



Science Action Plan (SAP) of CSK-2 (Final version)

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The Draft CSK-2 Science Action Plan (SAP) was prepared by the CSK-2 Task Force on SAP Development, which was formed as per the decision of the CSK-2 International Steering Group at its first meeting (virtual, 8 December 2021).

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1. Why the CSK-2?

The Kuroshio, one of the strongest currents in the world, is a warm ocean current on the west side of the North Pacific, originating from the North Equatorial Current near the east coast of Luzon, the Philippines. The Kuroshio flows northward along the east Taiwan Island into the East China Sea, returns to the Pacific Ocean through the Tokara Strait, and finally diverts eastward as the Kuroshio Extension (KE) off the east coast of Japan.

The Kuroshio holds vast cultural, social-economic value to most of countries in the North Pacific. It transports large amounts of heat and salt from the tropics to mid-latitudes, interacting and exchanging energy with atmosphere along its path, and thus moderating the global and regional climate. The Kuroshio, together with its adjacent current systems and the topography, forms a unique environment for material exchange between the land, marginal seas, the Kuroshio and the pelagic ocean. The transportation of nutrients and organisms by the currents and associated ocean processes gives way to a high level of marine biodiversity along the path, and contributes to abundant marine fishery resources in the Western and North Pacific.

Despite its importance, most of our knowledge about the Kuroshio is still limited to those generated from the Cooperative Study of the Kuroshio and Adjacent Regions (CSK), the first international ocean research project that the Intergovernmental Oceanographic Commission of UNESCO (IOC) conducted in the Western Pacific during 1965-1979. This project primarily focused on hydrography and fisheries along the Kuroshio path, with a number of observations and relevant studies conducted by participating countries. Since then, several oceanographic observation transect lines, such as the 137°E repeat hydrographic section, have been routinely observed. These time-series observations give an initial description of the climatological mean current patterns and volume transport of the Kuroshio and its branches. The CSK also enabled participating countries to establish infrastructure and build institutional capacity for ocean research, including oceanographic data sharing and management. The implementation of CSK stimulated ocean science cooperation among countries in the region, and finally led to the establishment in 1977 of a former IOC Working Group for the Western Pacific in 1977, which is now the IOC Sub-Commission for the Western Pacific (WESTPAC).

Over the past decade, the Kuroshio region has been known as one of the most responsive areas to the global warming. Its drastic changes seem to directly affect the regional weather and climate patterns. Moreover, it is becoming evident that the distribution of many organisms is changing and some of them are even at risk of becoming endangered as a result of global warming and escalating human activities. These changes to the Kuroshio are affecting various marine ecosystem services our society has been dependent on.

In this context, substantial knowledge gaps become increasingly prominent, and urgently need to be filled in the understanding of the Kuroshio, its changing conditions, and associated implications for regional and global climate change, biodiversity conservation and resources management in the region. Moreover, in view of the remarkable progress on observation and modelling technologies since the first CSK, the need for a new Kuroshio research becomes more pronounced against the backdrop of the ever-growing challenges for the sustainable development, especially for marine and coastal resources.

2. Objectives and Expected Outcomes

In response to the demands of these countries adjacent to the Kuroshio and the UN Decade of Ocean Science for Sustainable Development (2021-2030), the IOC Sub-Commission for the Western Pacific established the CSK-2 as a large scale multidisciplinary and multinational research programme. There are two major high-level objectives formulated for its initial development, which are:

Objective 1: to understand the Kuroshio and its impact on global and regional weather and climate, with a societal outcome to achieve improved regional weather forecasts and climate predictions;

Objective 2: to understand the Kuroshio in relation to its marine ecosystem, with a societal outcome to achieve better management of regional fisheries and aquaculture along the Kuroshio and in its adjacent regions.

To achieve the two objectives will rest on multifaceted science disciplines, including enhanced ocean–atmosphere, biological and biogeochemical observations, establishment and analysis of *in situ* and satellite datasets, model development, intake of local and indigenous knowledge. It will also involve science-innovation and science-policy interfaces, as well as capacity development and transfer of marine technology among participating countries and their institutions.

