-resolution satellite images, and eDNA/RNA analyses (Theme II) with numerical models (Theme III), we will elucidate details of the stable states in the climate and ecosystem, and the particulars of past and/or latent regime shifts. The proposed advanced ESMs (see Theme III) will also reveal how future global warming will alter the regime shifts and stable states. Careful bias adjustment and quality assessment will be conducted from the expert's point of view for the observations and models, which produce data of very different quality and resolution. Subsequently, a combination of machine learning (CPU) and/or deep learning (GPU) techniques (AI) will be implemented to make linear, non-linear, or complex correlations from data sets to achieve specific tasks.

Theme II: Ecosystem Response, Adaptation, and Evolution Mechanisms to Environmental Changes

Ecosystems provide a wide range of essential services for supporting human well-being. Considering only the economic aspect, it has been estimated that approximately 50% of the world's Gross Domestic Product (GDP) relies on nature. Based on the Organization for Economic Cooperation and Development (OECD)'s Ocean Economy Database, the ocean economy's output for 2010 (as the base year) has been estimated at 1.5 trillion US Dollars and projected to potentially double by 2030, with the value-added contributions of aquaculture and capture fisheries projected to grow even faster than the world economy overall. Healthy ecosystems are thus regarded as critical natural capital for society's development and survival. However, biodiversity is declining, and ecosystem functions are deteriorating due to global climate change and increasing human activities. With natural capital decreasing by 20% over the past two decades, the World Economic Forum has highlighted that challenges to restoring and conserving biodiversity to achieve maximum sustainable utilization of ecosystems are among the most significant societal issues confronting humanity today.

Achieving efficient restoration, conservation, and sustainable utilization of ecosystems necessitates a much deeper scientific comprehension of ecosystems, which embody natural capital in their structure, functions, and interrelationships. Comprehending the determinants (interlinkages) and limits of ecological responses is vital for assessing adaptability and resilience toward mitigating disruption or loss of ecosystem functions in response to environmental disturbances. This scientific endeavor is crucial for grasping the intricacies of global changes in the marine environment.

Ecosystems are dynamic systems propelled by condition-dependent interactions that are non-linear and involve countless interlinking biotic and abiotic elements. The environmental responses and adaptability of ecosystems result from at least three distinct mechanisms operating at different biological levels:

1. The organism (individual), a biological unit with a degree of independence and integration: Individuals change their traits and acclimate to the environment via physiological responses, such as exhibiting changes in gene expression and protein synthesis in response to environmental factors.
2. The population, a collection of individuals of the same species: Populations of multiple individuals with different gene sets change the population-level traits through an evolutionary process involving changes in gene frequency in response to environmental changes, thereby adapting to the changing environment.
3. The community composed of multiple species: Changes in community composition are believed to sustain ecosystem-level functions, such as material production under environmental variability.

Moreover, adaptive responses at each of these three levels alter interactions, changing ecosystem structure at other levels and impacting overall ecosystem functions. For instance, acclimation at the individual level (phenotypic plasticity) changes the selection pressure on individual genes, affecting the evolution of the population and community levels. Evolutionary changes in the traits of a species affect the dynamics and structure of communities, by altering interspecific interactions. To comprehend how ecosystems respond to changing environments, it is crucial to fully understand the relevant mechanisms at the individual, population, and community levels, as well as their interrelationships.

Theme II aims to scientifically elucidate the processes by which ecosystems respond and adapt to environmental changes by assembling a multi-disciplinary team of researchers who will coordinate the application of an unprecedented combination of leading-edge theoretical and empirical approaches to understand interconnectivity within marine ecosystems.

II-1. Discovery-based approach using large-scale data

The hallmark of this project is its data-driven methodology that employs extensive large-scale data on both biotic and abiotic elements. Marine ecosystems are vast and intricate systems, lacking fundamental equations to explain their dynamics. Consequently, this research will require a model-free approach, which does not presuppose the existence of *a priori* equations, applied to big data (large-scale data of high quality and in large quantity) to elucidate both their intricacy and plasticity.

To attain this goal, the project integrates data derived from monitoring different abiotic and biotic factors into a standardized data repository equipped with tools and a public user interface. These efforts promise to fill a significant gap in the scientific community in terms of basic research, applications that address changing coasts, and educational/training opportunities. Some examples of publicly available relevant data include those measuring:

1. Physical and chemical parameters (e.g., light, nutrients, temperature, salinity, turbulence) to assess ecological niches and 3D spaces;
2. Bio-indicators of the ecosystem threats at various levels (primary productivity of carbon and oxygen, light energy absorbed by primary producers (chlorophyll), biomass);
3. Bio-monitors of ecosystem sustainability (biodiversity, growth and maturity of species, gene expression (individual), gene frequency (population)).

Based on the projected comprehensive repository, the project seeks to establish condition-dependent correlations and causations between and among fluctuating abiotic and biotic parameters. This approach deviates significantly from the traditional method, which tries to parameterize a model based on limited data quantities and frequently unsupported assumptions. This discovery-based approach aims to uncover ecological principles, such as how complexity and resilience generate environmental responsiveness and adaptability and the general patterns that emerge as a result.

A key contribution to understanding how marine ecosystems respond to environmental changes has been made by PIs Kondoh, Obayashi, and Inagaki using biodiversity monitoring based on environmental DNA (eDNA; refs. 7-9 in Appendix 4). eDNA is a rapidly developing technique that enables the surveying of organismal distributions, relative biomass, and diversity at spatiotemporal scales and taxonomic resolutions not possible with conventional survey methods relying on species capture. For example, PI Kondoh established the eDNA-based biodiversity observation network ANEMONE (All Nippon eDNA Monitoring Network) in 2019 through collaboration with industry and local governments. This network spans *>77* stations, involves *>200* citizen volunteers, and continues to expand annually (ref. 8 in Appendix 4; **Fig. 7**). An ecosystem is a system in which species that are living in different temporal or spatial scales coexist and interact with each other and their environment. If climate variability and climate change overlap and fluctuate at various spatiotemporal scales, ranging from a few days to several decades, from kilometer to global scale, the responses would vary between and among

species. Also, a change caused to a species is transmitted to other coexisting species via diverse interspecific interactions, such as prey-predator and competitive ones, to shape the entire system's responses at varying scales.

New technologies often lead to new discoveries. Building on the existing concept of nucleotide and protein sequence repositories (e.g., GenBank, UniProt), we will build a central global repository for eDNA (including eRNA) sequence data for which there is currently no single repository public access and analysis. Our team has strengths in developing new rapid aquatic eDNA and eRNA detection kits (PI Ames, National Science Foundation [NSF]-funded international project; PI Kondoh ANEMONE DB project) that can be deployed by students and "community scientists" (i.e., via public outreach and educational programs, K-12 and undergraduate) to generate base-line assessments of biodiversity and functional ecology and add to global databases and repositories. The bulk of the initial eDNA data for Japan can be sourced from the ANEMONE database (**Fig. 7**) and a multitude of other repositories (e.g., GitHub) either through APIs or direct networking (NCBI), as well as from fieldwork conducted at the WPI-AIMEC. This central repository will be networked into a portal with a public user interface for personalized analysis that is updated in real-time, with ongoing data accession, to conduct analyses and predictions of biotic and abiotic interlinkages (**Fig. 8**). The basic service (such as analysis, predictions of distributions and interconnections, visualization, and mapping) will be free to the public and educational/research facilities, and offered as a paid plan to businesses desiring advanced access. The wealth of data amassed through public sources and generated *in situ* and *in vitro* (i.e., **"culturomics"**; see **Fig. 8**) at AIMEC and by our partners will provide the basis for theoretical modeling of eco-physiology and ecological interactions developed by PIs Smith and Kondoh. In addition, PI Smith has extensive experience developing and applying models of plankton eco-physiology (reviewed by Smith et al., Limnol. Oceanogr., 2011) and development and testing of algorithms/equations suitable for advanced ESMs (see Theme III).

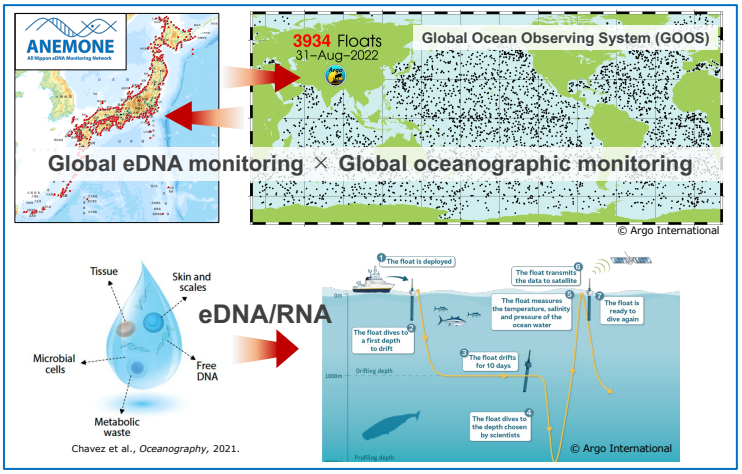


Fig. 7. Big data from Argo (physical and biogeochemical observations) and eDNA/RNA (including ANEMONE and its extension to the global ocean) will be analyzed in an integrated manner to clarify the climate-ocean-ecosystem complex and its dynamics. The bottom left figure components are modified from Chavez et al., *Oceanography*, 2021.

The integration of eDNA/RNA-based monitoring to the open ocean, and enabling these data to be linked to the Argo-based oceanographic parameters (see Theme I) offers a tractable method to decipher **how ecosystem and climate-ocean components are interrelated and what patterns emerge from their interrelations**. Consequently, the "big data" nature of our proposed basic research necessitates expertise in AI and machine learning skills. JAMSTEC and Tohoku University are equipped with High-Performance Computer Cluster facilities to efficiently perform tasks (assisted or unassisted) vast data sets to identify patterns and make confident predictions, requiring analytical, computational, and data storage capacity. Ultimately, data assimilation led by PIs Kawamiya and Koketsu will permit model parameterization optimization and testing of models for an advanced Earth-Human system, generating inaugural high-resolution models of the Northwest Pacific and consistent monitoring of ecosystem variability (see Theme III).

II-2. Integration of species-oriented and location-oriented approaches

Ecological theory provides explanations and predictions of observed patterns in the interactions between individuals with distinct physiological characteristics and between species with different traits, in response to environmental fluctuations, across different biological hierarchies such as individuals, populations, and communities. For example, the relationship between ecosystem complexity (often evaluated by the number of elements and density of interactions) and dynamic stability is a major unresolved topic in ecology, which is strongly related to catastrophes and regime shifts. Many open questions also remain as to the time and spatial mechanisms by which biodiversity enhances ecosystem functioning. It is noted that over the past 20 years, several mechanisms have been hypothesized (e.g., for phytoplankton communities in the North Pacific; Chen et al., Ecol. Lett., 2019). However, most studies have focused on either species or functional diversity, leaving the interaction between genetic diversity and physiological complexity within species, and their influence on ecosystem functioning, and their interactions with biogeochemistry, still largely unknown. Although multifaceted ecosystem function (e.g., considering simultaneously production, trophic transfer, and carbon sequestration) is a critical

feature, few studies have evaluated the relationships between multiple functions and biodiversity. Thus, it is essential to analyze data on all biological hierarchies and environmental data comprehensively to update ecological theory.

To achieve this goal, we propose to revolutionize our understanding of marine ecology and resource management by establishing a large-scale marine genomic database built on the integration of state-of-the-art metabarcoding technologies (encompassing eDNA/RNA) and long-read metagenomics "skimming" (Nanopore technology). By creating a common foundation for species ecology and community ecology from this rich trove of genomic data, we will deepen our understanding of marine environments and open new paths to sustainable marine resource management. Metabarcoding of molecular samples from the environment as a novel approach to studying geophysical ecology will allow for the detection of species present in the ecological niche of a target physical environmental space. This eDNA/RNA and **"culturomics"** technologies, when paired with isotope (bio)geochemistry analyses (e.g., hydrogen, carbon, nitrogen, oxygen, iron), offer a high-spatiotemporal resolution, while the integration of long-read metagenomics introduces the possibility of determining the whole genomes of marine species within these environments (**Fig. 8**). We aim to build a large-scale marine database based on marine samples and high-throughput sequencing technologies.

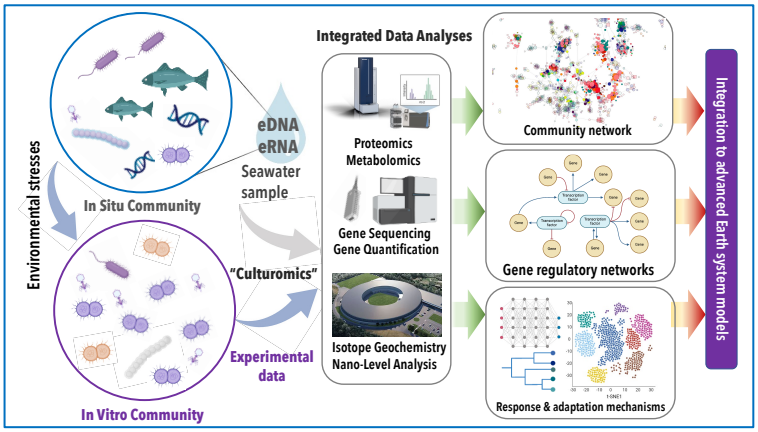


Fig. 8. Integrated physico-ecological approaches with eDNA/RNA samples.

This proposed database that includes accessioning of high accuracy genomes "skimmed" from long-read sequencing of metagenomic samples will be powerful for two primary reasons. First, individual genomes contain rich information about kinship, allowing for the accurate estimation of degrees of genetic relationships among individuals, which can illuminate spatiotemporal dynamics of marine species across generations. Second, whole genomes encompass all genetic information of a species, and in combination with gene network analysis, can help to elucidate the ecological significance of minor mutations scattered throughout the genome (i.e., network genome-wide association studies [GWAS]). This proposed repository facilitates estimates of the ecological functions of regional differences within target species and derive environmental conditions acting as selective pressures in different regions by comparing the whole genomes of population groups from numerous locations.

Spontaneous ecosystem changes represented by **"regime shifts"** (**Fig. 6**; see Theme I) are challenging to predict; however, a system nearing the brink of major change may present **"warning signals"**, e.g., change in community structure or slow recovery from small perturbations. Coastal ecosystems bearing tell-tale signs of loss of resilience due to unprecedented acute or long-term stresses are priority areas to tackle. From the perspective of biota, human activities along coasts are linked to a reduction in the abundance of endemic species, i.e., possible extirpation/extinction of key species (ref. 5 in Appendix 4). While alterations in biodiversity (variety of species) are considered significant signs of stress, changes in the abundance of endemics (local species) shift the balance of coastal ecosystems, leading to interruption and destabilization of ecosystem functioning. Marine-derived eDNA/RNA represents a **"barometer of disturbance"** given its potential to assess anthropogenic effects on ecosystems (refs. 8-9). By integrating legacy data from traditional marine censuses with molecular data from a combined use of eDNA/RNA, biogeochemistry, and culturomics approaches, both pre- and post-disaster, e.g., the Deepwater Horizon oil spill disaster in 2010 (Nizinski & Ames, U.S. Geological Survey Open-File Report, 2012) and Tohoku Great East Earthquake and Tsunami in 2011 (Adriansyah, Hydrobiology, 2022), we have been able to assess baseline biodiversity and endemism on local scales.

