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Editorial: Air-sea interaction and oceanic extremes

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Editorial on the Research Topic
Air-sea interaction and oceanic extremes

1 Introduction

Air-sea interaction processes control the exchange of energy, momentum and mass between the atmosphere and the ocean. These interactions are crucial for the development of oceanic systems at various scales, from microscale to global scale. They play a significant role in the formation and development of oceanic extreme events, such as cyclones, extreme waves, and ocean heatwaves, which pose substantial risks to offshore operations and coastal communities. Therefore, improving our understanding of air-sea interaction processes and incorporating them into weather and Earth System Models is the key to enhancing climate and ocean prediction and helping mitigate potential damages. Despite overall advancements in understanding these interactions, many knowledge gaps remain, especially under extreme conditions. This Research Topic collects 29 papers addressing the following six aspects of air-sea interactions and oceanic extremes presented in the Editorial in a random sequence.

2 Tropical cyclones

Tropical cyclones (TCs) are among the most destructive oceanic extreme weather systems. Their development is heavily influenced by air-sea interaction processes that control air-sea energy transfer. This Research Topic includes seven papers focusing on TCs. Kim et al. investigated how reducing the air-sea drag coefficient (Cd) in high winds affects TC intensity, particularly rapid intensification and lifetime maximum intensity. The authors found that a reduced Cd increases net energy, preventing TCs from reaching a steady-state and potentially causing bimodal intensity distributions. Lee et al. introduced a new parameterization for air-sea fluxes at extreme wind speeds. By decreasing Cd at high winds, they improved TC intensity predictions, reducing errors and biases, especially for the strongest TCs. Xu et al. enhanced a bulk turbulent air-sea algorithm with a "bag-breakup" scheme for spume generation. Numerical experiments on TC Narelle showed that including spume effects significantly improved the accuracy of modeling minimum central pressure and maximum sustained wind speed, impacting TC's intensity, structure, and size. Li et al. developed a new air-sea turbulent fluxes product using data from a Drifting Air-sea Interface Buoy during Typhoon Molave, highlighting the significant impact of sea spray on heat and momentum fluxes during cyclone development. To get more valued sea spray volume flux information, which is key to estimating the turbulent fluxed during cyclones, Wang et al. established a self-consistent system to estimate sea spray volume flux from laser intensity, incorporating an environmental variable to bridge laboratory and field observations.

Intensive air-sea interactions during TC development can alter the oceanic environment. Zheng et al. analyzed interactions between Super Typhoon Megi (2010) and the South China Sea using an atmosphere-ocean-wave coupled model. They found that fully coupled high-resolution models with proper surface physical parameterization improve the accuracy of regional numerical predictions compared to stand-alone or partially coupled models. Park et al. validated satellite salinity data using Argo float data to assess oceanic responses to typhoons in the Northwest Pacific. They discovered that salinity decreases on the left side of typhoons correlate with higher precipitation rates.

3 Extreme waves

Extreme waves pose significant threats to offshore activities, shipping safety, and coastal infrastructure. Mentaschi et al. developed a high-resolution, 73-year hindcast of waves and storm surges using an advanced circulation-wave coupled model, which, validated against various observational data, shows enhanced skill in reproducing sea surface height and significant wave height, offering valuable insights for global-scale coastal risk applications. Oh et al. found that the radius of the 34-kt wind speed is a more accurate parameter than the radius of maximum wind for estimating the maximum significant wave height induced by TCs. Davison et al. investigated extreme ocean waves in crossing seas during Typhoon Kongrey (2018), revealing that second-order interactions between wind sea and swell can produce larger crest heights than unimodal seas. Additionally, Wu et al. developed a numerical simulation model for 3-D freak waves, verifying its accuracy and exploring their distinct electromagnetic scattering characteristics for improved identification in offshore engineering.

In addition to traditional models, machine learning models have been developed in recent years for predicting ocean surface waves. Hao et al. evaluated the performance of the recurrent neural network, long short-term memory network, and gated recurrent unit network models for predicting significant wave height, finding that optimal prediction occurs with a 24-hour input length and that prediction accuracy decreases with longer prediction lengths. Additionally, Hao et al. introduced CBA-Net, a deep neural network model using the attention mechanism for regional significant wave height prediction, which improves significant wave height prediction accuracy over traditional methods.

4 Marine heatwaves

Marine heatwaves can significantly affect marine ecosystems, causing coral bleaching, harmful algal blooms, and mass mortality of marine species. They also impact weather patterns and human activities, posing significant challenges for coastal communities and industries. Lee et al. investigated marine heatwave processes in East Asia's marginal seas, highlighting the crucial role of upper ocean stability and surface wind mixing in early summer. Their findings suggest that weakening surface winds, rather than gradual decreases in surface buoyancy, are primarily responsible for the recent increase in extreme heating events. These findings emphasize the need to test regional environmental hypotheses rigorously. Similarly, Jeong et al. examined marine heatwave events near the Korean Peninsula in 1994 and 2018, identifying the role of strong North Pacific and Tibetan Highs in driving warm, moist air into the region. They found that downward latent heat flux significantly contributes to increased sea surface temperature (SST), with model experiments showing improved marine heat wave simulation when accounting for downward latent heat flux. Additionally, Pak et al. explored the underlying mechanisms of the extreme marine heatwave in the mid-latitude western North Pacific in July 2021.