The establishment of a multinational and multidisciplinary framework for cooperation among countries and their institutions is essential for the CSK-2 to identify, generate and use required knowledge to achieve its societal outcomes. Therefore, the well-coordinated implementation of multidisciplinary projects, multi-sourced data and information management and efficient exchange and outreach among relevant stakeholders, communities and public will constitute important cornerstones of the cooperation framework.

3. CSK-2 Knowledge Gaps

The CSK-2 will provide a multinational and multidisciplinary framework to unite countries, their institutions, and diverse stakeholders interested in the study of

Kuroshio and its changing conditions. Required knowledge or knowledge gaps to achieve these objectives are identified towards the expected societal outcomes. This part covers the present knowledge gaps identified from a CSK-2 feasibility study and region-wide consultations among scientific communities. The CSK-2 may evolve with more knowledge gaps identified, as diverse stakeholders are continuously involved in the co-development process.

3.1 Weather forecasting and climate prediction

To achieve improved weather forecasting and climate prediction, the CSK-2 will enhance the understanding of multi-scale ocean dynamics and air-sea interactions in the Kuroshio and adjacent regions.

Multi-scale ocean dynamics

The Kuroshio exhibits multi-scale ocean dynamics, such as current-current and current-eddy interaction in its upstream, mesoscale eddy-current interaction in its Extension region, and current-turbulence interactions via topography at the straits along its path. These multi-scale interactions can significantly modulate the main features of the Kuroshio and its branch currents. Likewise, the Kuroshio constitutes an important part of the North Equatorial Current (NEC)-Kuroshio-Mindanao Current system (NKM), its multi-scale variations will modulate other currents in the NKM region and even the associated counter-currents, under-currents and the Indonesian Throughflow (ITF). The details of the required knowledge include, but not limited to, the following:

- Impacts of mesoscale variations and structure in the Kuroshio system.
- Interaction among current, mesoscale/sub-mesoscale eddies and topography in the Kuroshio and its Extension (KE) region.
- The spatiotemporal variations of the branch currents of the Kuroshio and their mechanisms.
- Multiscale variability of the NEC bifurcation and the mechanisms that control the heat and transport of the NKM.
- The role of the ITF in tropical and global climate systems.
- The mechanisms of sub-surface counter current connectivity and climate effect.

Multi-scale air-sea interactions

Intense and complex multi-scale air-sea interactions in Kuroshio and its KE plays a crucial role in the regional North Pacific climate and even in a global scale. The CSK-2 aims to understand the local and remote influence of the Kuroshio and KE front and mesoscale oceanic eddies on the atmosphere and associated dynamics and feedbacks. Meanwhile, the CSK-2 will also address whether the major interannual,

decadal, and inter-decadal climatic variability modes can influence oceanic processes in the Kuroshio and KE region, and what might be the relative contributions of these climatic modes. The required knowledge in this respect includes global, inter- and intra-basin, regional scale, mesoscale, and sub mesoscale air–sea interaction, and weather, sub-seasonal, seasonal, interannual, and decadal variations of air-sea interaction over Kuroshio, and KE region. The details of the required knowledge include, but are not limited to, the following:

- Impacts of meso- and sub mesoscale eddies to the local atmospheric responses
- Impacts of SST front to the atmospheric response
- Maintenance mechanism of SST front in the Kuroshio region
- Development and maintenance mechanism of meteorological and marine hazards in the Kuroshio region

3.2 Fishery and aquaculture management

The Western Pacific Ocean is one of the most productive regions in the world, as the Kuroshio transports substantial nutrients from the low-latitude and exchanges them with the adjacent regions through its branch currents. The nutrient concentration of Kuroshio-influenced regions is modulated by various processes, which include current boundaries, upwelling of deep water and mixing with subsurface water, mesoscale eddies, material exchange between the open ocean and marginal seas, and aerosol deposition. The interactions between the Kuroshio and the coastal circulations regulate marine ecosystem structures and functions, and sustain fishery and aquaculture.