Linking each molecular data type with the evolutionary pressures exerted by environmental conditions creates further value. This opens the way for enhanced exploration of functional genes and functional species, with potential applications ranging from the discovery of organisms for environmental restoration and recovery. Subsequently, **WPI-AIMEC will merge vast whole-genome-based (species- and/or community-level) ecological studies to promote the analysis of interdependencies between marine communities and marine physicochemical parameters.**

II-3. Advancing practical ecology: Developing sustainable ecosystem management techniques

The primary goal of this sub-theme is to advance practical ecology by leveraging knowledge gained from investigation

into marine and coastal ecosystems. The marine realm is critical to the wellbeing of humankind, and there is a pressing need to develop sustainable ecosystem management techniques (ref. 1). However, large-scale ecosystem assessment, prediction, and control have not been successfully implemented in the Northwest Pacific (refs. 4 and 6 in Appendix 4). This shortcoming in practical ecology can be attributed to the complexity of ecosystems and the human activity within them, which are both vast and poorly understood. Moreover, critical variables remain obscure, precluding scientists' ability to predict environmental responses accurately, promote natural regeneration, or increase **"ecosystem use"** value. Fortunately, there is great scientific potential in developing control theory to predict ecosystem responses, forecast the future of the target ecosystem, and assist in promoting natural regeneration. The primary aims of this sub-theme are:

1. To leverage large-scale ecological data and advanced machine learning techniques to develop more scalable and accurate methodologies for processing ecological data. The project seeks to establish a two-way causal link between human activities and ecosystems, with a long-term emphasis on assessing feedback between human socio-economic activities and ecosystem services, as mediated by biodiversity and ecological complexity;
2. To develop practical ecosystem change prediction models to forecast negative events, including harmful algal blooms linked to shellfish poisoning, jellyfish swarms causing human envenomation, and rapid detection systems for fisheries species. By enhancing the ability to predict such ecological responses, this research will help to mitigate business risks associated with complex ecosystem fluctuations and increase the value of natural capital industries, such as fisheries; and
3. To display the aptitude to implement ecosystem control technologies that can direct ecosystems towards more desirable conditions, ultimately promoting natural regeneration.

For example, seafood provides 19% of the global population's animal protein, but overfishing, inequality and lack of sustainable practices threaten fisheries resources, ecosystems and human well-being (FAO, 2020). Through collaborations with Tohoku fishing coops PI Ames deploys mobile eDNA kits (Ames et al., Front. Mar. Sci., 2021) to identify species at the source, and genomic tools to assess stock abundance and dynamics thus addressing concurrent global challenges of marine bioresource conservation, food security, and sustainable fisheries for a **"Blue Economy"**. These new interdisciplinary technologies, as well as novel sampling and experimental opportunities coupled with the advanced ESM will be developed and introduced for further discovery in this WPI-AIMEC initiative.

This new and important research activity is in line with the objectives of the "**Task Force on Nature-related Financial Disclosures (TNFD)"** mechanism. The TNFD aims to encourage businesses to operate in a nature-positive manner by disclosing information about the risks and opportunities associated with their activities based on a scientific evaluation of their positive and negative impacts on the environment. This project's goal of advancing practical ecology will contribute to sustainable ecosystem use, environmental protection, and the enhancement of economic activities that rely on natural capital. By promoting sustainable practices that balance economic growth with environmental protection, this project will support the objectives of the TNFD mechanism.

Theme III: Projection of Marine Ecosystem Changes

Theme III addresses the understanding and prediction of the ocean using numerical models as tools. Breaking away from conventional ecosystem models that tend to focus on the species composition of marine lower-order ecosystems, we will develop a novel ecosystem model that focuses upon key traits and ecosystem functions for the ocean biogeochemical cycles, as obtained from eDNA/RNA, isotope (bio)geochemistry, and culturomics approaches (Theme II). This will contribute to the interpretation of observation data, construction of observation networks, and the projection of future changes **(Fig. 9**).

III-1. Development of the advanced Earth System Models (ESMs)

A quantitative perspective on the relationship between ocean environmental changes and productivity is becoming increasingly important. For example, the recent spate of poor catches of Pacific saury has been attributed to the occurrence of warm water masses off the Sanriku coast, and there are concerns about the effects of global warming as a background. However, the details have not yet been clarified on how such environmental changes affect the planktonic growth and other dietary conditions, the environment for the growth and migration of saury itself, leading to changes in catches. It is also unclear which of these changes in the marine environment are long-term trends caused by anthropogenic climate change or short-term events that occur within the range of natural variabilities.

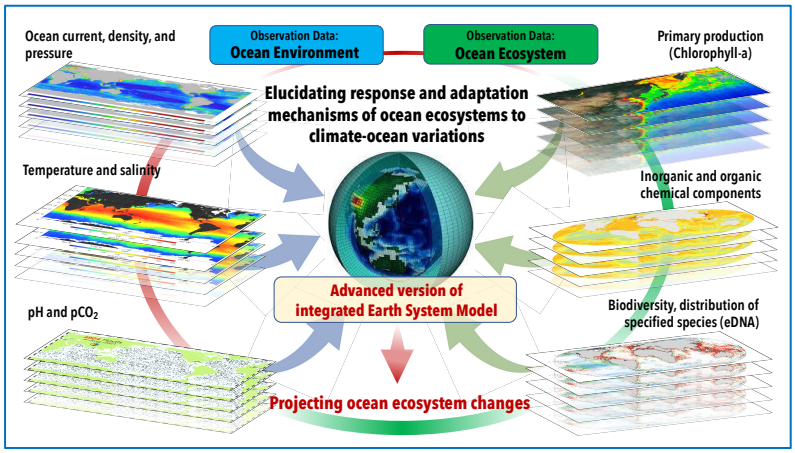


Fig. 9. Conceptual diagram of Theme 3. Diverse classes of data ranging from satellite and ship observations to in-vitro data, covering physical, chemical and biological properties of the ocean, are utilized to develop a novel type of an Earth System Model (ESM). The ESM is then applied to project the future of the ocean. The data considered include those obtained from eDNA studies so the ESM can accommodate functional aspects of the ocean ecosystem rather than its details of species composition.

It is essential to understand and predict how the marine ecosystems are affected for their maintenance and changes in productivity by disturbances in the physical environment, such as the generations and changes in mesoscale eddies found not only off Sanriku but also throughout the ocean, typhoons and ocean heat waves that have been occurring frequently in recent years, and the Madden-Julian Oscillation (MJO, a group of giant cumulus clouds with horizontal scales of several thousand kilometers that occur mainly in the Indian Ocean and move eastward). Comprehension of the mechanisms behind this would lead to confident prediction of relevant changes and, thereby, help society enjoy the bounty of the ocean and to further enrich our lives in the future. Furthermore, in clarifying the feedback of the cycling and emissions of various greenhouse gases (CO_2, CH_4, N_2O, etc.) and aerosols that are exchanged with the atmosphere mediated by the ocean ecosystems we will respond to this urgent issue for maintaining a favorable global environment, the common foundation of human existence.

To address these issues, WPI-AIMEC adopts the tools of a high-resolution ocean general circulation model (OGCM) and an Earth System Model (ESM), the latter of which is a climate model that includes both land and sea ecosystems (ref. 10). Although an OGCM with a sufficiently high resolution to represent short-term physical disturbances requires huge computing power to cover a wide-enough area of the ocean, recent advances in high-performance computing have made it possible to perform such simulations over a long timescale. JAMSTEC has developed an OGCM with a horizontal resolution of 0.1° (approximately 10 km) for the global ocean that resolves mesoscale eddies, which operates on the Earth Simulator, a supercomputer run by JAMSTEC (**Fig. 10**).

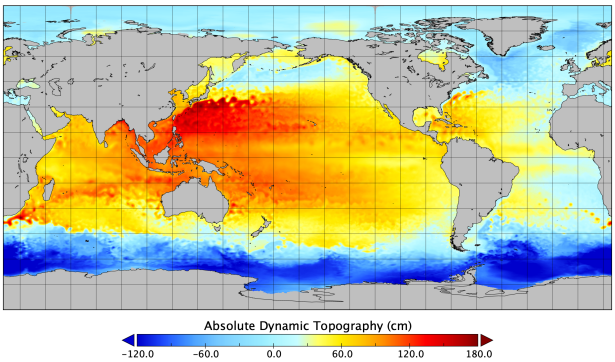


Fig. 10. Sea surface height distribution reproduced by an ocean general circulation model with 0.1° (about 10 km) resolution over the entire ocean.

By incorporating the latest marine ecosystem module into such a high-resolution OGCM and coupling it with an atmospheric model to create an ESM as needed, a comprehensive understanding of the physical environment and ecosystem of the ocean and their relationships with biogeochemical cycles becomes possible (**Fig. 9**; ref. 10 in Appendix 4). Previous ocean ecosystem models, have typically assumed a constant (empirically-based) elemental composition ratio for both zooplankton and phytoplankton, called the Redfield ratio. However, it has become clear in recent years that assuming a constant composition for plankton under-estimates observed variability, and it is only by considering the dynamics of phytoplankton composition that we can understand fundamental features in ocean ecosystems such as phytoplankton distributions (Masuda et al., Commun. Earth & Environ., 2021) and the closely related cycling of nutrients and carbon in the ocean (Masuda et al., Limnol. Oceanogr. Lett., 2023).

PI Smith and PIs at other international research institutes have developed a novel ocean ecosystem model that considers the variability of the Redfield ratio and shown that it agrees with the global scale pattern of oceanic chlorophyll observations (**Fig. 11**). This model also captures observed variations in the C:N ratio of oceanic phytoplankton, which is a key biogeochemical parameter linking phytoplankton and the ocean carbon cycle (Masuda et al., Limnol. Oceanogr. Lett., 2023), and as such it has the potential to improve the way that large scale models represent the biological uptake of CO_2 and the

storage of carbon. However, attempts to apply the OGCM coupled with such an ecosystem model on a large spatial scale and understand the functional aspects controlling the biogeochemical cycles, productivity, and their variations from a global perspective are not yet complete. In this regard, further progress can be expected by incorporating the connectivity among variables in Theme I and information from studies based on eDNA/RNA and culturomics (Theme II), which has been rapidly developing in recent years as addressed in Theme II, into the model using AI machine learning techniques (see III-3). To achieve the major goal of understanding the factors and dynamics replenishing the ocean, the reproducibility of the high-resolution OGCM under development should be further improved, and OGCM and ESM equipped with a state-of-the-art marine ecosystem module will be used as tools to elucidate climate-ocean-ecosystem system changes, the subject of Theme I.

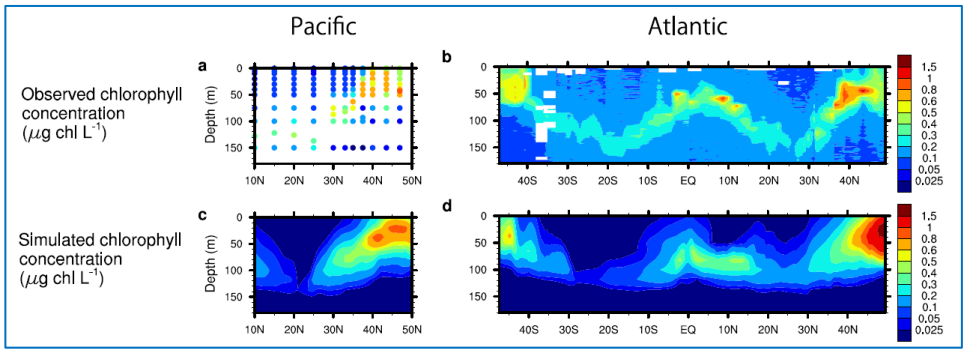


Fig. 11. Comparison of observed (**a**, **b**) and simulated (**c**, **d**) surface chlorophyll concentrations in the North Pacific (**a**, **c**) and Atlantic (**b**, **d**) (Masuda et al., Commun. Earth & Environ., 2021). The simulation results are from the FlexPFT model (Smith et al. J. Plankton Res., 2016) embedded in a coarse (1-degree horizontal) resolution ocean model considers variable Redfield ratio and captures the large scale pattern of subsurface chlorophyll maxima as observed in the ocean. More recently, preliminary coupling of the FlexPFT model with higher resolution ocean models has already shown the potential for even better reproduction of observed patterns (Masuda et al., personal communication).

III-2. Verification of consistency between real and virtual digital spheres

Data assimilation methods are used to integrate actual observation data with the system developed under this project to understand the real changes and to evaluate its functionality as a common research tool for the community of the project. It is known that numerical models that combine a high-resolution ocean circulation model with an ocean ecosystem model may reproduce many strong non-linear phenomena and that data assimilation is difficult (e.g., Forget et al., Ocean Sci., 2015; Park e al., Earth Syst., 2018).

Ultimately, the ESM that solves for the Earth's state using the outer boundary to be set at the top of the atmosphere (ref. 10) is necessary to represent phenomena more fully than in an individual system (experimenting only with the ocean circulation model), because biases that exist in the model with reality cannot be imposed on the boundaries within other systems. The key to resolving this lies in the improvement of the ESM itself (Moore et al, Front. Mar. Sci., 2019). In Theme III, we especially focus on the coupling of ecosystems and marine environments to evaluate whether parameterization focusing on the functions of ecosystems on material cycles can efficiently reduce the bias of marine ecosystem models and material cycle models with respect to real ocean, and to find optimal parameters that can reduce the bias. This will improve the reliability of the earth system model prediction.

Another major challenge in data integration is to assimilate data in a way that adequately handles non-linearities in the system. Most modern data assimilation methods assume linearity only in a narrow frequency band and simple statistical relationships between model results and observations, and it is not clear whether they can adequately handle a wide frequency-band of nonlinear phenomena, such as those addressed in this research project. For methods that handle the inherent nonlinearity in the data, one should incorporate mathematical findings in collaboration with mathematical scientists. For example, data assimilation using path-signature transformation, which is currently underway in the EDDA project under JST AIP Trilateral AI Research (Grant number JPMJCR20G5), can be used to utilize information on nonlinearities inherent in observed data for data assimilation in this area. Path signature transformations are a powerful method in that they represent the features of the series data without losing their nonlinearity and can represent the non-linear function of the original path by the path signatures' linear combination. This can be also applied to machine learning methods in Themes I and II. Another approach is to incorporate transformations/functions using neural networks (deep learning) and other methods used in the research field of AI into data assimilation (Storto et al., Mon. Weath. Rev., 2021), which can model complex function forms in parameterizations to represent the actual relationships in the system while preserving the degree of freedom of their forms. Again, this approach can be adapted from the machine learning methods used in other

themes. Starting from the current cutting-edge methodologies, we will further establish a more robust method and explore its application to complex models by conducting large iterations and ensemble experiments, as is done in machine learning, using ideal and comparative models.

More practically, the initial phase of this study will use both 1) a relatively low-resolution system that is good at reproducing long-term variability and 2) a high-resolution model that reproduces coastal variability and requires high-frequency, high-density observations to integrate data, observations, and theoretical considerations for wide-area application, forecasting, and experiments will be conducted.

By using a relatively low-resolution (1-0.25° model), we will reproduce the decadal variability on a 100-year scale and conduct experiments that match the phases of real-world phenomena (Theme I). We have successfully estimated physical and well-known geochemical parameters to meet observations (Osafune et al., Ocean Model., 2022; Doi et al., JAMES, 2015), and in this study, will incorporate parameterization to quantitatively new reproduce the climate and ecosystem variability assumed from past ecosystem changes. We will work to reproduce real ocean by only changing parameters within this model. This allows us to evaluate the optimal values and reliability of the key parameters (suggested in Theme II) in the parameterization focused on ecosystem functions from the perspective of wide-area data. The key parameters themselves represent the essence of ecosystem diversity and merit comparison with those (Theme II) as parameter estimates for the global ocean ecosystem consistent with broader observations through the model. In addition, the key parameters will be used for future projections and retrospective experiments to clarify the relationship between ecosystems and environmental change more generally in the global environment. In particular, large regime shifts that are estimated to have occurred in the past or are predicted to occur in the future can be used to study the prediction of ecosystem change.

Furthermore, models that reproduce coastal changes at high resolution can be used to evaluate how coastal ecosystems change as a result of inflow to ocean coasts, primarily from rivers, using the results of the comparative low-resolution model described above (ref. 4). As the part of coastal water is distributed broadly, it is also important to understand the broad influences in the ocean. To ensure data integration using higher-resolution models, substantial high-density data is required. In addition to primary, high-density data such as satellite data, AI-based spatial mapping information obtained through Theme I can be used as secondary observation data to accumulate knowledge in this area and test whether it can function as a social infrastructure by conducting biodiversity assessment targeting specific coastal areas (ref. 6). In both cases, it is important to successfully handle non-linearity in ecological and environmental fields, and basically a large number of ensemble experiments will be conducted in conjunction with data integration. The most basic data integration will present a representation of the many states in this ensemble but will focus on whether less frequent phenomena in the ensemble experiments cause systematic changes, which can be understood through model equations for regime shifts.

