OUTLINE FOR PROGRESS REPORT (May 2021 – April 2023) AND FUTURE WORKPLAN AND BUDGET (May 2023- April 2025)

PROGRESS REPORT ON THE INDO-PACIFIC OCEAN ENVIRONMENT VARIATION AND AIR-SEA INTERACTION (IPOVAI)

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1. Introduction and justification

The whole Asia, Indian and Pacific Ocean areas have been facing two important scientific issues, that is, how to accurately forecast & project the burst of Asia summer monsoon and the evolution of Typhoon. The above two not only have high common research interests, and also are highly related with reduction and mitigation of marine hazards. Among all other physical processes, air-sea interaction is believed to play key role in the Indo-Pacific area.

From the point view of scientific research, air-sea interaction has been the key link between ocean and atmosphere, and so has received high attention from scientific community. However, compare with ocean or atmosphere, the data and accurate parameterizations on air-sea interaction are quite limited. What are the effects of surface wave in modulating momentum flux, and what are the effects of sea spray from surface wave breaking in heat flux between ocean and atmosphere? The effects of sea spray on heat transfer may be much larger than the traditional estimated flux. The vertical mixing in the upper ocean plays critical role in the regulation of sea surface temperature, and then air-sea interaction. All above scientific issues will definitely affect the performance of coupled models which are key tools for the forecasting of Asian monsoon and Typhoon. The scientific foci of this international cooperation project will be, (1) to collect data and develop parameterizations on air-sea interaction, especially to identify the role of surface waves; (2) to develop new air-coupled model based on new parameterizations; and (3) to test the performance of new model of the forecasting & prediction on Asia summer monsoon and Typhoon.

Regional air-sea interaction in the tropical warm pool region, ranging from eastern Indian Ocean to northwestern Pacific, plays key role in the multi time scale climate variability and associated natural hazard and modulating the Indo-Pacific warm pool, thus has important implications to climate variability of the region. As the key region of the global climate variation, warm pool area as well as the western Pacific region provides huge energy into the atmosphere, which induce kinds of climate variations with the help of instability. The Asian monsoon system presents dramatic impact on the WESTPAC member states and the relevant variations of the monsoon system always trigger huge disasters over Southeast Asian region such as flood and dry deduced from Asian monsoon, Typhoon deduced from tropical air-sea interaction. The variations of the Indo-Pacific area should be carefully addressed to lay the solid basis for the mitigation of marine and climate hazards.

While studies related to air-sea interaction in the warm pool region has significantly increased with more observations available and developed numerical model skills, our scientific understandings on the regional pattern of air-sea interaction and related mechanism, and its impact on the large scale atmospheric circulation are still quite limited. Scientific issues that need to be addressed include: What are the characteristics of the interannual variation of different ENSOs, IOD, IOB, and their intensity? What are the three dimension features of the key current system including Kurushio and Indonesia Through Flow (ITF) and their seasonal/interannual variation? What are the heat fluxes and SST pattern related to the different ENSOs, IODs? How does the monsoon change with different ENSO forcings? What is the potential impact of air-sea interaction on local climate and weather, e.g. monsoon rainfall and tropical cyclones?

To facilitate studies of air-sea interaction at different time scale in the warm pool region at larger spatial coverage, satellite remote sensing, field observation and regional air-sea coupled models have been employed to provide oceanic and atmospheric datasets of different variables, such as wind, SST, precipitation and salinity. Other variables such as air-sea fluxes can be calculated based on satellite or in situ observations. Using the relationship between the monthly mean near-surface air specific humidity, latent heat flux in the warm pool have been calculated mainly based on the Tropical Rain Measuring Mission Microwave Imager (TMI) and further verified using sounding measurements. Several latent heat fluxes in the warm pool derived from satellite measurement have also been compared with in situ observations. Although all products qualitatively reveal similar patterns in climatological fields, they have substantial differences with in situ observations. Simulations of air-sea processes over tropical Indian Ocean and Pacific are extremely sensitive to the momentum, fresh water and heat fluxes across the interface, which are usually represented by various parameterization schemes in models. Choices of the parameterizations strongly rely on observations under different meteorological and oceanic conditions. The determination of the exchange coefficients of air-sea fluxes not only depends on wind condition but also relies on the wave condition and other dynamical processes in the ocean. Large systematic biases still exist for climate models in the cold tongue, due to unique characteristics of air-sea interaction, such as high wind speed and evaporation, strong convection, and heavy precipitation. Over the past decades, many efforts have been dedicated to develop and improve air-sea coupled models in the warm pool region. Model errors are specifically related to coupling techniques, lateral boundary conditions, and data assimilation technology. To reduce the errors and obtain optimal parameterization schemes as well as initial and boundary conditions suitable for the warm pool region, large amount of observational data are essential.