To achieve better management of fishery and aquaculture, the CSK-2 will endeavor to understand the current status of the Kuroshio ecosystem and the impacts of the changing Kuroshio on fisheries and aquaculture in the region. The required knowledge for CSK-2 was identified as below:

- Natural and anthropogenic nutrient supply mechanisms in the Kuroshio region along the path.
- Phytoplankton community structure and productivity and their responses to natural and anthropogenic perturbations.
- Response of fishery target species to the change in the Kuroshio ecosystem.
- Response of the environment and productivity of aquaculture grounds along the Kuroshio to natural and anthropogenic perturbations.
- Future structure and productivity of the Kuroshio ecosystem under the global change.

4. CSK-2 Action Framework

The CSK-2 will stimulate, harness, facilitate and coordinate the development of inter- and multi- disciplinary ocean research to generate data, information and knowledge needed to achieve the CSK-2 objectives and societal outcomes. It will provide an international cooperative framework for participating countries, their ocean research institutions and other diverse stakeholders to advance ocean science and technological innovations, leverage resources and research infrastructures, enhance research capacity and ocean literacy, and foster meaningful partnerships.

Given its large geographic coverage and ambitious objectives, the CSK-2 will embody a number of initiatives-CSK-2 Actions. The CSK-2 Actions will involve creation of ocean information and knowledge through in situ and remotely-sensed observations and analysis, a hierarch of Earth system models, observational and modeling studies, particularly related to predictability. Each CSK-2 Action will be encouraged to integrate capacity development, including ocean literacy, as part of its development and implementation. To achieve its societal outcomes, the CSK-2 has been and will be continuously co-developed with various stakeholders interested in and/or benefitted from the Kuroshio.

4.1 Endorsements of CSK-2 Initiatives/Projects

To achieve its objectives and societal outcomes, CSK-2 will be underpinned by a number of initiatives addressing different aspects of the Kuroshio, which will be

Endorsement Criteria for CSK-2 Initiatives

1. Accelerate the generation of knowledge about the Kuroshio and its environmental, social and economic value, and contribute to fulfilling the UN Ocean Decade Challenges;
2. Contribute to the achievement of CSK-2 objectives: i. to understand the Kuroshio and its impact on global and regional weather and climate, with a societal outcome to achieve improved regional weather forecasts and climate predictions; ii. to understand the Kuroshio in relation to its marine ecosystem, with a societal outcome to achieve better management of regional fisheries and aquaculture along the Kuroshio and in its adjacent regions.
3. Endeavor to “co-design and co-deliver” the project with relevant stakeholders to facilitate the uptake of CSK-2 science and knowledge for societal needs;
4. Provide a feasible implementation plan, including a list of project implementation partners, liaise with ISG and communicate about the project progress;
5. Ensure the data and resulting knowledge are shared and deposited as per the CSK-2 data and information management plan;
6. Integrate capacity development activity as part of the project implementation for younger generation

developed and carried out by a wide range of stakeholders, including, but not limited to, governmental agencies, research institutions, international organizations/programmes, NGOs, and education sectors.

The request for endorsement of CSK-2 initiatives will be via periodic calls for CSK-2 initiatives, to ensure alignment of the proposed initiative with the CSK-2 objectives and societal outcomes. The initiatives in Annex I, proposed at the CSK-2 feasibility study, form a solid basis for CSK-2 at its inception stage.

4.2 Implementations and collaborations of CSK-2 Initiatives/Projects

The CSK-2 development workshops will be held on a regular basis, serving as one key means of implementation. It provides opportunities for discussions among, but not limited to, various CSK-2 initiatives, to share generated knowledge, review the progress, and explore synergies and possible areas of collaborations and partnerships. It will also be open to any partners who are interested in the CSK-2.