III-3. AI-driven approaches

The field of atmosphere and ocean science has also seen strong and rapid adoption of AI technologies in recent years, although its number of adoptions is still limited. Current applications of AI in this area are broadly classified into four types (Reichstein et al., Nature, 2019):

[1] Detection of specific patterns (e.g., extreme weather detection and ocean heat wave)
[2] Resolution enhancement (e.g., statistical downscaling)
[3] Short-term forecasts (e.g., El Niño forecasts)
[4] Time series modeling (e.g., model parameter tuning).

All these types will be utilized in this proposal. For example, Type [1] will be used to detect ocean heat waves, which have attracted attention in recent years, and to assess their impact on ecosystems; Type [2] will be used as a surrogate for model nesting technology, or for red tide forecasting combined with [3] through higher resolution in coastal areas; Type [4] will be used for model parameter optimization based on

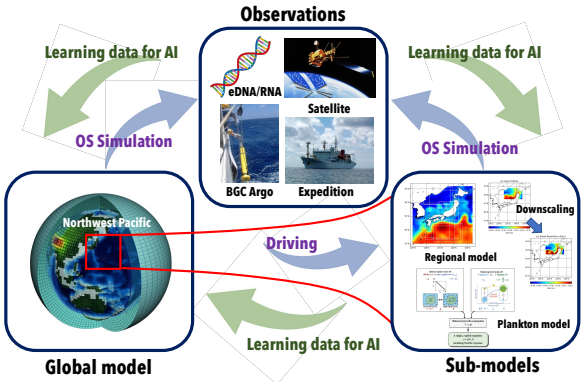


Fig. 12. Earth system modeling framework integrated with the Observing System (OS) using artificial intelligence techniques (Adapted from Schneider et al., 2017). Observations can provide training data to improve performance of the ESM and process models through AI techniques, which can then be applied to construct an efficient observation network again with AI. It will also facilitate the development parameterization schemes of used in a coarse-resolution global ESM based results from high-resolution models. Activities across a wide range of oceanographic disciplines can be optimized by the proposed approach.

information obtained from observations including geophysical, molecular ecological, and biogeochemical approaches (**Fig. 8**; see Theme II).

For a new utilization of AI, it is also possible to apply AI-based technologies towards the optimization of observation networks, which has long been addressed using data assimilation techniques. Such applications can be viewed as a variant form of Types [3] and [4], since the degree of improvement in forecast accuracy and the degree of modification of model parameters are used as indicators of optimization. More recently, an approach has been advocated to advance the whole process of model development which considers the entire cycle of **"observation data acquisition"**, **"model improvement"**, and **"optimization of the observation plan using the model"** as a single system (Schneider et al., GRL, 2017; see **Fig. 12**) while possibly integrating the four types of AI-driven applications.

While the establishment of such a system is conceptually possible by integrating traditional efforts such as data assimilation techniques and the application of high-resolution models, the use of AI would greatly facilitate its implementation by significantly reducing the computation load. Nevertheless, there are many challenges that must be overcome. For example, for a model to be used with observational data assimilated, the model's reproducibility itself must be of sufficient quality. Even today's state-of-the-art models are at a stage where further performance improvement is desirable, especially for the ecosystem part. In this regard, the results of Theme III-1 will be fully utilized. In addition, when "optimization of observation planning using models" is conducted, it is essential to ensure flexibility in observation planning. The experience accumulated by JAMSTEC, one of the world's leading organizations specializing in oceanographic observations, is expected to provide valuable knowledge for the management of observations.

The efforts to realize the system depicted in **Fig. 12** can be seen as an attempt to optimize a substantial part of the research activities in the field of ocean science itself, and we are approaching a time when we can expect a renewal of the research domain thanks to technological developments such as AI, computational power, satellite observations, and the accumulation of scientific knowledge such as eDNA/RNA and improved model performance (ref. 10 in Appendix 4).

■ An iterative approach to achieve holistic understanding

This proposed project aims to overcome the limitations of conventional ecological theories, which lack generality, by combining large-scale data on all biological and non-biological elements with innovative modeling techniques that identify common principles across many ecosystems. Conventional theories have typically been based on theoretical predictions derived from *a priori* assumptions, embodied in simplistic mathematical models. For example, to explain and predict the dynamics of a community, multi-species individual population dynamics models, assuming fixed-strength inter-specific interactions (such as the generalized Lotka-Volterra model) have typically been used. This simplification was often due to the lack of sufficient data or evidence to adopt more complex processes, rather than supporting empirical data. By contrast, we propose to adopt an approach based on large-scale data acquired at multiple sites, in order to discover yet unknown general patterns in the structure of ecosystems. Based on these newly discovered patterns, we aim to construct new models, formulate new hypotheses, and develop and test, via targeted observations, a new high-level theory beyond the reach of conventional marine physics and ecology (**Fig. 13**). The aim is to make new theoretical predictions that will guide new and more informative empirical research, which will in turn enhance the ability to make predictions, and thus generate a positive and productive feedback between the three themes within the WPI-AIMEC.

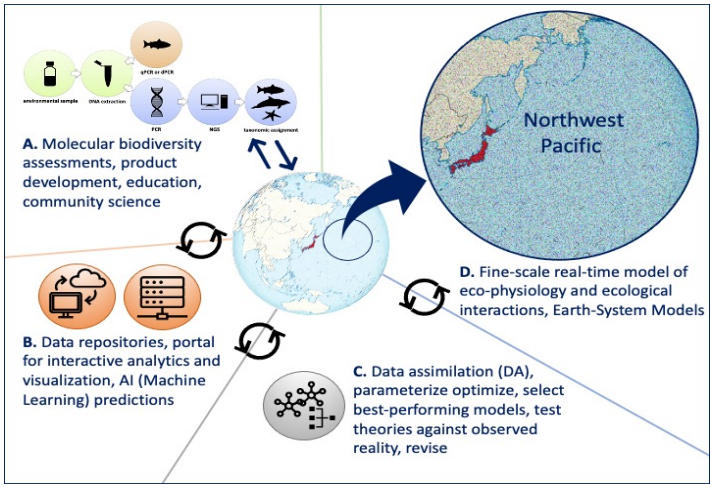


Fig. 13. A schematic of the specific yet partially overlapping components proposed to catalyze fusion research. (**A**) Assess and monitor fluctuations in genetic biodiversity and functional ecology by newly acquiring eDNA/RNA and multi-omics techniques; provide training (K-12) and community science opportunities; develop/patent product/services for low-cost, rapid detection of aquatic biota connectivity. (**B**) Develop repositories for eDNA and metabarcoding data; build a portal operated by AI and machine learning as a search engine for sequence matching and taxonomic identification. (**C**) Theoretical modeling of eco-physiology and ecological interactions and optimization with D. (**D**) Build an interactive model of "Ecosystem Response, Adaptation, and Evolution Mechanisms to Environmental Changes".

2) -3 System for advancing the research

* Describe the center's research organization (including its research, support and administrative components) and your concept for building and staffing the organization.
* Describe your concrete plan for achieving the center's final staffing goal, including steps and timetables.
* Describe your concrete plans (steps and timetables) for achieving the center's gender-balance plan. The plans should be divided into the following two categories, describing each:
  a. plans at the executive level including the center director and administrative director
  b. plans among principal investigators (professors, associate professors) and other researchers
* In establishing a research collaboration system at the center organization level with overseas institutions (Section 5.(8) of the Call for Proposals FY2023), provide the name(s) of the partner institution(s), and describe their roles, personnel composition and structure, and the collaborative framework between host institution and partner institution (e.g., contracts to be concluded, schemes for resource transfer). Also, if the center will form linkage with other institutions, domestic and/or foreign, *by establishing satellite functions*, describe in the same manner as the above.
* If the center will form linkage with other institutions, domestic and/or foreign, *without establishing satellite functions*, provide the names of the partner institutions and describe their roles and linkages within the center project.
* Appendix 5: "List of Principal Investigators" (If there are changes from the PI list in the first screening application documents, describe the points changed and reasons.) (to be attached)
* Appendix 6: "Biographical sketch of principal investigator" (to be attached)
* Appendix 7: "Composition of personnel in center" (to be attached)
* Appendix 8: "Letters from researchers invited from abroad or other Japanese institutions expressing their intent to participate in the center project" (to be attached)

Center's research organization

As its original plan in 2023, this center will establish a global network of multidisciplinary scientists that realizes an ideal international and multidisciplinary research environment, including free and active exchanges of research ideas. We will focus on diversity, higher education, and training of exceptional young researchers, and promote international brain circulation. The total of PIs is ***17***, and among them, ***10*** PIs are faculty members of Tohoku University or tenured scientists

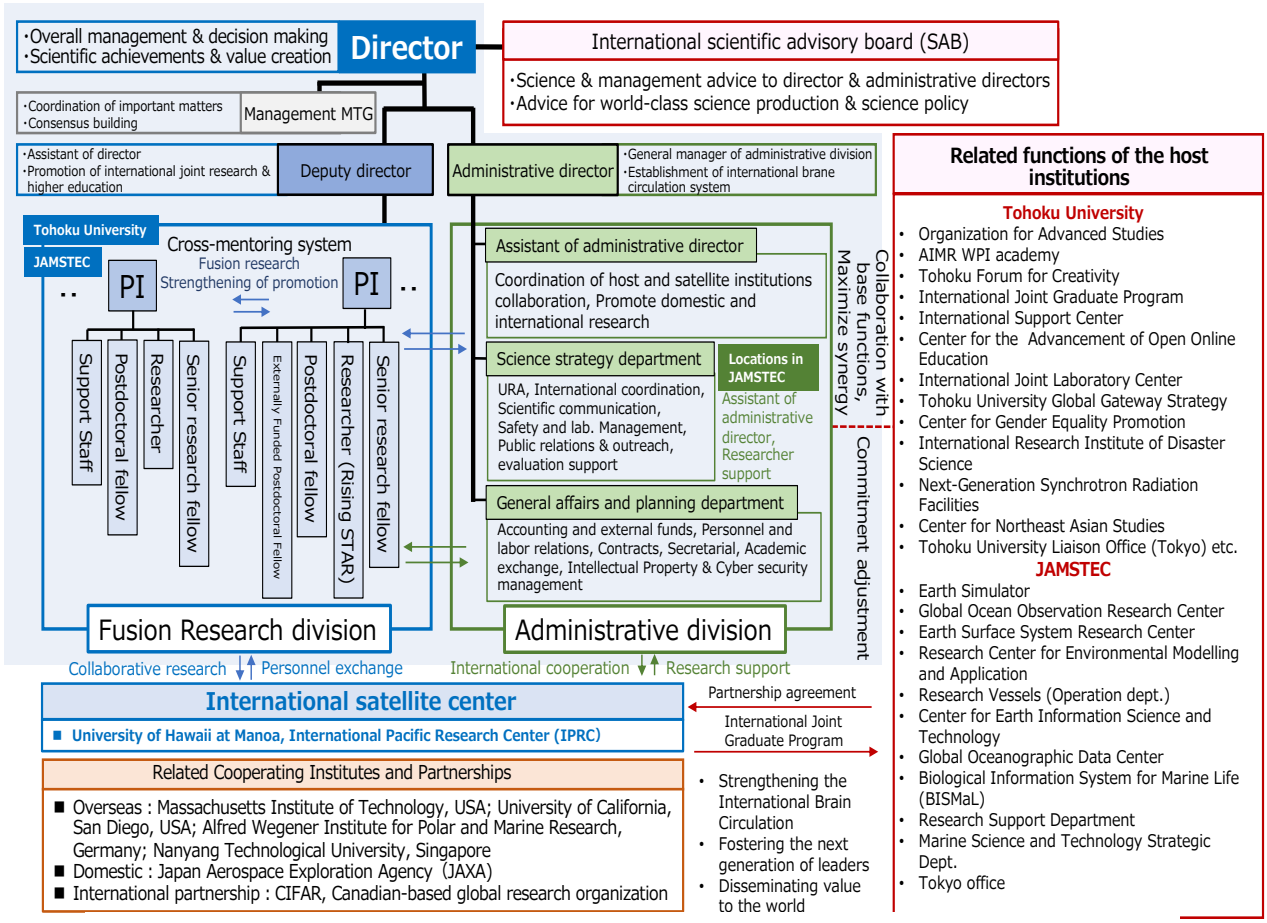


Fig. 14. The organization structure of the WPI-Advanced Institute for Marine Ecosystem Change (AIMEC).

of JAMSTEC (58.8 %), including ***2*** overseas researchers. Among all ***17*** PIs, ***7*** are non-Japanese (41.2%) and ***4*** PIs are female (23.5%) (Appendix 7). We will establish the **"Fusion Research Division"**, where each PI will work with a senior scientist (equivalent to Associate Professor), a staff scientist (equivalent to Assistant Professor), one or a few early-career researcher (postdocs and/or graduate students; see **Fig. 14**). A total of ***12*** support staff will also be hired according to the research environment of three themes. The recruitment of the AIMEC postdocs will be conducted through ***9*** times of international open calls, accounting for ***18*** **postdocs per year** (**ca. *54* postdocs for FY2023-2032**). The recruitment guidelines will be published in authoritative journals and international conference organizations to ensure uncompromising, worldwide, and fair selection based on research ability and diversity. Including the number of participants from Tohoku University's faculty members and JAMSTEC research groups, the maximum number of the **"Fusion Research Division"** and the **"Administrative Division"** will be ***110*** and ***40***, respectively (***~150*** **in total**: **Fig. 14**); however, these numbers may change with additional postdocs and/or support staff hired by external funding. **The target ratio of overseas and female researchers will be both over 30%** (Appendix 7).

In the fiscal year 2024 after the start of research center construction project, highly ranked researchers both in Tohoku University and JAMSTEC joined the AIMEC as PIs (two 2 male overseas researchers and three (3) domestic male researchers). We plan to employ or request joining female researchers as PIs in future. Initially, we planned to hire 18 new post-doctoral researchers per year, but taking into account the generation of researchers concurrently appointed from Tohoku University and JAMSTEC, we decided that we shall improve gender and generational diversity and to hire researchers with more career experience than post-doctoral researchers, paying attentions to gender, overseas, and generation balances. Therefore, the plan to hire 18 new post-docs per year was changed to about ten (10) new post-docs, several researchers and zero-to-few PI per year.

■ Satellite institute

The international satellite institute will be the **International Pacific Research Center (IPRC), the School of Ocean and Earth Science and Technology (SOEST), University of Hawai'i at Mānoa**, U.S.A. (**Figs. 1**, **14**). The IPRC has been a great icon of U.S.-Japan Common Agenda for Cooperation in Global Perspective at the governmental level, which was established in a cooperative agreement between the University of Hawai'i and JAMSTEC in 1997. Ever since, the IPRC has been a global leader in climate and ocean change observation and modeling research in the Asia-Pacific region. Tohoku University also has an agreement with IPRC and SOEST with the **"International Joint Graduate Program in Earth and Environmental Sciences (GP-EES)"**, chaired by the Director Suga, which is a core educational framework in cooperation with this WPI alliance center's initiative. PI Schneider, the Director of IPRC, and Prof. Angelicque White will join the WPI-AIMEC's initiative from the University of Hawai'i at Mānoa, and will explore ocean-atmosphere-biosphere systems in the Asia-Pacific region to ocean ecosystems.

