博士論文要約（Summary）

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氏名 Name：喬煜翔

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"General Introduction"

The Kuroshio transports large amounts of warm water from the tropics to the sea surrounding Japan. It has been known that the East Asian atmosphere system sensitively responds to the variations in the Kuroshio and its extension current (i.e., Kuroshio Extension). For example, from May to June, a rainy season in East Asia (i.e., the so-called Meiyu-Baiu season), a convective rainband embedded in the large-scale rain belt can be formed along the path of the Kuroshio in the East China Sea, because of the convective instability triggered by the Kuroshio warm water along with its overhead abundant vapor (Sasaki et al., 2012; Xu et al., 2011; Xu et al., 2017). Furthermore, our recent study found that the increase in the sea surface temperature over the Kuroshio, which was related to global warming, had contributed to the local rainfall enhancement during the Meiyu-Baiu season over the last four decades (Qiao et al., 2024), meaning the Kuroshio in the East China Sea plays a crucial role in the East Asian climate change. In addition, the Kuroshio is also important for the marine life dependent on the oceanic environment. For example, Igeta et al. (2022) suggested the interdecadal Kuroshio's trends contributed to the decrease of Japanese jack mackerel (Trachurus japonicus) along the southern coast of Japan (i.e., Pacific Ocean side) and the increase along the western coast of Japan (i.e., Japan-Sea side), through the particle-tracking experiments based on output from the data assimilation system.

Studies regarding the variability in the Kuroshio are necessary, because of its effects on marine biological resources, which are closely related to fishery, and also its impacts on terrestrial biological resources through severe weather such as strong rainfall, which is important to agriculture. Thus, many researchers had investigated the regional features of the Kuroshio or Kuroshio Extension on interannual to interdecadal timescale (Andres et al., 2009, 2011; Chang et al., 2015; Deser et al. 1999; Han & Huang, 2008; Jo et al., 2022; Kang & Na, 2022; Kuo et al. 2023; Liu et al., 2014; Liu et al., 2019, 2021; Nakamura et al., 2012; Qiu et al. 2003, 2005; Sasaki et al. 2011, 2013; Soeyanto et al., 2014; Taguchi et al. 2007; Wang et al., 2016; Wu et al., 2014, 2017, 2019; Yan et al., 2016; Zhang et al., 2020). However, no research has yet systematically explored the interannual to interdecadal variability of the Kuroshio over the entire stream. Therefore, as shown in Chapter 1 of this doctoral thesis, I first studied the decadal variability of the Kuroshio and Kuroshio Extension System. This was because it had not yet been established whether the Kuroshio–KE System responds with uniform spatial and temporal patterns throughout or whether different subsystems respond differently regarding variabilities on decadal timescale.

On the other hand, interannual variability in the East Asian climate tended to be amplified over the last 2 decades. For example, Fujiwara & Kawamura (2022) exhibited that the rainfall over southern Kyushu has varied remarkably on a quasi-4-year timescale since 2000, but not before 2000. As they explained, the El Niño–Southern Oscillation (ENSO) over the tropical Pacific underwent a type transformation, that is, the occurrence-frequency of the Central Pacific (CP) El Niño events have increased substantially after the 2000s, whereas that of the traditional Eastern Pacific (EP) El Niño events decreased
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(Lee & McPhaden, 2010; Yu & Kim, 2012; Freund et al., 2019). This type transformation of the ENSO had changed the teleconnection pattern due to remote responses of the atmosphere over the western Northern Pacific to the tropical air-sea conditions, and resulted in the amplification of the interannual variance in the rainfall of southern Kyushu.