4.3 Collaborations with Stakeholders

The success of CSK-2 hinges on the ability of the programme to address the needs of the stakeholders. The CSK-2 key stakeholder groups cover a diverse range of communities, including various academia and scientific communities; national government agencies responsible for meteorology, fisheries, aquaculture, disaster risk reduction; business and private sectors, local communities, education sectors and the general public. Therefore, it is essential to get them engaged in the development process of CSK-2. Information and knowledge generated from the CSK-2 should be shared, discussed with relevant stakeholders, and translated into formats that could be used to serve their purposes.

4.4 Data and information management

Data and information generated from CSK-2 will be the cornerstones to achieving its objectives and societal outcome. The CSK-2 will adopt the IOC Oceanographic Data Exchange Policy, and further formulate its data and information management plan in line with the FAIR Data Principles (Findable, Accessible, Interoperable, and Reusable). The plan is attached as Annex III.

4.5 Capacity Development

Capacity development forms an integral part of the CSK-2, given the disparity in research capacity across generations, genders and countries in the region. Having a multinational collaborative program provides a perfect opportunity for students and early career researchers to advance their knowledge and spirits of cooperation. Participation in the research activities of different research groups will provide

exposure to different cultures, technologies, and operating procedures. The IOC Sub-Commission for the Western Pacific will facilitate the development of and/or the exchange of information on training opportunities/programs through its various networks and comprehensive capacity development tools, including the WESTPAC Regional Network of Training and Research Centers on Marine Sciences (RTRCs). Regular scientific symposia to exchange results and ideas will be scheduled. Opportunities of student scholarships and exchange visits will be explored with member states and institutions.

Kuroshio literacy is defined as the understanding of what the Kuroshio is, how it behaves, and how it interacts with people. The collaborative research that will be undertaken in CSK-2 will shed light on the impacts of Kuroshio, in particular on our regional and global climate and sustainability of fishery and aquaculture. CSK-2 will develop and conduct outreach activities to increase awareness on the Kuroshio and its importance, stimulate young generations and communities to appreciate the value of ocean science and cooperation, and ultimately engage in the collective effort to achieve ocean sustainability.

5. Coordination and Governance

To achieve the CSK-2 objectives and societal outcomes requires coordination at the regional/international level among member states, and their institutions. It also requires a co-design and co-delivery process with ocean stakeholders such as government agencies, non-profit organizations/non-governmental organizations, companies, educators, and citizens.

An International Steering Group (ISG) was established with a mandate to provide guidance and oversight, and make recommendations and report to the IOC Sub-Commission for the WESTPAC on the development and implementation of the CSK-2. The ISG, consisting of national representatives and experts from national agency closely related to CSK, and research or other relevant communities. The ISG will conduct their business in accordance with the Terms of Reference attached as the Annex II.

The WESTPAC Office will act as the primary coordination unit for the CSK-2 and the Secretariat for the ISG. The establishment of CSK-2 Support Offices will be explored, if deemed necessary, with participating countries and/or their institutions. These Support Office are legally separated from the UNESCO and its IOC, and operated under the responsibility of the host countries or entities. They will provide scientific and administrative support to relevant CSK-2 initiative(s) in cooperation with the WESTPAC Office.

As the CSK-2 will be continuously developed to accommodate emerging needs and changes over its timespan of nearly ten years, a reporting and monitoring process

will allow rapid identification of, and response to, those needs and changes. Each CSK-2 initiative will be required to report annually, in a succinct manner, on its progress, outputs and achievements. The ISG will review, from time to time, the progress of all CSK initiatives, provide recommendations on their further development, conduct comprehensive evaluations of the CSK-2 development, and eventually make necessary revisions or adjustments to the Science Action Plan.

Annex I: A non-exhaustive list of proposed CSK-2 initiatives during the CSK-2 Feasibility Study in 2021

(1) Time series observations of Kuroshio variability in the East China Sea

This project aims to obtain continuous time series of the Kuroshio variability at more than one latitude band in the East China Sea (ECS). By deploying mooring instruments to observe current velocities at different latitudes along the Kuroshio, this project would help understand the latitudinal connectivity and shelf intrusion of the Kuroshio in the ECS.

PI and contributors: Na, Hanna; Nakamura, Hirohiko; Nishina, Ayako; Min, Hong Sik; Kim, Dong Guk.