2. Timeframe and objectives

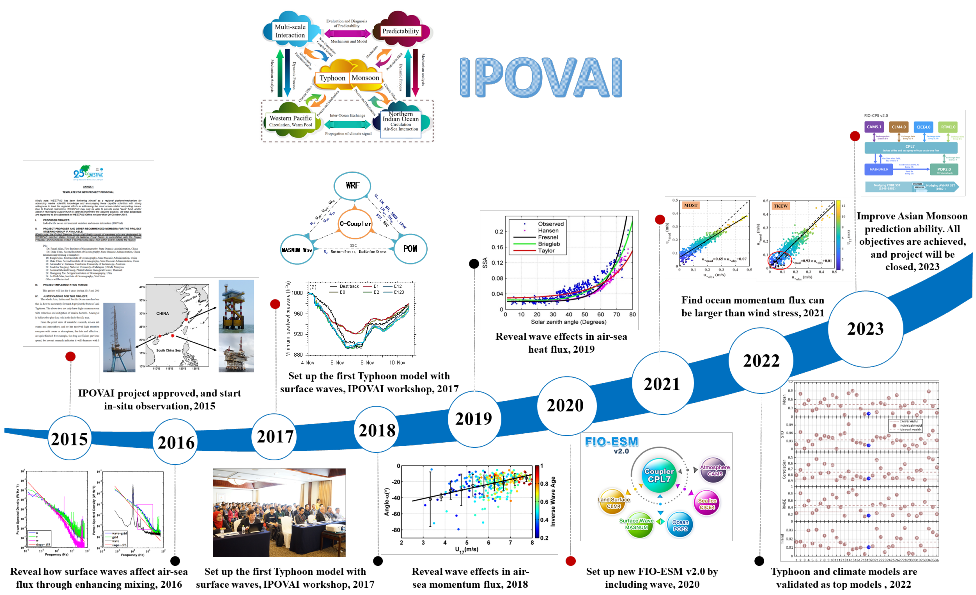

Figure The timeframe of IPOVAI

The objectives of this project are: (1) To get new findings on air-sea interaction through in-situ observation by considering surface wave; (2) To improve our scientific understanding on the role of surface wave in air-sea interaction in the Indo-Pacific Oceans, and get new parameterization on air-sea fluxes especially for high wind conditions; (3) To improve the prediction ability of typhoon intensity and Asian monsoon system.

The outcomes of the project are: (1) to advance our understanding on the dynamics of the Indian Ocean and Pacific oceans' natural variability, especially reveal the mechanism of air-sea interaction; (2) The results are expected to publish kinds of scientific papers; (3) The expected update schemes from this IPOVAI project, which are relevant to typhoon and monsoon prediction, will be useful for model development; and (4) most importantly, the forecasting models on Typhoon and monsoon will be improved, which can benefit all human beings along the coasts on Indo-Pacific area and all over the world.

3. Major activities, outputs & outcomes over the last intersessional period (May 2021-April 2023)

(1) We discovered the key role of surface waves in wind stress, and parameterized the process;
(2) We discovered the key role of sea spray in air-sea heat flux, and parameterized the process;
(3) We discovered the momentum flux in the ocean can be much larger than the wind stress, while scientific community believes that wind stress is the ceiling of momentum flux in the ocean;
(4) We developed new Typhoon model by including surface waves. The new Typhoon model can reduced the Typhoon intensity simulation error by 40% which has been a bottleneck problem for several decades. This is the solid base for accurate Typhoon forecasting;
(5) We developed new generation climate model by including surface waves, developed FIO-ESM v2.0 and jointed the CMIP6. This Earth System Model is validated and ranked top for all advanced 59 CMIP6 models. This is the solid base for accurate climate prediction;
(6) We propose a solution to improve prediction ability of the Asian Monsoon by considering the strong diurnal variation of sea surface temperature.

4. A summary of key achievements since its establishment

This IPOVAI project was approved in 2015. Since then on, with endless efforts from the project team, the following key achivements are received: (1) On scientific understanding: IPOVAI reveals the key role of surface waves in air-sea momentum flux; discovers that the momentum flux in the ocean can be much larger than the wind stress because of surface waves; finds the key role of surface wave in air-sea heat flux, especially the sea spray from wave breaking; (2) On new generation model development: IPOVAI developed new Typhoon model with surface waves which improves the whole year Typhoon intensity hindcast by 40%, while the Typhoon intensity simulation/hindcast/forecsast has been a bottleneck for several decades; IPOVAI developed new Earth System Model, FIO-ESM v2.0, by inclusing surface waves, and joined the 6th international Coupled Model Intercomparison Project (CMIP6). Lee et al. (2021) comprehensively evaluated all 59 CMIP6 climate models on their performance in reconstructing historical ENSO events, and FIO-ESM v2.0 ranked No. 1; Zhang et al. (2022) evaluated the performance and interdependency of 37 GCMs from CMIP6 in terms of seven key large-scale driving fields over 14 CORDEX domains, and concluded that MPI-ESM1-2-HR and FIO-ESM-2-0 rank top two. We proposed a scheme to improve the prediction ability of the Asian Monsoon by including the SST diurnal variation.

5. Self-assessment on implementation against objectives

Through the following comparison between objectives of IPOVAI project and results achived, we can get the solid conclusion that this project has perfectly achived all objectives.

Objective 1: To get new findings on air-sea interaction through in-situ observation by considering surface wave;

Results: Since 2015, IPOVAI project organized series scientific observation on air-sea fluxes, as these kinds of observation are very difficult. From the new data, we discovered the key role of surface wave in air-sea fluxes.

Objective 2: To improve our scientific understanding on the role of surface wave in air-sea interaction in the Indo-Pacific Oceans, and get new parameterization on air-sea fluxes especially for high wind conditions;

Results: IPOVAI has received the following parameterization schemes: wind stress by considering surface wave; heat flux by considering sea spray and Stokes drift; Albedo by considering surface wave.

Objective 3: To improve the prediction ability of typhoon intensity and Asian monsoon system.

Results: The simulation and forecasting of Typhoon intensity has been a bottleneck for several decades. IPOVAI gets a breakthrough on Typhoon intensity hindcast by killing the error of 40%, and it is under testing in Typhoon operational forecasting system in China meteorological Administration (CMA). For the Asian monsoon, we developed the new Earth System Model of FIO-ESM v2.0, and we find that diurnal sea surface temperature variation is a key factor to improve Asian Monsoon prediction.

6. Problems encountered and recommended actions

No problem encountered.

7. Objectives to be achieved, if applicable, over the next intersessional period (May 2023-April 2025)

This project has achieved all planned objectives, and will be terminated in April 2023.

8. Planned activities for May 2023- April 2025

This project is terminated in April 2023.