■ Partnerships to enhance the center

In addition to the above, we will collaborate with researchers at the Scripps Institution of Oceanography at the University of California, San Diego, the Massachusetts Institute of Technology, and the Alfred Wegener Institute for Polar and Marine Research in Germany, a leader in oceanographic research in the sea ice region. Also, Prof. Benjamin Horton, the Director of the Earth Observatory of Singapore at the Nanyang Technological University, a leader in subtropical climate and oceanographic research, will join the WPI-AIMEC initiative. These international partnerships through co-PIs will promote international collaborations, leading to the creation of world-class research outcomes (**Fig. 1**). Furthermore, we plan to sign **a partnership agreement with CIFAR**, a global research organization in Canada (https://cifar.ca), immediately after the proposal for this center is officially adopted (Appendix 2). Since the inception in 2019, PI Inagaki has cooperated as an Advisor of CIFAR's Earth4D Program to support joint research activities and promote exceptional young researchers through CIFAR. Envisioned collaborations with CIFAR include organized international workshops/symposiums, virtual seminar series, and project-based research collaborations. The CIFAR's "Azrieli Global Scholarship" will also support exceptional young AIMEC researchers. In addition, through cooperation with CIFAR's outreach teams, we will promote knowledge sharing, co-production, and mobilization from basic science to the general public (and *vice versa*) and address important global environmental and societal challenges that will lead to a new set of **"Planetary Stewardship"** principles.

Furthermore, Tohoku University has signed a Memorandum of Understanding/Collaboration (MoU/C) with *249* institutions in *35* countries, and JAMSTEC also has established a MoU/C with *22* institutions in *13* countries. Based on these MoU/C, including MoU/C with the University of Hawai'i, we will establish the new **"WPI-AIMEC International**

Joint Graduate Program", of which this alliance center will be the core, to promote international higher education, early carrier researchers' exchange and international joint research projects (see Section 4)-2).

a) Principal investigators (full professors, associate professors, or other researchers of comparable standing)

(persons)

* Paste onto table a) in Appendix 7.

	At beginning of project	At end of FY 2023	Final goal (Date: April, 2027)
Researches from within Tohoku University	7	7	7
Researches from within JAMSTEC	3	3	3
Researches from within the host institution 3	N/A	N/A	N/A
Foreign researchers invited from abroad	6	6	6
Researchers invited from other Japanese institutions	1	1	1
Total principal investigators	17	17	17

b) Total number of members

* Paste onto table b) in Appendix 7.

	At the beginning of project		At the end of FY 2023		Final goal (Date: April, 2027)	
	Number of persons	⌟	Number of persons	⌟	Number of persons	⌟
Researchers	49		51		109	
Overseas researchers	11	22	13	25	36	33
Female researchers	11	22	11	22	46	42
Principal investigators	17		22		27	
Overseas PIs	8	47	10	45	10	37
Female PIs	5	29	5	23	8	30
Other researchers	32		29		82	
Overseas researchers	3	9	3	10	26	32
Female researchers	6	19	6	21	38	46
Research support staffs	0		2		7	
Administrative staffs	7		14		29	
Total number of people who form the "core" of the research center	56		67		145	

	At beginning of project		At end of FY 2023		Final goal (Date: April, 2027)	
	Number of persons	%	Number of persons	%	Number of persons	%
Doctoral students	24		30		81	
Expected employment	3	12.5	9	30.0	33	40.7

2) -4 Securing research funding

Past record

* Give the total amount of research funding (e.g., competitive funding) secured by the principal investigators who will join the center project. Itemize by fiscal year (FY2018-2022).

Funding prospects after the establishment of the center

* Based on your past record, describe your concrete prospects for securing resources that match or exceed the WPI grant (FY2023-2027).
* Calculate the total amount of research funding (e.g., competitive funding) based on the amount of funding that the researchers will allocate to the center project. Be sure that the funding prospects are realistically based on the past record.

As shown in the table below, the PIs of this center have acquired large-scale competitive funding during the period 2018-2022. The average annual amount of external funding received was **~$6,600,000**, and the average per person was **~$390,000**. The actual acquisition of research funding has **exceeded ~$3,200,000 - ~$3,600,000/a** in the Appropriation Plan (see Form 4), which demonstrates that **our budget outlook is *realistic***. In cooperation with hosts, satellite and partner institutions, PIs and young researchers will form project teams to systematically work on obtaining external funding, including competitive and commissioned research funds from private companies, foundations, and local governments, large-scale research projects by government ministries and agencies, and international research calls from private foundations that are members of the Science Philanthropy Alliance in the U.S. and the EU Horizon 2025. The Administrative Division will also assign staff to strengthen the functions of collecting information on external funding and provide information to researchers to support proposal developments. In addition, we will accelerate the promotion of world-class research at the center by collaborating with the "Moonshot Research & Development Programs" and with "SIP Strategic Innovation Promotion Program" that JAMSTEC and Tohoku University's researchers act central roles. Furthermore, as with the WPI-Academy AIMR, we will establish **a research promotion funds** in collaboration with the "Tohoku University Fund".

Year	2018	2019	2020	2021	2022	Total
Budget	**$4,722,827**	**$5,321,991**	**$6,527,964**	**$7,002,759**	**$9,423,902**	**$32,999,444**
Five examples of large-scale competitive funds	Southeast Asia SEA-Level program (SEA2) (2020-2025, PI: Horton, $9,248,343) NSF Hawaii Ocean Time-series (HOT) (2018-2023, PI: White, $9,000,000) Integrated Research Program for Advancing Climate Models (2017-2021, PI: Kawamiya, $8,075,765) JST CREST (2013-2019, PI: Kondoh, $3,400,000) Advanced Carbon Mineralization Initiative, Yogesh Surendranath (2022-, PI: Ono, $3,000,000)					

(Currency: 1$=136.21JPY)

2) -5 Interdisciplinary research

* Describe the fused research domains, why interdisciplinary research is necessary and important in the target field(s), and what new academic field(s) can be expected to be created by way of this project. Describe your concrete strategy for fusing different research domains and creating new academic field(s) by the fusion.

The response, adaptation, and evolutionary processes of marine ecosystems to climate and ocean change proceed fluidly in a complex system of multiple subsystems that are intertwined with each other. To better understand the integrated mechanisms of marine ecosystem change, it is essential to conduct a comparative analysis of time-series data on physicochemical changes that define the habitat of organisms and time-series data on the diversity, functionality, and adaptability of the communities that make up the ecosystem, and to construct models that can be applied to a variety of spatiotemporal scales (**Figs. 9, 12, 13**). In previous studies, the accuracy and resolution of the sensors installed in the observation system and the frequency of sampling varied, resulting in a body of individual studies at specific events/locations or snapshot studies that lacked a temporal component. Therefore, it has been challenging to centrally assemble, assimilate, and extrapolate physical, geochemical, and biological data, especially in dynamic and extensive marine environments, and extrapolate them into a quantitative nonlinear model. In addition, concerning the mystery of sudden phenomena represented by **"regime shifts"**, we may have shortsightedly and unconsciously overlooked the signs of important triggering factors. Since launching the WPI-AIMEC, experts in marine physics, meteorology, ecology, biology, molecular biology, geochemistry, and mathematical information science will collaborate under the AIMEC's initiative, working on system validation and verification by applying dynamic stability indicators to actual observational and experimental data, and on clarifying regime shift mechanisms by utilizing AI machine learning and deep learning (**Fig. 6**). We will utilize innovative observation platforms such as new ocean physical/geochemistry sensors, and instruments

with eDNA/RNA samplers. We will also incorporate wide data from satellite and seafloor observation networks and economic and social components data such as fishing activities that are strongly influenced by ecosystem services. The WPI-AIMEC will create a new academic field of **"Ocean-Ecosystem Change Systematics (OECS)"**. By doing so, we will contribute to **"Planetary Stewardship"** in solving global-scale issues such as adaptation and mitigation of the global warming and regeneration and restoration of the oceans and ecosystems. We will compile a database of the results and intermediate products of themes I-III and their fusion research and construct a system for identifying and listing factors relevant to the marine ecosystem change based on the database by the fifth year. Furthermore, we will subsequently advance this system and aim to build an advanced projection models for marine ecosystem changes by the 10th year, which will be applicable and usable to generative AI by the 10th year. Here, generative AI, for example, means to output potential factors contributing to changes in a specific ecosystem (or geophysical change) and model future projections based on the vast and diverse information in the database and will be used for further interdisciplinary research in WPI-AIMEC. **The strategy of the WPI-AIMEC is in the heart of UN Decade of Ocean Science for Sustainable Development (2021-2023) (UNDOS)**, which was proclaimed by UN General Assembly in 2021 to pursued multidisciplinary science and to contribute to societal needs from marine science.

3) Global Research Environment and System Reform

3) -1 System for advancing international research

* Describe your concrete plan for building an international research center including the makeup of its foreign researchers, a research collaboration system at a center organization level with overseas institutions, establishment of oversea satellites, or similar functions. Include a time schedule for the plan.
* Describe concretely your strategy for staffing foreign researchers (e.g., postdoc positions) through open international solicitations. Describe the procedures you will use to do so.

In the event of acceptance of this WPI proposal, this center, two host institutes (Tohoku University and JAMSTEC) and a satellite institute (IPRC/SOEST, University of Hawai'i at Mānoa), will immediately enter a MoU/C with our satellite institutions and partner organizations to initiate mutual cooperation and collaborations (**Figs. 1**, **13**). The latter will include formal agreements to nurture and support young researchers, including postdocs, through the advanced **"WPI-AIMEC International Joint Graduate Program"** (see Section 4)-2). By establishing a high-dimensional fusion center system equipped with broadband and Digital Transformation (DX) systems between Sendai, Yokosuka, Yokohama, Honolulu, and other locations worldwide, we will create an ideal environment in which research cooperation and collaborations can be carried out smoothly as well as to enhance physical international exchange.

For staffing foreign researchers, we plan to use the strong networks, which **Directors and PIs have already established with world-class international scientists**: for example, Director Suga had been a co-chair of the steering committee of the International Argo Program, which is supported by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and involves more than *30* nations. He is also a core member of the Global Ocean Observing System (GOOS), which involves more than *50* nations. These international networks are directly linked to the Intergovernmental Panel on Climate Change (IPCC) and UN Decade of Ocean Science for Sustainable Development (2021-2030) that the UN has proclaimed to support efforts to preserve the cycle of decline in ocean health and gather ocean stakeholders worldwide (i.e., Stakeholder Forum). Deputy-Director Inagaki is one of the leaders of the International Ocean Discovery Program (IODP), which is organized by more than *20* nations including Japan, the U.S., and European countries. He has occupied leading positions within the Alfred P. Sloan Foundation's Deep Carbon Observatory, and currently serves as an Advisor of CIFAR Earth 4D: Subsurface Science & Exploration Program. Other PIs also play crucial roles in international research frameworks, including the Environmental DNA Observatory Network, and the Scientific and Technological Economic Commission for Fisheries (STECF). By utilizing these international networks and research opportunities, **we will hire a total of *18* postdocs per year**, **resulting in the support of a total *54* postdocs for FY2023-2032**. The staffing of postdocs and young researchers will be annually processed by an International Coordinator through annual open calls for 10 years, which will be globally announced through e.g., the homepage, satellite institution, international scientific frameworks that PIs are involved in, high-profile journals (e.g., *Cell*, *Nature*, and *Science*), international conferences, and global academic foundations.

3) -2 Establishment of international research environment

* Describe your concrete strategy for establishing an international research environment, administration system, and

support system (e.g., appointment of staff who can facilitate the use of English in the work process and the provision of startup funding) to accommodate researchers from overseas.

* Concretely describe how the center will provide an environment in which researchers can work comfortably on their research by being exempted from duties other than research and related educational activities (e.g., allocation of adequate staff support to handle paperwork and other administrative functions). Include your procedure and time schedule for doing this.
* Describe your strategy, procedure and timing for periodically holding international research conferences or symposiums (as a rule, at least once a year).

The official language will be English for both research and administration.

Approximately ***4,000*** **m^2** of common space owned by the Tohoku University will be used to launch the WPI-AIMEC. Within 3 years, a new building will be established on the Tohoku University's Aobayama New Campus in Sendai, Japan, to serve as the main base of this center, creating an **"under-one-roof"** fusion research environment where research, administration, and support systems will be all centralized together. The Aobayama New Campus, where the next-generation synchrotron radiation facility is almost ready to use, is the new base for the university's **"Science Park"** concept. The main base will provide advanced laboratory spaces for PIs and other researchers and facilitate an open laboratory space to promote international brain circulation. Accommodations for researchers from overseas already exist within the university, the **"University House"** dormitories on the Aobayama New Campus and other areas in Sendai. The WPI-Academy AIMR has accumulated the know-how and experience to accept overseas researchers and visitors, promote fusional research and communications, and establish a world-class research environment. These WPI-oriented international functionalities were transformed as a university-wide function in April 2022, Tohoku University established the **"International Support Center"**, which has a function as research reception center with successor staff who provide high quality support to the oversea researchers and visitors in English, regarding their accommodation, daily lives and research collaboration, as established based on the expertise of the WPI-Academy AIMR. JAMSTEC also have long term experiences to accept many foreign scientists (*51* scientists, 12.7%) in the organization naturally since the establishment of Frontier Research System since about 20 years ago. In addition, international **"JAMSTEC Young Research Fellowship Program"** has been started since 2014, and total of *40* early-carrier scientists have spent their research lives in JAMSTEC with the strong administrative support. Through the International Support Center, diverse sets of infrastructure of Tohoku University, JAMSTEC, University of Hawai'i at Mānoa, and other international partners, **this WPI alliance will have an international research environment that maximizes human interactions and joint trans-dimensional research activities from the launch of the center.** In addition, by participating in international programs and projects related to marine ecosystems, such as Decade Action Programme/Projects of UN Decade of Ocean Science for Sustainable Development, in cooperation with the United States, Europe, and other major institutions around the world, we will build mutually beneficial relationships with these institutions.

The Administrative Division will be responsible for creating an environment in which AIMEC researchers can concentrate on their research (**Fig. 14**). Translation and/or instruction between English and Japanese may be required when coordinating with housing, education, hospital, daily life, etc., which will be supported by an international coordinator and bilingual staff in the Administrative Division. For overseas researchers who cannot stay in Sendai or Yokohama/Yokosuka, we will promote the sharing of research equipment and DX pipelines to improve the research quality and integration and establish a high-dimensional fusion research system between the main base and satellite/partner institutions. Using these functionalities and international networks, we will hold online *weekly* meetings, monthly webinar series (in cooperation with Tohoku Forum for Creativity [TFC], Marine Science and Technology Strategy Department in JAMSTEC, and CIFAR), and all-hands *annual* workshops/symposium coupled with the meeting of **"International Science Advisory Board"** (SAB; **Fig. 14**), which will be established to provide scientific and administrative advices by renowned scientists from Japan and abroad. Furthermore, to promote efficient fusion of disciplines, a cross-mentoring system for young researchers, postdocs and graduate students will be introduced, and tutorial seminars for researchers in different fields will be held ***on a regular basis.***

3) -3 Center management and system reform

* Describe the roles of the center director and the administrative director.
* Concretely describe your concept for establishing the center's administrative organization, the center's decision-making system, and how authority will be allocated between the center director and each host institution. (Describe concretely the mechanism for decision making when the person in charge of management and the person in charge of research and education in the center are different, and describe the responsibility relationship between the two.) Also, describe

the establishment of a governance system that enables effective and efficient management of the center, including risk management, to be carried out in cooperation with each host institution.

* Concretely describe how the center will adopt a rigorous system for evaluating research and will introduce a system for merit-based compensation (e.g., annual salary scheme). Describe your procedures and timing for operationalizing these systems.

■ Leadership & center management

The provisional Director Suga has the authority to make all decisions regarding institutional management and scientific operations. The Director is ultimately responsible for directing, supervising, and coordinating the entire research domains in the Fusion Science Division, and for orchestrating trans-dimensional fusion research and the creation of planetary stewardship principles. He will also be responsible for fostering next-generation human resources linked to higher education in association with the WPI-AIMEC International Joint Graduate Program (see "System reform" and Section 4)-2). The provisional Deputy Director Inagaki will support the director's management of this center from the two sites of host institutes. The provisional Administrative Director Ando, who is a chairperson of the IOC Sub-Commission for the Western Pacific (IOC/WESTPAC, Appendix 3: ref. 2), will lead the Administrative Division to support researchers at all career levels to ensure exceptional scientific output. The Administrative Director will assist the Director to ensure smooth and unhindered operation in both host institutes and promote international brain circulation with the satellite institution and other partner organizations. His responsibility will, moreover, include outreach activities, such as dissemination and narrative of integrated scientific knowledge and planetary stewardship.