5 Mesoscale air-sea interactions

Mesoscale oceanic surface features can significantly influence air-sea interaction processes, which are often not captured by low-resolution models. Fernández et al. assessed the coupling between SST and the marine atmospheric boundary layer (MABL) in the northwest tropical Atlantic, revealing that the SST-MABL relationship varies with spatial scale. Their findings highlight that fine-scale SST features significantly increase latent heat flux, with dynamic contributions playing a major role, and these results were validated through high-resolution numerical simulations. Similarly, Teng et al. investigated the effects of wind stress on oceanic eddies in the northeast tropical Pacific using satellite data from 2000 to 2021. They found that wind stress work on eddies varies seasonally and is strongly linked to wind stress curl. Here, the wind energy input is sensitive to wind stress curl, challenging the notion that eddies always hinder wind energy input.

6 Large scale air-sea interactions

The air-sea interaction processes can also affect and be affected by large-scale climate systems. Uppara et al. found that interdecadal variations significantly influence sea level anomaly trends in the tropical Northwest Pacific, with the absence of La Niña events after 2012 contributing to the weakening trend from 1993 to 2020. Han et al. identified key factors contributing to July sea level variability in the East Sea from 1994 to 2021, including ocean heat transport divergence, atmospheric heat flux, and mass divergence, highlighting the need for precise analysis of these contributions.

Li et al. evaluated the ability of CMIP6 models to simulate the relationship between Hadley Circulation (HC) and tropical SST under different meridional structures, identifying significant inter-model differences. The models with accurate ENSO event simulations better capture the HC-SST relationship, suggesting improvements for modeling large-scale tropical air-sea interactions. Chen et al. examined the impact of mixed-type El Niño events on the double intertropical convergence zone (ITCZ) pattern over the eastern Pacific. They found that the combined effects of EP-type ("SST warming with a maximum at the equator") and CP-type ("north-warm and south-cold") SST anomalies in mixed-type El Niños amplify the north-south asymmetry of the double ITCZs, providing insights into the climatic effects of ENSO diversity. Li et al. investigated the formation of type-east extreme Indian Ocean Dipole (IOD) events, highlighting the role of strong East Asian and Australian monsoons in creating easterly wind anomalies that enhance vertical motion and upwelling. These conditions contributed to the transformation of type-east positive IODs into extreme events in 1961 and 1994, offering insights into IOD diversity. Meng et al. examined the influence of Southern Hemisphere SST anomalies on the Indian summer monsoon, highlighting the role of Wind-Evaporation-SST (WES) feedback in enhancing monsoon rainfall through northward-propagating intraseasonal oscillations.

Yu and Yang identified distinct warm and cold spots in the waters around Cape Cod, Massachusetts, using high-resolution satellite SST data. The findings reveal that Nantucket Sound has experienced significant warming, while Nantucket Shoals has seen cooling trends, highlighting the diverse responses of coastal waters to climate change. Warm blobs are persistently warmer-than-normal seawaters over the Northeast Pacific. Chen et al. examined the warm blobs in the Northeast Pacific during 2021 and 2022 based on a mixed-layer heat budget analysis, highlighting the significant role of atmospheric processes in their formation. The reduced latent heat loss and increased shortwave radiation were key factors, with the persistence of these warm blobs resulting from the interplay between atmospheric and oceanic processes.

7 Numerical simulations and model development

Numerical models are crucial for exploring air-sea interaction processes. Li et al. introduced an updated real-time Experimental Platform of Marine Environment Forecasting system for the North Indian Ocean (EPMEF-NIO), which now includes the western Indian Ocean and improved horizontal resolutions for weather forecasts. It also features a three-domain-nested wave forecast and extended forecast times. The system shows promising performance in weather, wave, and storm surge forecasts, attributed to advanced techniques like scale-selective data assimilation and handling of southern Indian Ocean swells. Qin et al. examined the prediction skill of the central Indian Ocean mode in subseasonal-to-seasonal models, finding that ECMWF and UKMO models perform best, and highlighted the need for better simulation of tropical subseasonal zonal winds to improve predictions during the Indian summer monsoon.

Han et al. simulated a sea fog event in the South China Sea using a coupled ocean-atmosphere model, finding that the coupled model more accurately predicted sea fog duration compared to the uncoupled model. They noted that air-sea temperature differences are important in fog formation and dissipation, with rising wind speeds being the main factor in fog dissipation.

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Conflict of interest

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