The above-mentioned fact posed a question of whether the ocean over the western North Pacific has responded to the CP-ENSO after 2000. During the investigation for decadal variability shown in Chapter 1, I noticed that oceanic eddy activities over the subtropical countercurrent zone east of Taiwan, which plays a crucial role in the Kuroshio variability through the collisions with Kuroshio, experienced an abrupt transition regarding the timescale near 2005, that is, the eddy kinetic energy transitioned from quasi-decade to quasi-3-year variability east of Taiwan near 2005. With the investigation deepening, I finally found that the Kuroshio in the East China Sea also underwent the same timescale transition as the East Asia atmospheric system, implying that the ocean over the western North Pacific might have responded to the CP-ENSO effectively. Historically, most researchers tended to regard that the effect of ENSO on the Kuroshio in the East China Sea was unclear. Therefore, as shown in Chapter 2, I focused on the interannual variability of the Kuroshio in the East China Sea and dedicated to clarifying the mechanism of how the ENSO affected the Kuroshio in the East China Sea since 2005.

“Chapter 1”

On decadal timescale, it has not yet been established whether the Kuroshio responds with uniform spatial and temporal patterns throughout or whether different subsystems respond differently. Hence, in Chapter 1, we will investigate the synchronized features of decadal variabilities in current intensity and current position over the Kuroshio System. Hovmöller diagrams, showing the temporal and spatial variability for the Kuroshio System, indicated that the Kuroshio comprised three subsystems characterized by coherent phase relations: namely, 1) Kuroshio in south of Japan and Kuroshio Extension (KE), 2) Kuroshio from east of Taiwan (ETW) to East China Sea (ECS), 3) Kuroshio from east of Luzon Island to Luzon Strait. More importantly, we found an out-of-phase relationship in current intensity between the Kuroshio from ETW to ECS and the KE during 2006–2014, which governed almost the entire Kuroshio System. This synchronization was caused by coherent phenomena comprising two kinds of baroclinic Rossby wave propagations along the KE and the subtropical countercurrent (STCC), which was related to the Pacific Decadal Oscillation.

“Chapter 2”

On interannual timescale, previous studies had shown that interannually modulated East Asian summer precipitation was caused by an atmospheric response to the El Niño–Southern Oscillation (ENSO). However, it is still uncertain whether the western boundary of the North Pacific region dynamically responded to the ENSO; therefore, in Chapter 2, we aim to address this problem in terms of the relation of the interannual ECS-Kuroshio variability to the ENSO. We found that the surface velocity and position of the ECS-Kuroshio were synchronized on a quasi-3-year interannual timescale from 2005–2016. We further determined that, during 2005–2016, baroclinic Rossby waves along the STCC zone east of Taiwan, which were excited by wind forcings related to the ENSO, played a leading role in the interannual ECS-Kuroshio variability, and mesoscale eddy activities in the STCC zone probably played a secondary role. Moreover, we suggested that, since the mid-2000s, the change of the primary ENSO timescale and the amplification of the sea surface temperature variability in the tropical ocean have led to the occurrence of the quasi-3-year interannual variability of the ECS-Kuroshio through the western North Pacific atmospheric response to the ENSO.

“General Conclusion”

This doctoral thesis aimed to reveal the mechanisms for interannual to interdecadal variability in the Kuroshio using satellite observed data and other reanalysis data from 1993–2018. In Chapter 1, I studied the synchronized decadal variabilities in the Kuroshio–KE System. In Chapter 2, I focused on the interannual variability in the ECS-Kuroshio.

As a general conclusion, the atmospheric forcing related to the ENSO and PDO modulated the ECS-Kuroshio on interannual to interdecadal timescales, suggesting a sensitive oceanic response in the western boundary region to the climate change over the North Pacific. Importantly, variability in the ECS-Kuroshio has changed since 2005/2006 on both interannual and interdecadal timescales due to the changes in the ENSO and PDO, as described in Chapters 1 and 2. In the future, we should pay close attention to the phase relations of the ECS-Kuroshio to the ENSO and PDO to confirm whether the current mechanisms are robust or not.

On the other hand, how the PDO- or ENSO-related ECS-Kuroshio variability affected the local climate and oceanic environment is still unrevealed in the present study. Therefore, in the future, it is needed to construct a framework that clarifies the “bridge roles” of the ECS-Kuroshio in the relationships between the East Asian air-sea conditions and North Pacific climatic changes.