The Administrative Division will consist of the **"Science Support & Promotion Office (SSP)"** and the **"General Affairs & Planning Office (GAP)"** (**Fig. 14**). The SSP office, including the University Research Assistants (URAs) in Tohoku University and its correspondences in JAMSTEC, will conduct international coordination with the International Support Center, science communication, education and outreach, data system management, and evaluation support. The GAP office will be in charge of accounting and funding, human resources, labor relations, contracts, and intellectual property and rights. The responsibilities of each administrative staff will be periodically reviewed to keep pace with constantly changing scientific advancements. To strengthen the function of the SSP office, we will hire dedicated international coordinators and a professional science communicator. The document management will be streamlined through DX pipelines and improve the processing speed and effectiveness. From the launch, a Joint Steering Committee between two host institutes will be established with the memberships of Director, Deputy Director, Administrative Director, and Deputy Administrative Directors for the purpose to support decisions of the Director. In addition to in-person meetings, an online management system will be established among the managers, that will enable the continuation of management meetings. A multifaceted evaluation system based on a **"Target and Feedback (TF) sheet"** will be introduced, with clearly defined evaluation factors. The *annual*-based salary system will be set uniquely for the AIMEC's employees, and subject to reviews.

■ System reform

Tohoku University is currently undertaking university-wide reforms to make administrative processing smoother and more immediate, and creating a **"One-stop, One-point"** system for researchers. Also, under "Declaration of Online

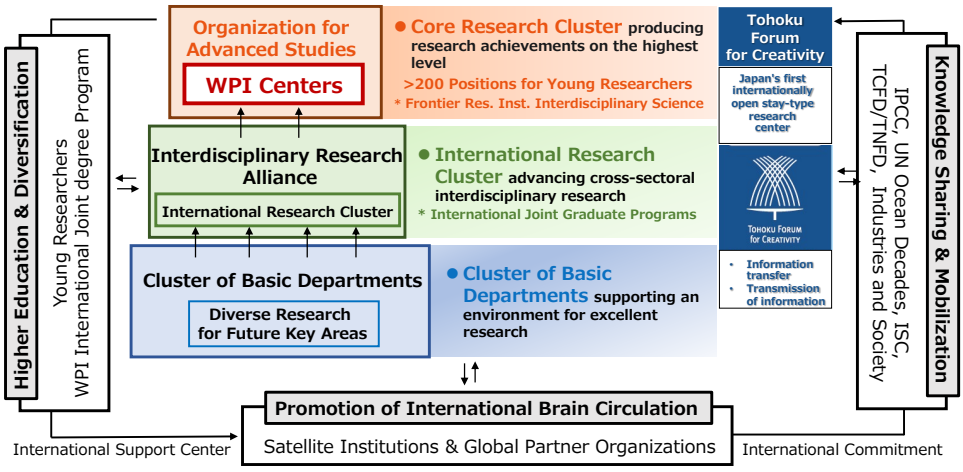


Fig. 15. Tohoku University's 3-layered "Research Innovation System", linked with "WPI-AIMEC alliance and WPI-Academy AIMR" and "Tohoku Forum for Creativity (TFC)".

Administration", we will promote a virtual environment to create an education and research environment. The URA system will be further strengthened, and provide strong supports to researchers. As for the high-valued experimental and analytical equipment used in research, the **"Technical Support Center (TSC)"** will coordinate detailed arrangements for researchers (**Fig. 15**), and the information and operations of the experimental and analytical equipment of AIMEC researchers will be obtained by the TSC.

In addition, under the President's leadership, Tohoku University has been promoting a **"Research Innovation System"** since 2018 by layering the university-wide research system into three foundational layers: 1. Organization for Advanced Studies (OAS), 2. Interdisciplinary Research Alliance, and 3. Cluster of Basic Departments (**Fig. 15**). **This WPI center will be positioned at the top-tier "Organization for Advanced Studies (OAS)" from the launch, building a solid collaborative system that will take advantage of the WPI-brand and its functionality**. The OAS includes the WPI-Academy AIMR, the International Joint Laboratory Center, which promotes the world-class research centers through international collaborations, and the Frontier Research Institute for Interdisciplinary Science (FRIS), where >200 young researchers conduct cutting-edge interdisciplinary research in an independent research environment. The **"International Joint Graduate Programs"** including GP-EES and a new **"WPI-AIMEC International Joint Graduate Program"** is positioned at the 2nd layer "Interdisciplinary Research Alliance" (for higher education, see Section 4)-2). Taking this university-wide system reform, we will cooperate/collaborate with GP-EES, FRIS, and other programs in the Cluster of Basic Departments to establish a world-leading transdisciplinary research institute.

JAMSTEC is in the period of the 4th mid-long-term plan from 2020. Since then, JAMSTEC has operated research departments by providing high degree of freedom to the directors. In this WPI alliance, JAMSTEC will build a similar mechanism for the director to have a large discretionary power to the management of AIMEC. In addition to the reform in JAMSTEC, two host institutes (Tohoku University and JAMSTEC) and University of Hawai'i will collaborate develop the unique platform of **"Mutual Utilization Laboratory (MUL)"** as one institute. The operation of the MUL will be supported and promoted by the Administrative Division and will allow all researchers in the center to use necessary functions equally in three institutes. Given the main challenges of the Center, only strong cooperation between highly qualified people from various research institutes can tackle its solutions. MUL is the one essence of the WPI alliance center and the advantage which WPI Core will not have.

3) -4 Research environment

* Concretely describe how equipment and facilities, including laboratory space, will be provided in a manner appropriate for a "world premier international research center." Include your procedure and timing for doing so.
* If determined that it will be effective to set up the center's operational areas in multiple locations, describe in detail the effectiveness of the setup and how it will be implemented in a way equivalent to an under-one-roof environment.
* Concretely describe how the center will consider arranging for its researchers to participate in the education of graduate students.
* Describe new measures to improve or abolish existing systems and practices in the host institution toward optimizing the center's research environment.
* Concretely describe the plans by the host institutions to provide a support system and to work toward improving the environment for achieving gender balance.
* Describe your measures other than those described above for ensuring that world's top researchers from around the world can comfortably devote themselves to their research within an international and competitive environment at the center.

Tohoku University is the host institution for the **new next-generation synchrotron radiation facility "NanoTerras"** is established at the Aobayama New Campus of Tohoku University, which will include the soft X-ray (3 GeV) analytical tools. Tohoku University and JAMSTEC cooperate some international observation networks, e.g., most advanced observation network for seismic waves, global ocean physicochemical factor monitoring systems, and high-resolution organic matter analysis systems, which will be available for the WPI's fusion research of marine ecosystem change. JAMSTEC is the owner of the **supercomputer "Earth Simulator"**, which provide the best circumstances for Earth Environmental Simulation research, and also operating Argo data system and OBIS data system. By the strong supports from the host institutes, AIMEC will also foster research opportunities and infrastructures at satellite institutions, including the accessibility to computational infrastructures and data centers such as Argo data system and OBIS data system at JAMSTEC and the IPRC's **"Asia-Pacific Data Center",** providing one-stop access to a wide range of climate (satellite) and ocean observation (Argo) data and conducts research to improve data products. In addition, **by activating *hub* functions of the international network, we will provide young researchers with unprecedented opportunities to experience cutting-edge fusion science and to play a role in international and transdisciplinary research projects**.

The offices and laboratories in Aobayama New Campus will be located close to each other, and support staff will be stationed there. In JAMSTEC, we plan to station support staffs close to scientists mainly in Yokohama Campus, to which we provide strong DX system with Aobayama New Campus. Among two host institutes, a satellite institute, and partner organizations, we will connect by DX in real-time, and diminish disadvantage to conduct fusion research among. The facilities for analyses, experiments, and calculations will meet the standards necessary for conducting fusion research and the world-class higher education (for detail, see Section 4)-2).

■ **Realization of gender balance**

As part of efforts to realize gender balance, Tohoku University has prepared the largest on-site childcare environment of any national university in Japan, including the Kawauchi Keyaki Nursery School (capacity: 22) and the Aobayama Midori Nursery School (capacity: 116), which are available to all university employees. JAMSTEC aims to create excellent R&D results and science and technology innovation based on diverse values, and not only actively recruits women based on gender equality, but also respects individuality regardless of nationality, race, gender, gender identity, age, disability, etc. The Tohoku university is also engaged in recruitment activities with a view to realizing a working environment in which individuality is respected regardless of nationality, race, gender, gender identity, age, disability or otherwise. In addition, Tohoku University has established a teleworking environment for faculty and staff in line with the promotion of digitization of work. In addition, as it is expected that many foreign researchers will be hired in the future, information on obtaining a CoE (Certificate of Eligibility), housing and other information considered necessary for starting life in Japan is made available on the website at the time of recruitment procedures.

4) Values for the Future

4) -1 Generating and disseminating the societal value of basic research

* Describe concretely and quantitatively the center's policy for widely disseminating the societal significance and value stemming from the results of its basic research to the general public.

■ Societal significance and value of basic research

To date, various nations and public sectors, including private industries, are making progress in efforts related to **"Carbon Neutral"** and **"Nature Positive"** initiatives following the **"Sustainable Development Goals (SDGs)"** adopted at the UN Summit in September 2015. The concept of **"Planetary Boundaries"** has been proposed in basic research as a **"Diagnostic of the Oceans and the Earth"**. Upon assessing the current status of nine indicators, including global warming and ocean acidification, the threshold values for the sustainable operation of Earth's subsystems, so-called 'tipping points', have been presented. As a result, it has been demonstrated that some items related to climate change and ecosystems have already been transcended.

"How we adapt to change is an important dimension for understanding society."

Given expected exponential population growth and modified human activity in coming decades, the land-to-sea boundary is ground zero for the biggest forecasted environmental change-related societal impacts. Considering the immense significance of oceans and coastal regions for both local and global economies, the future of **"Blue Economy"** – an established framework for deriving wealth from the ocean on a sustainable basis – depends on robust policies and practices from the perspective of coastal resource management. This domain proposes basic research and dissemination goals as a rigorous strategy to address SDGs laid out in the **Agenda 2030 "Plan of Action for People, Planet and Prosperity"** (UN, Transforming our world: the 2030 Agenda for Sustainable Development, 2015), and particularly focusing on SDG14 (Life under water), UNDOS has started since 2021.

At the 15th Conference of the Parties (COP15) to the Convention on Biological Diversity (CBD) held in December 2022, each nation's effort toward the long-term goal of **"A World in Harmony with Nature"** by 2050 will be shared, and the **"30by30"** goal of conserving at least 30% of the land and sea by 2030. Nevertheless, there are overwhelmingly fewer examples of basic research on marine ecosystems than on terrestrial ecosystems. At the G-Science conference held in March 2023, **"Restoration and Recovery of Oceans and Biodiversity"** was proposed. This proposal describes the need to establish international roles for not only 'conservation' but also 'recovery and restoration' of the oceans and their biodiversity, as well as the need for scientific research that utilizes global ocean observation networks such as the Argo program. On the other hand, the response and adaptation mechanisms of marine ecosystems to environmental changes, which are critically significant to the recovery and restoration processes, remain unclear.

Currently, there is a huge gap between time-series studies of biological habitats defined by principles in ocean physics and interdisciplinary research on the functionality of mobile ecosystems and their plasticity, complexity, and adaptability at the genome expression level. This situation makes it difficult to understand and project the internal and external regulation of ecosystem-node functions that promote accurate projection of marine ecosystem change, recovery, and restoration. The AIMEC aims to solve these bottlenecks in basic science and realize more accurate projections of marine ecosystem change. Considering the fact that 41% of the global ocean area is impacted by humanity (shipping, fishing, resource development, etc.) and that many countries and regions, including Japan, benefit from marine ecosystems (i.e., ecosystem services), the transdisciplinary basic research and well-reasoned forecast information from the WPI-AIMEC have societal significance in providing scientific guidance to future marine industries, policymakers, and other public stakeholders, and in contributing to the improvement of humanity's well-being and prosperity (**Fig. 16**). This is in-line with the Implementation Plan of UNDOS, and according to the plan, IOC as a steward organization of UNDOS has been calling actions for UNDOS. WPI-AIMEC will respond the call for actions to pursue the substantial contributions to societal significance. The action of UNDOS will not only be done by researchers but also by administrative staffs, and our scientific comunicators in the Administration Division will play major role for co-design/co-production/co-delivery with various stakeholders in society.

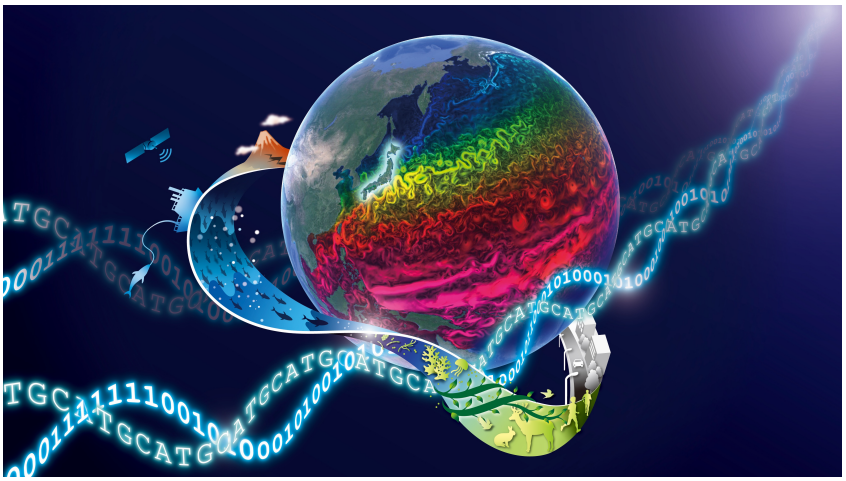


Fig. 16. Concept illustration of the new academic field **"Ocean-Ecosystem Change Systematics (OECS)"** that WPI-AIMEC will create value and disseminate to the globe.

■ Dissemination of societal value of basic research

Since 2015, Tohoku University has been promoting **"Research with Social Impact"** on difficult-to-solve issues facing modern society to create a sustainable and mindful society. By directly linking the scientific results of this center to those research themes and issues, we will create outcomes and value creation for the entire university. We are hiring a dedicated international coordinator and science communicator in the administrative division to strengthen public relations and outreach functions, including video and SNS distribution. In doing so, AIMEC will make full use of the Center for Knowledge Creation, Tohoku University's information dissemination hub, the Tohoku University Museum, JAMSTEC, the University of Hawai'i, CIFAR's international academic and PR network, and relevant UN agencies and frameworks such as UNESCO/IOC. It will continuously and effectively disseminate information to stakeholders to enhance literacy in marine ecosystems and also to co-design/co-production/co-delivery our state of the art of AIMEC's sciences. Through these efforts, we will accumulate assets of scientific knowledge from two host and satellite institute and will bring values to our society and human lives (**Fig. 16**). The research results and the integrated findings obtained from the research will be disseminated in an effective and timely manner to diverse stakeholders through regular roundtable meetings with the general public and policy makers, information dissemination via SNS and websites, and the establishment of our own video distribution channel, while making maximum use of relevant organizations and international programs, such as the United Nations.

4) -2 Fostering next-generation human resources linked with higher education

* The center should be a platform for establishing a research system in which new interdisciplinary domains can be created within a rich international environment. Describe concretely and quantitatively the initiatives to be taken to foster young researchers, including doctoral students, through participation in such a research system within the center.
* Describe your plans for fostering researchers with a view to achieving gender plans, and your plans for conducting domestic and international promotion activities to attract female researchers to the center.

We will create a system that allows young researchers to be actively involved in the doctoral programs of related departments and build a system that allows us to provide research guidance to graduate students from Japan and abroad.