(2) Philippine Rise Integrated Marine Environmental Research

This project aims to achieve three objectives. The first is to conduct a more detailed study of the Benham Bank and the biophysical mechanisms which can potentially support the natural productivity of the bank. The second is to conduct a wider area investigation including the eastern Luzon, Luzon Strait and the NEC Bifurcation area, where the interaction of the Kuroshio and the Luzon shelf and coastline produces areas of enhanced biological primary production as well as the role of mesoscale eddies. The third is to build capacity of local government units and academic institutions along the eastern Luzon coast.

PI and contributors: Cesar Villanoy; Rene A. Abesamis; Wilfred John E. Santiañez; Rachel June Ravago-Gotanco; Victor S. Ticzon; Fernando P. Siringan; Caroline Marie B. Jaraula, Deo Florence L. Onda; Laura T. David; Charina Lyn Amedo.

(3) Air-Sea Interaction in the Kuroshio Extension and its Climate Impact Phase II

This project aims to develop sustainable observation networks in the Kuroshio extension region; establish the theoretical framework of the multi-scale ocean-atmosphere interaction in the mid-latitudes, especially in the Kuroshio extension region, to provide a theoretical basis for understanding and predicting the global climate change; reveal the key physical processes in determining climate change and improve the understanding of ocean and climate predictability in the Western Pacific.

PI and contributors: Lin Xiaopei; Chen Zhaohui.

(4) Assessment of Ocean Carbon Dynamics in the Sunda Shelf Region on dealing with Issues of Climate Change and Ocean Acidification

The project aims to do the following assessment: the spatio-temporal variability of the carbonate system in relation to the issue of ocean acidification, including its physico-chemical drivers; the flux of particulate and dissolved organic carbon that contributes significantly to carbon burial and enrichment of coastal and continental shelf sediment; seagrass's carbon stock and sequestration as an ecosystem service

useful for climate-change mitigation by means of reducing CO₂ emissions through the natural capacity of marine vegetation.

PI and contributors: A'an Johan Wahyudi; Patrick Martin; Hiroshi Ogawa; Hanif Budi Prayitno; Udhi Eko Hernawan.

(5) *The Circulation and Ecosystem Study in the Indonesian Seas under the Influence of the Western Pacific Variability*

This project aims to measure the circulation, material flux, biology, and ecosystem variability in the eastern Indonesian seas, i.e. eastern Sulawesi Sea, Maluku Sea, Lifamatola Passage, Halmahera Sea, Savu Sea, Timor Strait, and 133°E section.

PI and contributors: Adi Purwandana; Mochamad Riza Iskandar; Mochamad Furqon Azis Ismail; Dongliang Yuan; Li Yao.

(6) *Mid-latitude air-sea interaction studies through the Climatic Hotspot2 project in Japan*

The project aims to further the understandings mechanisms and predictability of mid-latitude ocean-atmosphere interaction processes that span multiple spatio-temporal scales (from extreme weather events to global warming) and interplay among them through tight collaborations of latest observational and numerical modelling tools.

PI and contributors: Masami Nonaka, and 60 contributors from Japanese universities and institutes

(7) *Hybrid-Intelligence estimation and Prediction of Ocean Productivity in the Kuroshio area of influence*

This project aims to estimate the variability of ocean primary productivity (PP) as precise as possible using various cutting-edge technologies; understand the PP related processes in detail to develop and/or improve marine ecosystem models; make better prediction of PP focusing seasonal to interannual variability by developing a hybrid-intelligence prediction system on top of coupled physical-biogeochemical dynamic models.

PI and contributors: Hyoun-Woo Kang; Choi Dong Han; Jang Chan Joo; Kim Dongseon; Kim Yong Sun; Kwon Minho; Lee Yeonjung; Min Hong Sik; Pak Gyundo; Park Jae-Hyoung; Park Geun-Ha.