We will thereby foster young researchers to become world leaders of the next generation and beyond. With regard to the postdoc program of this WPI alliance center, we will actively recruit young researchers through international recruitment, hiring *6* postdocs in the first year and *18* postdocs per year in the following years. Over the course of 10 years' WPI program, we will support more than *54* postdoc researchers in 10 years, for which over *30%* will be overseas and/or female researchers (Section 2)-3 and Appendix 7). Young researchers with particularly outstanding achievements will be designated as **"Rising STAR Researchers"**. The **"Transdimensional Research Promotion Award"** will be implemented as a stimulative research grant to promote transdisciplinary fusion research led by young researchers and to enhance international competitiveness. Furthermore, researchers who have demonstrated visible leadership in Japan and abroad will be given the status of specially-appointed associate professor or assistant professor (with a fixed term), provisionally associated with the Tohoku University's tenure-track system, and researcher (with a fixed term), associated with the JAMSTEC human affair system.

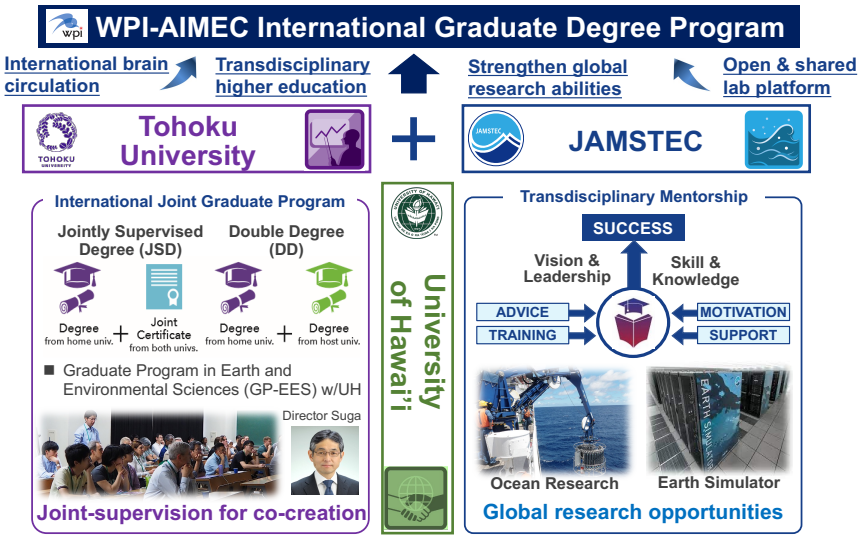


Fig. 17. Schematic figure of the new WPI-AIMEC International Graduate Degree Program that will be established for international and transdisciplinary higher education in collaboration with the host and satellite institutions.

To foster international and interdisciplinary graduate students, we will collaborate with Tohoku University's International Joint Graduate Programs (**Fig. 14**); e.g., in collaboration with the University of Hawai'i at Mānoa, the GP-EES has produced *10* jointly supervised degree recipients since 2018. In this WPI alliance initiative, we will establish a new **"WPI-AIMEC International Joint Graduate Program"** and strengthen the higher education program more world-wide and interdisciplinary, in which WPI's world-class researchers engage in graduate student education and training (**Fig. 17**; see Appendix 2). Students will take cross-disciplinary lectures from the second year of master course after learning the basics of each specialized field, participate in summer schools, etc. at overseas partner institutions, and practice research activities at overseas partner institutions for six months or more during the doctoral course. In addition, we will promote overseas participation in this program by utilizing the mechanisms for accepting international students at each graduate school. As a result, in tight corporation with Tohoku University, JAMSTEC, and University of Hawai'i at Mānoa, the AIMEC will employ up to *33* doctoral students per year, producing ~*120* Ph.D. recipients in 10 years.

For employing female researchers or postdocs, from the experiences at the 1st calls for postdoc's and researcher's recruitments of AIMEC, very high ratio of female in postdoc's employments (8 females among 9) and high ratio of that in researcher's employment (4 females among 7). AIMEC will continue the current system for the call and ensure that the personal system is appropriate for women to continue working both at Tohoku University and JAMSTEC.

4) -3 Self-sufficient and sustainable center development

* The center needs to become self-sufficient and sustainable after the funding period of 10 years ends. Describe the host institution's mid- to long-term plan and schedule for supporting the center's development, including the reform of the host institution's organization, the provision of personnel with priority allocation of tenured posts to the center, fundamental financial support, and material support including land and buildings.

Tohoku University's 4th Mid-Term Plan describes a university-wide goal that a world-class research environment and its support system will be established and expanded, and promotes system reforms to strengthen the self-sufficient and independent strategic management under the **"Tohoku University Global Gateway Strategy".** Tohoku University has pledged its *utmost support* for the continuation of this WPI for *10* fiscal years and *beyond* (see Form 5). Specifically, this WPI center will be positioned *from the launch* at the OAS of the Tohoku University's Research Innovation System, which enable us to promote mutual cooperation with the WPI-Academy AIMR, FRIS, GP-EES, and the new "**WPI-AIMEC**

Intentional Joint Graduate Program" (**Fig. 17**). During the decadal WPI program, we will develop a strong system of cooperation and collaboration within the university in terms of research and administration, including the areas of human resources, administrative structure, research support system, and joint guidance of graduate students in higher education programs. Furthermore, by utilizing the framework of JAMSTEC's joint graduate school system, we will provide the researchers within the WPI alliance framework with the best opportunities for hands-on education at the field level that JAMSTEC can provide, enabling researchers to pursue broader and more advanced careers in the future. These proactive, university-wide, system reforms and cooperation at Tohoku University and in solid collaboration with JAMSTEC will allow this center to develop a self-sufficient and sustainable center after the decadal grant period ends, and generate powerful synergies to enhance academic excellence, international education, integrated knowledge mobilization, and sustainability in the future.

In JAMSTEC's 4th Medium-to-Long-Term Plan, the head of each research department manage with great discretion and conduct research. As for this WPI alliance center, a new department will be established immediately after selection, and the researchers and administrative supporters of the existing departments will be relocated. After the end of the support period, we will continue the established department and realize management with a large.

Director's Vision

Advanced Institute for Marine Ecosystem Change (AIMEC)

Toshio Suga, Professor of the Graduate School of Science, Tohoku University

Over the past 4 billion years, periodic changes in Earth systems have been controlled by astronomical factors (e.g., Earth's orbit and tilt of rotational axis) and planetary factors (e.g., plate tectonics, mantle convection, volcanic activity). However, with human activities now integrated into the Earth system, the natural periodicity has been disturbed, leading to cascading and rapid changes that threaten sustainability. Global warming, ocean acidification, loss of biodiversity, and degradation of ecosystem functions are some of the most visible impacts. The **WPI-Advanced Institute for Marine Ecosystem Change (AIMEC)** aims to foster interdisciplinary research to advance fundamental sciences and apply the knowledge gained to contribute to the sustainability and well-being of humanity.

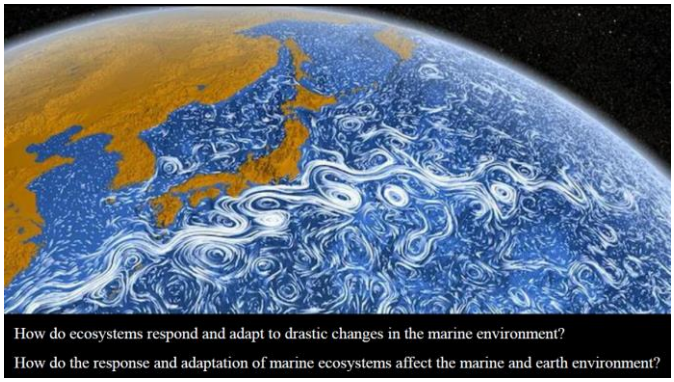
Marine ecosystems (i.e., Hydrosphere [including the atmosphere] and Biosphere) account for approximately half of global primary production and support about 80% of Earth's total animal mass. Interactions between the oceans and the continents, i.e., Geosphere, have shaped the structure and vigor of the marine ecosystem and drive the evolution of life on Earth. However, the addition of human activities to the Earth system leads to changes in the marine ecosystem that we have yet to fully comprehend. Marine ecosystems provide humans with various material and functional benefits known as **"ecosystem services,"** including food supply, atmospheric and marine chemical component regulation, nutrient cycling, wastewater treatment, recreation and culture, and shoreline protection. Despite this, **we lack a fundamental understanding of how marine ecosystems respond and adapt to anthropogenic environmental changes compared to terrestrial ecosystems.** While studies have shown that human activities have had a global impact on terrestrial ecosystems, we lack highly accurate scientific predictions for marine ecosystem changes in relation to system feedback. In order to address the issue of how alternations of biodiversity and functionality affect the global environments and impact human socioeconomics, it is necessary to develop an integrated analysis that encompasses external factors (environmental stressors) regarding ***stability***, ***connectivity***, and ***adaptability***, which are vital components for ecological sustainability.

Although the geographic distribution of biodiversity from the surface to shallow water has been partly elucidated, our understanding of their interactions and linkages with cyclic marine environmental changes remains incomplete. During a decadal-scale change in the marine environment, there are tipping points where extreme ecosystem changes occur rapidly, known as **"regime shifts"**. However, the mechanisms that trigger, transform, and terminate such shifts are still unclear. Specifically, there are many unknowns, such as what is the mechanism by which ecosystem functions are maintained through changes in biodiversity even under fluctuating environmental conditions; what are the mechanisms of sudden extinctions and outbreaks at the community, individual, and molecular levels; and what are the limits of ecosystem plasticity due to changes in genome and protein functionality. Over the past 100 years, in conjunction with global warming, the frequency of marine heat waves showed marked increase and led to rapid increases in ocean temperatures over days to years. These phenomena are thought to cause catastrophic damage to migratory fish catches, such as saury and yellowtail, and benthic organisms, such as crabs and scallops. They may also induce declines in the higher-order predators, such as sharks, penguins, and whales, and induce abnormal blooming of harmful and toxic algae and jellyfish. However, details of their mechanisms of change remain a big mystery.

The WPI-AIMEC aims to enhance human sustainability and well-being by **addressing the fundamental and critical question: "What are the response and adaptation mechanisms of marine ecosystems to Earth-Human system dynamics?"**. To achieve this, we integrate digital data from satellite networks with on-site observations ranging from local to global scales, analyze diverse and large-scale observational data including environmental DNA/RNA (eDNA/RNA), acoustics, images, and other tools, and assess biological, geochemical, and geophysical factors from the mesopelagic zone to the deep sea. By integrating these data over the next decade, **we will illuminate the marine ecosystems' response and adaptation mechanisms during decadal-scale changes, particularly those related to regime shifts in climate and ecosystems, and enhance the accuracy of projections of marine ecosystem change.**

The Northwest Pacific is one of the most biodiverse regions on Earth, extending from low to high latitude, due to the interactions of arctic, subarctic, subtropical, and tropical environments across a range of spatiotemporal scales. The variability has a significant impact on fisheries and the ecosystems of coastal megacities. Japan, situated in this region, is in an optimal geographic position to study Earth-Human system dynamics in the ocean. There is currently a global emphasis on **proactive restoration and recovery of the ocean and ecosystems** beyond conservation and maintenance. To achieve this challenging goal, it is crucial to expand our knowledge of the mechanisms of spatiotemporal variability in marine ecosystems as soon as possible. Given the importance and urgency of this issue, **AIMEC will establish and globally lead a new academic field called "Ocean-Ecosystem Change Systematics (OECS)" for sustainability,**

which integrates various disciplines of marine physics and ecology with data science approaches, making full use of state-of-the-art observational and experimental techniques and information analyses.



Tohoku University has pioneered many studies on atmosphere-ocean interactions and their effects on ocean environmental changes, mainly focusing on the Northwest Pacific region. For example, prospective center director Suga and his team were developmental leaders for the International Argo Program, a global ocean observation network of several thousand automated observation robots (profiling floats). By applying machine learning and other techniques, we have produced ocean-scale, high-resolution maps that combine in-situ and satellite data, which has given us insights into the formation of specific marine environments and the mechanisms of material circulation. In ecological studies, Prof. Kondoh and his team lead data-driven science on ecosystems and biodiversity by deploying ANEMONE, an eDNA-based biodiversity monitoring network, along the coast of Japan, in riverine areas, and recently in the open ocean. These accomplishments and accumulated scientific knowledge provide a solid foundation for understanding the mechanisms of marine ecosystem change in the Northwest Pacific. Dr. Kawamiya and his team at **Japan Agency for Marine-Earth Science and Technology (JAMSTEC)** have pioneered climate evolution models of the atmosphere-ocean system. They are recognized as one of the world's leading institutions as demonstrated by the development of the Earth System Models (ESMs) combined with an ecosystem model. The advanced ESM system can also assimilate global observation data to find the optimal model parameters and reproduce the actual ocean state. Furthermore, the **University of Hawai'i at Mānoa**, together with Tohoku University and JAMSTEC continue their long-standing collaboration at the organizational level. Together they have an international meteorological and oceanographic base in the central Pacific Ocean, and lead observational research in the Asia-Pacific region with the International Pacific Research Center. In order to address the pressing issues that we face, it will be most effective and impactful to work as an international alliance-type initiative, where data can be shared strategically in a focused ocean region rather than to have universities and research institutions work individually. Under the WPI flagship, I will **lead systematic collaboration between Tohoku University, JAMSTEC, the University of Hawai'i, and other partner institutions to understand and digitally project the mechanisms of marine ecosystem change at various spatiotemporal scales**. This initiative will serve as an international academic foundation to nurture the next generation of researchers and leaders and to pass on values to future generations.

As the first WPI alliance center, AIMEC will initiate interdisciplinary research that integrates the physical, chemical, and biological aspects of marine environments and ecosystems in the Northwest Pacific. Currently, data obtained from various sensor-based measurements, continuous observation methods, and automated observation networks vary in nature and quantity across different fields, resulting in a decreasing spatiotemporal coverage level of data generally by an order of magnitude in the physical, chemical, and biological fields, respectively. To effectively integrate and unify such data, it is essential to foster mutual scientific respect and understanding of the relevance of data from different disciplines and harmonize data with different granularity. The AIMEC will develop an **"under one roof"** research environment where researchers from different disciplines can routinely collaborate from the stage of basic data generation. Initially focusing on research in the Northwest Pacific for the first five years, data products will be structured for global extension in the middle to latter five years, with the aim of developing international data utilization beyond the subject area boundaries and world-class global research within a 10-year period. The results and intermediate products of the fusion research will be sequentially compiled into a database, and a prototype of a generative AI for marine ecosystems based on this database will be created for further interdisciplinary research. In 10 years, we aim to expand the system to a generative AI that can be released to the public, and internationally lead **OECS**.

Through developing the AIMEC WPI alliance center and its initiatives, I am determined to work with like-minded colleagues to **deliver contributions to "Planetary Stewardship" that will lead to the sustainable development of the Earth-Human system for the next generations**. Since 2016, I have led an International Joint Graduate Program based on joint supervision of degrees between Tohoku University and the University of Hawaii and trained numerous jointly supervised degree students. Expanding this framework and allowing JAMSTEC researchers to provide degree guidance through the new **"WPI-AIMEC International Joint Graduate Program,"** we will **accelerate the development of global human resources who will lead the next generations**. Furthermore, a dedicated university research administrator

and international communicator will be appointed to take charge of public relations and outreach and to disseminate information continuously and effectively to the scientific community, relevant UN agencies, policymakers, private companies, and the general public, thereby improving the visibility and synergy effects.

Host Institution's Commitment

June 1, 2023

To MEXT

Name of host institution 1: Tohoku University
Name and title of head of host institution 1: Hideo Ohno, President
Name of host institution 2: Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
Name and title of head of host institution 2: Hiroyuki Yamato, President

I confirm that the measures listed below will be carried out faithfully and concretely as follows regarding Advanced Institute for Marine Ecosystem Change (AIMEC) if it is adopted under the World Premier International Research Center Initiative (WPI).

Concrete Measures

・Describe the concrete measures that the host institution will take to satisfy the following requirements.

1) For the center to become a truly "world premier international research center" and independent by the time WPI support ends, each host institution must clearly define the center's role within its own mid-to-long-term strategy and provide comprehensive support from the time that the funded project starts, while showing that the center contributes to achieving each host institution's missions, etc.

※Describe how the center will contribute to achieving the host institution's missions, enhance its founding spirit/philosophy, and contribute to realizing the objectives of its operation, etc.

※Describe the center's role within the host institution's own mid-to-long-term strategy.

Tohoku University and Japan Agency for Marine-Earth Science and Technology (JAMSTEC) will **develop an "under one roof" center that builds on the robust partnership between the two institutions and leverages their respective strengths in a mutually complementary manner.** Moreover, **the two institutions will collaborate to provide full-scale support for the center both during the funding period and thereafter,** establishing a world-leading research center that is the hub of international brain circulation. In order to realize integrated operation of this WPI-AIMEC, the two institutions will not only **mutually establish multiple laboratories and deploy researcher cross-appointment systems**, but also work in close collaboration to **build a research environment providing researchers affiliated with the center free access to research infrastructure at both host institutions, enable them to commit to higher education, and pursue appropriate value-adding of knowledge assets.**

(Tohoku University's Commitment)

Since its foundation Tohoku University has pursued to contribute to the development of a peaceful human society based on the principles of "Research First," "Open Doors," and "Practice-Oriented Research and Education." As a hub of knowledge we have produced world-class research findings, shared them with wider society, and powered innovation. Drawing on that strong track records and heritages, we are currently pursuing university system and management reforms designed to realize an advanced virtuous cycle of education, research, and co-creation with community.

The proposed center WPI-AIMEC will not only serve as a leading model for Tohoku University's various reforms but will also contribute substantially to realizing the university's mission of becoming an internationally renowned research institute by driving world-class research, the development of international-standard research support systems, and international brain circulation. Specifically, the center will develop cross-border collaborative frameworks for the mobilization of top-level researchers in related fields and the maximum leverage of our internationalization strategy of strengthening our international networks and employing international researchers using the university's own financial

resources. These will be rolled out to advance university-wide system reforms, further enhancing the university's international presence as well as leading creation of new academic fields based on outstanding research findings.

We have **committed to securing resources equal to or greater than the funding provided under the WPI** for use in the proposed center's management and research activities. Moreover, the center will be **given the status of an official organizational unit of Tohoku University from the outset, and provided with across-the-board support so it can become one of the university's flagship research centers after the funded project ends.** Specifically, it will receive around the same level of resources as our WPI-AIMR (approximately 800 million yen).

As a Designated National University Corporation, we conducted a comprehensive analysis of the university's research capabilities with a view to generating premier world-class research findings and boosting our international presence, **identifying nine priority research areas from the perspective of strengths and future potentials.** Out of these nine areas, the current proposal focuses on research in **Environmental & Earth Sciences**, in recognition of the importance of which **the President designated the Institute for Integrated Earth Science (IESS) as a Center for Key Interdisciplinary Research as of February 2022, implementing financial support at the President's discretion.** The IESS is already pursuing research activities as a university-wide research hub, including, in May 2022, an international workshop with six international research leaders in a variety of fields, not only Earth Science, invited as guest speakers.

We have constructed a **university-wide, three-layer structure of research institutions** forming part of our **Research Innovation System** (Fig. 15 in Form 3). The first and uppermost layer is the **Organization for Advanced Studies**, and **within this we have established as an autonomous entity the WPI-AIMR, which completed its mission as a WPI center in 2016 and has since been operating with funding from the university itself.** The proposed center AIMEC will similarly be a new addition to this layer. In addition to the WPI-AIMR and our three other world-leading Core Research Clusters that share the WPI-AIMR as their core unit (Fig. 15 in Form 3), the Organization for Advanced Studies comprises a Division for the Establishment of Frontier Sciences that opens up new areas of research, an International Joint Laboratory Center that uses international joint research to form global research hubs, and a Frontier Research Institute for Interdisciplinary Sciences where early-career researchers engage in cutting-edge interdisciplinary research in an independent environment. The organization is **pursuing world-leading integrative, cross-disciplinary, and frontier research, supported by priority investments under the President's leadership.**

This three-layered Research Innovation System and the Organization for Advanced Studies are **positioned as key initiatives in the Tohoku University Vision 2030** that sets out an ambitious outlook for the university's future toward 2030, and in the university's **Fourth Evaluation for Current Mid-Term Goals and Mid-Term Plan**. **Positioning the proposed center within the Organization for Advanced Studies will enable it to utilize the systems and expertise nurtured in the WPI-AIMR** and to function as a global research hub supported by full-scale priority investments.

The systems and know-how cultivated at Tohoku University will also be deployed across JAMSTEC, and Tohoku University as a whole will provide support such as coordination by the Executive Vice-Presidents and Vice-Presidents as required in order to enable integrated, "under one roof" operation of the center through robust collaboration, including with the University of Hawai'i.

(JAMSTEC's Commitment)

The main initial research to be pursued in this center, "Interdisciplinary and Integravitive Research of Physical, Chemical, and Biological Facets of the Marine Environment and Ecology in the Northwest Pacific," is consistent with JAMSTEC's **initiative on "research and development to understand the current status of the global environment and predict change," which is one of the research and development themes identified in JAMSTEC's Fourth Mid to Long-Term Plan (FY 2019 to FY 2025).**

In addition, in March 2023 we published the Manifesto outlining JAMSTEC's approach to activities moving forward, and we are currently pursuing the development of research and technology that requires strengthening from a long-term perspective, as well as establishing the mechanisms needed to realize such development. The **manifesto also declares JAMSTEC's aim to become a world-class research center**. We will thus collaborate with Tohoku University to **support activities of the proposed WPI center AIMEC and contribute to its development as a world premier research center** as part of JAMSTEC's Mid to Long-Term Plan and Manifesto.

Moreover, JAMSTEC will furnish equipment and facilities for the center including the use of its own

supercomputer, Earth Simulator, and provision of access to observational databases such as the Biological Information System for Marine Life (BISMaL). These contributions will **secure resources equivalent to or greater than the funding provided under the WPI program** as well as adding strong impetus to the center's activities. Expertise in areas such as system reform that are gained through the WPI initiative will also be deployed within JAMSTEC, and the entire organization will work in unison with Tohoku University to **deliver integrated support for the center.**

Development of human resources is positioned as **one of the key pillars of JAMSTEC's Manifesto**. We are committed to strengthening our research environment to attract outstanding young researchers from Japan and overseas, and enhancing the capability of the administrative personnels who support JAMSTEC. **The technologies and knowledge held by the talent we attract will be fed into initiatives that help actualize the WPI-AIMEC's research vision.** Moreover, this proposal is built on the many years of international joint research between JAMSTEC and the University of Hawai'i on the global environment and changes therein, centered on the Asia-Pacific region. It will **further advance collaboration between Tohoku University, JAMSTEC, and the University of Hawai'i** and support the formation of a research center of the highest international standard.

2) Provide a mid-to-long-term policy on the direction of each host institution's operating organization, one that includes the reform of the institution's existing organization in ways that will achieve the center's independence and create a permanent place for the center within each organization. A concrete plan must be established and a schedule set for carrying out the restructuring of each host institution's organization.

※Describe your mid-to-long-term policy on the direction of the host institution's operating organization and provide a concrete plan and schedule.

(Tohoku University's Commitment)

As a designated national university, Tohoku University is rapidly advancing **unified reforms of governance and operational funding** befitting a world-class research university, under the leadership of the President. The three-layered Research Innovation System described above is one part of these reforms. WPI-style management with personnel assigned across departments has been adopted in the WPI-AIMR within the Core Research Cluster, as well as the three other Core Research Clusters established in the abovementioned Organization for Advanced Studies. These Clusters have been **pursuing world-leading research supported by priority investments (strategic financial support, early-career research personnel support, etc.)** under the President's leadership, with environments and organizational structures for the advancement of world premier research already being put into place. **The Fourth Mid-Term Goals and Mid-Term Plan state the goal of raising the number of centers growing into the uppermost layer, toward further development of the Research Innovation System.**

The university established the WPI-AIMR as an autonomous entity from the outset. This status was maintained even after the end of the WPI grant period, as the institute continued to be afforded powers, resources, and infrastructure, including the allocation of tenured positions. Today, it maintains a scale and activity profile befitting a WPI-Academy center, and its stable advancement in the medium to long term is assured.

The proposed center AIMEC will also be positioned as a permanent entity within the Organization for Advanced Studies from the time of its establishment and will be allocated personnel and space, enjoying the university's robust support not only during the grant period but also in order to operate autonomously thereafter. The plan in the event that the center is selected for the WPI is to quickly complete the process of establishing a research support organization, including the assignment of successive employees required for the center's operation, by the end of the 2023 fiscal year.

If the center is selected, the **Working Group for a Future Vision for a World Premier International Research Center** (provisional title) will be formally launched as a permanent body involving executive officers from the Tohoku University and JAMSTEC, instituting a coordinated drive by the university and JAMSTEC to support the center's autonomous operation and to realize its action plan.

(JAMSTEC's Commitment)

Under JAMSTEC's Fourth Mid to Long-Term Plan, the head of each research division is granted considerable discretion in the management and conduct of research in their institute. In addition, pursuant to the Fourth Mid to Long-term Plan, new organizations have been established to pursue research not only funded by operating expense grants but also by external funds such as competitive research grants awarded to JAMSTEC. For the proposed center AIMEC too, a new organization will be established promptly following selection for WPI, and researchers and administrative support staff will be reassigned to it from existing organizations within

JAMSTEC. The organization thus established will be operated with a high degree of freedom even after the funding period has ended. Moreover, the responsible Executive Director of JAMSTEC will participate in the **Working Group for a Future Vision for a World Premier International Research Center** (provisional title) established promptly after selection, and will be involved in intensive coordination at the institutional level toward support for autonomous operation of the center and realization of plans for its development.

3) Describe the host institution's concept for allocating it's basic and other budgets and providing sufficient support for carrying out the center's operation and research activities, including necessary human, financial, and system support. In addition, when utilizing external funds other than the WPI grant for the center's operation and research activities, toward realizing the missions of the host organization, show the relationship between the center and other external funds.

(Tohoku University's Commitment)

Through the pursuit of outstanding education and research, Tohoku University is pushing forward with **a shift to engagement-style university management, which involves enhancing the university's brand, creating new societal value and strengthen the university's fiscal foundations through co-creation with a wide range of stakeholders, and strategically reallocating the internal resources generated thereby under the leadership of the President.** The President is directing the priority allocation of external funds to projects with strong growth prospects and large-scale integrative project research, so that enhanced external funding boosts the performance of the university as a whole.

As stated above, because of the center's importance, **the university has already committed to securing resources equal to or greater than the funding provided under this program** for the purpose of operating the center and supporting its research activities. We will assign successive faculty and administrative employees to the center as appropriate and pursue priority investments of university resources. We already have a track record of developing the systems to manage an alliance-type WPI center, and the Executive Vice-President for Research and the center director will engage in direct daily communication to ensure that the necessary systemic reforms are undertaken immediately.

Furthermore, guided by the **Connected University Strategy** drawn up in July 2020, we are vigorously advancing the **establishment of an international cross-appointment system, overseas dispatch of young researchers, remote provision of joint-use facilities, and new approaches to international exchange utilizing online tools**, with university-wide systems and environments already in place. We will actively mobilize this kind of institutional support also to enable the center to pursue a dynamic program of international research activities and become a hub of international talent circulation.

Growing the proposed center into a hub not only for the promotion of world premier research but also the university's governance reforms is one of the key pillars of Tohoku University's management strategy, and we will provide the personnel, funding, and systems needed to support it.

Support will also be provided by the university as a whole to acquire a wide range of funding and donations to be utilized in the center's operation and research, including the development of large-scale industry-university research partnerships with corporations and other partners based on innovative ideas generated by the center.

(JAMSTEC's Commitment)

JAMSTEC is strengthening the involvement of its President and Executive Directors in the development of basic policies and practical allocation of budgets pertaining to prioritization and efficiency gains in the assignment of personnel and prioritization of tasks and funds. Specifically, we have instituted a process whereby the Executive Directors coordinate across the institutes for which they are responsible with a view to outcomes in 2-3 years' time, and report the results of this coordination to the President, who ratifies them. This process ensures that resources are allocated in accordance with strong leadership. We have just invested the resources necessary for strategic advancement of programs in the 2023 fiscal year in line with the abovementioned Manifesto. In light of the importance of the proposed center WPI-AIMEC, we will provide strong personnel support through appointment of individuals who have worked as research directors in JAMSTEC and have experience in leading world-class research projects to positions in the proposed center such as deputy director, PIs, and administrative director. Furthermore, under the strong leadership of JAMSTEC's President and Executive Directors, we have committed to allocating resources to the proposed center equivalent to or greater than the value of funding provided by the WPI program. Specifically, JAMSTEC will provide robust backing for the WPI's activities by furnishing equipment and facilities including use of its own supercomputer, Earth Simulator, providing access to observational databases such as the Biological Information System for Marine

Life (BISMaL), and contributing know-how related to the operation and development of the autonomous observational robot Argo float. Additionally, we will establish a new organization immediately after the proposed center is selected for the WPI program and provide support essential for the center's operation and research activities including by reassigning researchers and administrative support staffs to it from existing JAMSTEC organizations.

We will also contribute to advancement of the proposed center by deploying the outcomes from activities by external funding from MEXT with the aim of generating and providing scientific evidence for use in the development of climate change adaptation policies and mitigation programs toward the realization of a zero-carbon society.

4) Provide for the independent operation of the center including after the WPI grant period ends. Provide necessary support to include the long-term provision of human and financial resources, facilities, equipment and other elements needed to retain the center as a "World Premier International Research Center." Based on coordination among the host institutions participating in the alliance, also secure and provide from an early stage of the center's establishment the infrastructure needed for it to carry out its activities (e.g. land, research facilities and equipment, research space), and do so with a commitment to continually maintaining this infrastructure after the WPI grant period ends.

(Tohoku University's Commitment)

As outlined earlier, when the WPI-AIMEC is established, it will be made part of the **Organization for Advanced Studies**. We already have a history of deploying the research and administrative systems developed by WPI-AIMR across the whole of the Organization for Advanced Studies, enabling maximal use of a variety of priority investments and strategies for personnel and financing. **This has led to a steady increase in the number of internationally highly-cited papers, greater international competitiveness, and joint research projects with corporations and other partners based on world-leading innovative ideas, realizing major achievements in the social application of research that include large-scale university-industry research partnerships.**

We will provide the proposed center with the same kind of robust support to enable it to pursue outstanding research of the highest global standards. At the same time, we will seek to attract a variety of external funding and donations, and make every effort to prepare for the center's autonomous operation in the future.

In terms of infrastructure, in the event that the center is selected for the WPI, initially it will make use of **4,000m^2 of common space owned by the Tohoku University and available for mutual establishment of multiple laboratories,** and later coordinate closely with JAMSTEC in the Working Group for a Future Vision for a WPI Research Center (provisional title) to construct, as soon as feasible, a building to **house the entire center to bring together the knowledge from two institutions and centers abroad under one roof**, securing infrastructure that can be utilized even after the grant period. We will not only provide sophisticated laboratory spaces and residences for PIs and associated researchers, but also facilities to promote interaction within the center and open laboratory space to accommodate joint research projects with external partners. These initiatives, together with the development of an environment that can be utilized freely by PIs based at JAMSTEC and overseas PIs, will enable us to build a platform that promotes research of the highest global standards.

(JAMSTEC's Commitment)

Even after the grant period of WPI, JAMSTEC will **continue to support the WPI-AIMEC in various ways** including provision of the Earth Simulator (one of the world's foremost computing resources) and expertise associated with marine observation, development of climate models linking the atmosphere and oceans, development of planetary system models in combination with ecosystem models, and the **provision of talent in the form of world leaders in research** utilizing our resources. Moreover, JAMSTEC will **continue to secure the space required for unified operation of the center together with Tohoku University**, contributing to the realization of the WPI center's vision as well as pursuing joint research projects and other initiatives that sustain the world-class research center developed through collaboration between Tohoku University, JAMSTEC, and the University of Hawai'i at Mānoa.

5) Provide a system that will in practice allow the center director to make decisions in implementing the center project, including personnel and budgets, and that will secure the autonomy of the center's operation.

(Tohoku University's Commitment)

As was the case for AIMR, in order to secure the autonomy of the center's operation under its director, we will institute an executive structure **that gives the director effective control over the center's personnel and budgetary expenditure**. Moreover, expenditure of subsidies within the center will not be tied to strict budgetary parameters, and funds – including those allocated from the university's general budget – will be used at the discretion of the director.