(8) *Observations in the origin region of the Kuroshio*

This project aims to monitor the water mass modification to the east of the Philippines by the air-sea interactions and upwelling of the subsurface and to study the transportation of modified water by the currents to the East China Sea and the east of the Ryukyu Islands in terms of spatial scales from basin scale to submesoscale.

PI and contributors: Akira Nagano; Iwao Ueki; Takuya Hasegawa

(9) *Dynamical and ecological interaction between the Kuroshio and coastal circulation*

This project aims to investigate interaction between the Kuroshio and coastal circulations using state-of-the-art, numerical ocean circulation models.

PI and contributors: Tanaka, Kiyoshi; Miyama Toru; Toyoda Takahiro, Kutsuwada Kunio and Takahashi Daisuke

(10) *Ocean circulation in the Indonesian seas and its climate effects*

This project aims to estimate the transport of the ITF and study the variability and dynamics of the Pacific-Indian Ocean exchange.

PI and contributors: Dongliang Yuan; Wang Zheng; Zhao Xia; Wang Jing; Yang Ya

(11) *Subthermocline currents and eddies in the NEC-Kuroshio-MC region*

This project aims to build a long-term continuous observation network in the origin area of the Kuroshio, especially in the area east of the Philippine coast.

PI and contributors: Wang Fan; Zhang Linlin

(12) *Kuroshio Extension Observatory*

This project aims to maintain a long-term Ocean SITES reference time series in the Kuroshio Extension recirculation gyre.

PI and contributors for KEO surface mooring: Meghan Cronin; Adrienne Sutton; Dongxiao Zhang

PI and contributors for KEO sediment trap: Makio Honda

Annex II: Terms of Reference of the International Steering Group on CSK-2

The International Steering Group on CSK-2 will provide guidance and oversight, and make recommendations and report to the IOC Sub-Commission for the Western Pacific (WESTPAC), on the development and implementation of the CSK-2 programme.

Functions

- i. Review and provide inputs to the development of the CSK-2 Science Action Plan, and relevant strategic documents and guidelines;
- ii. Review the development progress on CSK-2, and recommend actionable strategies for engagement and resource mobilization to support CSK-2 development and implementation;
- iii. Provide coordination and facilitate collaboration among relevant countries and their institutions in the developments and implementation of CSK-2;
- iv. Promote the development of new CSK project(s) and ensure their outputs/outcomes to be in line with CSK-2 objectives and relevant operational guidelines;
- v. Review and recommend endorsements of new CSK-2 project(s);
- vi. Promote and raise awareness of CSK-2, and engage its stakeholders into the development and implementation;
- vii. Support communications, and provide information to the WESTPAC Office to enable its posting to the WESTPAC Website, and reporting or dissemination to IOC and other organizations; and
- viii. Submit reports, and if needed, make recommendations to the Sub-Commission and/or its advisory group.

Composition and terms

The ISG will consist of national representatives nominated by the WESTPAC Member States who are willing to participate in CSK-2. No more than three representatives could be nominated from each country with one preferably from national agency closely related to CSK, and 1-2 from CSK research or other relevant communities. Individual experts or other stakeholders could be invited, if deemed necessary. The WESTPAC officer and the Head of Office will serve as ex-officio members.

The Sub-Commission will seek the nomination once every two years. A member of ISG shall serve a two-year term and could be renominated for no more than three consecutive terms. The ISG will select two co-chairs, and their terms will be two years and can serve no more than two consecutive terms. In case of resignation, inactivity or other issues affecting the work of ISG, his/her replacement (substitute) could be recommended by her/his country, and the substitute shall perform the required functions for the rest of the term.

Meetings

The ISG will meet at least once per year to perform the functions. Specific sub-groups may be established and mandated for conducting technical tasks as decided by the ISG. These technical working groups may meet as often as required by their members.

Secretariat support

The WESTPAC Office will assume the secretariat function at the regional level, acting as the primary coordination unit for the CSK-2 and the Secretariat for the ISG. Decentralized secretariat support at the project level will be encouraged. These

structures shall have well-defined mandates which are developed in close consultation with the WESTPAC Office.

Annex III: Data and Information Management Plan for CSK-2