(JAMSTEC's Commitment)

JAMSTEC's Fourth Mid to Long-Term Plan commencing in 2020 created a system allowing the heads of each research institute to exercise a high degree of freedom in management, and facilitating the production of high-level scientific outputs. With regard to the operation of the proposed center, we will establish a new organization immediately following selection for the WPI program, and **institute a system that guarantees a high degree of discretion** for the center director with regard to matters such as personnel and budgetary expenditure.

6) Provide support to the center director by coordinating with other departments regarding assigning researchers to the center and creating an effective environment for the center within the host institution. Needed adjustments to do so should be made proactively while giving consideration to their effect on the educational and research activities of those departments.

(Tohoku University's Commitment)

In preparation for applying for this program, the proposal for this WPI center was fully coordinated within the host institution based on detailed coordination among the President, the Executive Vice President for Research, and the related departments. **Structures have been developed for close collaboration and cooperation with the home departments of PIs involved in the center on personnel affairs, administrative functions, research support, and supervision of doctoral students. The heads of departments participating in the proposed center have particularly high expectations in relation to doctoral student supervision.** After the proposed center is selected for the WPI grant, we will **support the center director and proactively coordinate across the university** to build a system enabling collaboration with related departments and the involvement of JAMSTEC PIs in educational activities, in order to invigorate the center's research activities and establish win-win collaborations that will advance education and research in those departments.

(JAMSTEC's Commitment)

The research institutes to which PIs participating in the proposed center are affiliated operate monthly divisional research meetings, which serve as opportunities for information-sharing to facilitate internal collaboration. In order to advance collaboration with other organizations within JAMSTEC, we hold monthly inter-divisional meetings chaired by JAMSTEC executives. The deputy director and/or administrative director of the proposed center will attend these meetings as required, engaging in discussion and coordination in order to develop systems for collaboration between the center and other associated organizations, thus supporting the center's activities in JAMSTEC and the work of the center director.

7) Offer cooperation in flexibly applying, revising, or supplementing the host institution's internal systems as needed for the center to effectively implement new management methods unfettered by conventional modes of operation (e.g. English-language environment, merit-based pay, top-down decision making, linkage to graduate school education).

(Tohoku University's Commitment)

As was the case with WPI-AIMR, the center will adopt a performance-based compensation system and a **top-down management approach**. **English will be the official language** for both lecturers and administrative personnel, enabling top-class researchers from Japan and abroad to gather at the center and invigorate its activities as a hub of international research activity. The proposed center will also deliver **high-quality support for research and daily life for international invited researchers.** The Organization for Advanced Studies where the center is to be located is already equipped with an **International Affairs Center (IAC)** that has functions including a research reception center and an international publicity office that conducts global outreach activities, and is staffed with **successive employees and other personnel who provide English-language support.** The know-how developed in WPI-AIMR will be leveraged to support the center based on strong

partnership with the International Support Center established in April 2022 as a university-wide organization providing support that enables international researchers to make a smooth start to their research activities at Tohoku University.

For post-graduate education, collaboration with the International Joint Graduate Program and other schemes has enabled us to reach agreement with related postgraduate departments on the participation of our center's researchers in postgraduate education and supervision, including in centers abroad. Further, we will establish a new **"WPI-AIMEC International Joint Graduate Program"** linked to transdisciplinary education systems unique to Tohoku University, namely the Massive Open Online Course (MOOC) developed by our Center for the Advancement of Open Online Education and the double degree system we have instituted through partnership agreements with leading universities overseas. We will provide strong support for university-wide coordination toward the establishment of this graduate program.

As part of promoting the value-adding of knowledge assets across multiple host institutions, we will proactively coordinate internally and across institutions to facilitate JAMSTEC's involvement in programs offered by Tohoku University's graduate schools, pursuing post-graduate education that leverages the diverse resources JAMSTEC has at its disposal.

(JAMSTEC's Commitment)

JAMSTEC already hosts a considerable number of international researchers, and is developing English-language administrative services and providing communications in English. We have already adopted a salary system that does not hinge on age seniority. After establishment of the center, the proposed center will **use English as its official language and employ similarly a salary system that is decoupled from age seniority. JAMSTEC has also entered into partnership agreements with 14 universities** and most of our researchers have experience in supervising students. Furthermore, our Manifesto sets out an organization-wide policy of strengthening and expanding research supervision and education, so the engagement in graduate school education and research supervision by researchers involved the center is consistent with JAMSTEC's policy

8) Provide other types of assistance to give the center maximum support in achieving its project and in becoming a world premier international research center in both name and deed.

(Tohoku University's Commitment)

Underpinned by Tohoku University's research strategy, international strategy, and management strategy, the center will serve as a platform for the design of a future vision built on collaboration with wider society, furnishing encounters with a wide variety of stakeholders and opportunities for procuring financial resources.

The center will be located in the Organization for Advanced Studies, the uppermost layer of the Tohoku University Research Innovation System noted above. It will provide a research organization of the highest world standard, as well as **developing robust intra-university collaborations** with the Tohoku University Graduate School of Science, Graduate School of Life Sciences, and Graduate School of Agricultural Science. In addition, through collaboration with the **International Joint Graduate Program, WISE Program, the Moonshot Research and Development Program** and other programs for which Tohoku University has already been selected, mechanisms **will be created for the sustainable development of the center from the perspective of "comprehensive knowledge" by promoting the participation of the diverse researchers and students across our comprehensive university** and the researchers gathered in the center itself.

An international administrative system extending beyond the center itself is currently being actively developed through university-wide reforms aiming to provide **one-stop, one-point administrative services** and greater administrative efficiency based on the **Introduction of Digital Administration at Tohoku University**. We will also enhance the **University Research Management Center**, at which high-level experts (University Research Administrator) conduct research analysis and offer research support, the **Core Facility Center** for device-sharing in remote environments, and the **International Support Center** that functions as a university-wide research reception center. Moreover, in April 2023, we established the Center for International Law and Policy with the aims of communicating knowledge on international law to wider society and delivering policy recommendations relating to the formulation of international rules. We will use the Center for International Law and Policy to apply the outstanding research outcomes of the proposed center in the formulation of international rules and norms, and policy recommendations. These activities will build a platform for the proactive promotion of joint research projects not only within the center but also with researchers from outside the university including at JAMSTEC and our overseas centers, with **priority services provided to the center in particular as a hub for international talent circulation.**

(JAMSTEC's Commitment)

We will build a robust collaborative framework within JAMSTEC, including links with the MEXT-Program for The Advanced Studies of Climate Change Projection (SENTAN) which forms part of the plan for enhancing the activities of the center WPI-AIMEC and the global research activities already carried out by the Research Institute for Global Change, which is most closely connected to the research activities of the proposed center. Collaboration with other related research institutes will also be pursued through various meetings such as cooperation meetings among research institutes. In collaborating with the center's researchers and a variety of other researchers and students gathering to the one roof in Tohoku University, we will deepen integration through cross-appointment systems and initiatives leveraging institutional partnership agreements. We will also develop administrative systems to support researchers involved in the center's research activities both by collaborating with existing research support organizations and by employing new personnel, taking into account the division of roles with Tohoku University's administrative organization.

9) Each host institution is to self-evaluate the results of the system reforms achieved by the center and distribute the results that it evaluates highly to all of the departments throughout its organization.

(Tohoku University's Commitment)

A university-wide cooperative system has already been built in relation to advancing the center as a permanent organization, as seen in its above-mentioned designation as a Center for Key Interdisciplinary Research. The **Working Group for a Future Vision for a WPI Research Center** (provisional title) will also be established immediately after the center's selection to ensure that outstanding innovations emerging from the center are deployed university-wide. Just as the system reforms achieved in the course of establishing WPI-AIMR as a world premier international research center have now been extended throughout the university, the proposed center will **conduct self-assessments as needed and, based on these, share its successful initiatives with the rest of the university to further advance the process of reforming the university's systems.**

Further, in April 2021, as a survivor of the Great East Japan Earthquake, Tohoku University established the Green Goals Initiative to further strengthen research and collaboration with society so as to resolve environmental and social issues and create a path toward a sustainable green society that is resilient in the face of natural disasters and infectious diseases. Through collaboration with the various projects pursued by the Green Goals Initiative, the scientific findings and results produced by the center will be deployed in social activities as the university's contribution to solving issues on the Global Agenda.

(JAMSTEC's Commitment)

In accordance with the Act on General Rules for Incorporated Administrative Agencies, JAMSTEC is obliged to conduct self-assessment at the end of June each year and publish the results, as well as reporting them to the MEXT Minister. For this purpose, the JAMSTEC President conducts self-assessment pursuant to an annual self-assessment meeting chaired and attended by JAMSTEC executive officers, which reviews the status of activities in the fiscal year in question. This arrangement will also be used in evaluation of the proposed center's research activities, and the feedback from evaluation will be shared through inter-divisional meetings and strategic meetings and applied across the whole of JAMSTEC.

10) (For host institutions that already have an existing WPI center and/or Academy center) Fully support and sustain the existing WPI and/or Academy center and advance its development as a world premier international research center, while being capable of fully supporting the new center at the same time.

(Tohoku University's Commitment)

Following the end of its WPI grant period, WPI-AIMR was certified as part of the WPI Academy, and continues to hold official status as an autonomous unit of the university, positioned as the Organization for Advanced Studies which comprises the first and uppermost layer of our Research Innovation System. **The university's Fourth Mid-Term Goals and Mid-Term Plan includes the progressive strengthening of that first layer through priority investments by the President and development and enhancement of its world-class research environment and research support system** as a university-wide objective. In acknowledgment not only of the steady progress made on developing WPI-AIMR since the end of the WPI grant period and but of its maintenance of high-quality research and international outlook, the **renewal of WPI-AIMR's WPI Academy certification was approved this year.**

Through activities such as the use of overseas satellites for international talent circulation and networking,

model initiatives in expanding employment through cross-appointments, and the internationalization of the university administrative organization, WPI-AIMR has taken the lead in reform of university systems and contributed greatly to raising the presence of Tohoku University internationally. The university is now pursuing system reforms under the **Tohoku University Global Gateway Strategy** designed to further strengthen the university's distinctive, self-reliant strategic management approach by enhancing its global brand. Establishing a position as a global gateway will enable the university to marshal knowledge from across the world, accelerate international industry-academia partnerships based on novel frameworks such as future business strategy development and talent development in companies, and thereby **strengthen its capacity to attract external funding and create of societal value in an era of great transformation.** External funding will be used under the President's leadership for priority resource allocation in accordance with a research portfolio strategy, with the aim of accelerating the development of the **positive cycle directed to operational strengthening** of the university, and using these resolute reforms to **enable the provision of ample support both for existing centers and for the development of new centers.**

11) (For host institutions that already have an existing WPI center and/or Academy center) Take the initiative to spread the existing centers' good system reform results to other departments throughout the host institution and apply them to implementing the host institution's own reforms.

(Tohoku University's Commitment)

Following the success of the WPI-AIMR, the President recognized the need for top-down international research institute management, distinct from the university's existing divisions and departments, and **the Organization for Advanced Studies was thus established in 2018**. This establishment provided the framework for the establishment of a WPI-style Core Research Cluster comprising four areas in which the university is particularly strong: (i) Material Science, (ii) Spintronics, (iii) Next-Generation Medicine, and (iv) Disaster Science. The cluster is now **promoting the generation of world premier class interdisciplinary research across the entire university**. Moreover, the know-how and logistical expertise in relation to planning and operating international conferences and hosting researchers from outside Japan that has been fostered by the WPI-AIMR has now been inherited by the International Support Center (an organization established in April 2022 to provide university-wide international researcher support), the International Affairs Center located within the Organization for Advanced Studies, and the Tohoku Forum for Creativity Programs, a residential visiting research program that is the first of its kind in a Japanese university. Furthermore, initiatives such as interdisciplinary research, career development for early-career researchers, and international talent circulation – areas of particular focus as part of WPI-AIMR's WPI mission – have had immense flow-on effects for the host university, and led to the establishment of organizations including the International Joint Laboratory Center and the Frontier Research Institute for Interdisciplinary Sciences, which are designed to support career development and provide interdisciplinary research environments for early-career researchers. In addition to these developments, the WPI-AIMR's new performance evaluation-based salary system has been applied to the university's Distinguished Researchers program, cross-appointment schemes have been established to attract talented researchers from outside Japan, and an outsourcing system has been introduced that enables international researchers to be paid compensation for specified tasks even if they do not come to Japan in person. These and other advancements show that **the outstanding achievements of WPI-AIMR have been proactively deployed throughout the host institution and have led to system reforms.**

World Premier International Research Center Initiative (WPI)

List of Principal Investigators

・If the number of principal investigators exceeds 10, add columns as appropriate.
・Give age as of 1 April 2023.
・For investigators who cannot participate in the center project from its beginning, indicate the time that their participation will start in the "Notes" column.
・If there are changes from the PI list in the first screening application documents, describe the points changed and reasons in the "Notes" column.
・Include principal investigators affiliated with satellite institutions. Give the name of their satellite institutions in the "Notes" column.

	Name	Age	Current affiliation (Department/ School/Institution)・Title	Specialization	Effort * (%)	Notes
1	Toshio Suga	60	Department of Geophysics / Graduate School of Science / Tohoku University・Professor	Physical Oceanography	90	Director
2	Fumio Inagaki	51	Department of Earth Science / Graduate School of Science / Tohoku University・Professor	Geomicrobiology, Earth Life Eengineering	80	Vice Director
3	Benjamin Horton	52	Earth Observatory of Singapore / Nanyang Technological University・Director	Oceanography	10	
4	Sabine Kasten	59	Section Marine Geochemistry / Alfred Wegener Institute・Head	Sediment geochemistry, Biogeochemistry	15	
5	Michio Kawamiya	53	Research Center for Environmental Modeling and Application / JAMSTEC・Director	Meteorology, Earth System Modeling	80	
6	Michio Kondoh	49	Department of Ecological Developmental Adaptability / Graduate School of Life Sciences / Tohoku University・Professor	Theoretical Ecology	80	
7	Takeshi Obayashi	47	Department of System Information Sciences / Graduate School of Information Sciences / Tohoku University・Professor	Systems Genomics	80	
8	Yusaku Ohta	44	Research Center for Prediction of Earthquakes and Volcanic Eruptions / Graduate School of Science / Tohoku University・Associate Professor	Solid State Geophysics	80	
9	Riko Oki	58	Earth Observation Research Center / Space Technology Directorate I / Japan Aerospace Exploration Agency・Director	Atmospheric and Hydrospheric Science	30	
10	Shuhei Ono	51	Department of Earth / Atmospheric and Planetary sciences / Massachusetts Institute of Technology・Professor	Isotope Geochemistry	25	
11	Niklas Schneider	60	International Pacific Research Center / Department of Oceanography / University of Hawai'i at Mānoa・Director, Professor	Oceanography	40	University of Hawai'i at Mānoa
12	Angelicque White	48	Department of Oceanography / University of Hawai'i at Mānoa・Professor	Biological and Chemical Oceanography	30	University of Hawai'i at Mānoa
13	Shang-Ping Xie	59	Scripps Institution of Oceanography / University of California, San Diego・Professor	Climatology, Physical Oceanography	30	
14	Cheryl Lynn Ames	52	International Integrative Research & Instruction / Graduate School of Agricultural Science / Tohoku University・Professor	Molecular Biology	80	
15	Shinya Koketsu	46	Global Ocean Observation Research Center / JAMSTEC・Director	Atmospheric and Hydrospheric Science	80	
16	Sherwood Lan Smith	52	Research Institute for Global Change / JAMSTEC・ Senior Researcher	Marine Ecology	80	
17	Sayaka Yasunaka	46	Center for Atmospheric and Oceanic Studies / Graduate School of Science / Tohoku University・Professor	Marine Environmental Sciences	80	

* Percentage of time that the principal investigator will devote to working for the center vis-à-vis his/her total working hours. (Activities carried out using competitive funding can be included as effort as long as they correspond to the purpose of the WPI center and are conducted for the center.)