

Long-Term Global Wave Statistical Analysis Based on d4PDF Dataset

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Introduction

According to projections from the physical climate models assessed in the IPCC Sixth Assessment Report, continued carbon emissions are expected to drive a substantial rise in future sea level, potentially exceeding 1 m. To more comprehensively and systematically evaluate the evolution of global waves, we performed seamless, high-resolution global wave simulations using winds and sea-ice fields provided by multiple members of the d4PDF dataset.

In this project, we focus on the statistical characterization of significant wave height H_s , examining its annual mean and maximum value across different scenarios and estimating their return periods. We further quantify and compare the changes between a +2°C future climate and historical conditions.

Model Setting

d4PDF (Database for Policy Decision Making for Future climate change) is a large-ensemble climate dataset designed to quantify internal variability and scenario uncertainty. Each member represents an equally plausible realization generated by perturbing initial SST conditions, and more detailed information is referred to Table 1. We choose 3 members (HPB-m004, m005, m006) for historical hindcast for 1951 to 2010, and 3 members (GF-m101, MI-m101, MR-m101) for future forecast for 2031 to 2090. Their wind and sea-ice data are used as the forcing conditions in simulations.

We simulate global waves using WAVEWATCH III (WW3), a third-generation spectral wave model developed by NOAA. WW3 solves the action

balance equation with different contributions to give the wave information. We constructed a global unstructured mesh using OceanMesh2D and alphaBetaLab, achieving 5 km resolution in coastal regions while coarsening to 60 km in the open ocean to maintain computational efficiency. Wave model outputs are stored at a 2-hour temporal interval.

Result and Discussion

In Fig. 1, we present the annual mean H_s at a single grid point (lon = 136.75, lat = 34.92) across different d4PDF members. This location coincides with the NOWPHAS Isewan observation station. Owing to the imposed perturbations and model differences among the contributing institutions, the members exhibit similar overall tendencies, while showing noticeable discrepancies in finer-scale variations.

To assess extreme events in long-term evolution, we estimate return levels of the annual maximum H_s from each member. Fig. 2 shows the global distribution of the 10-year return level of maximum H_s derived from HFB-2K-MI-m101. Elevated values appear over the North Pacific, North Atlantic, and the western and southern Indian Ocean, indicating enhanced risk of extreme waves in these regions. Notably, the waters southeast of Japan exhibit the highest values globally. In Fig. 3, we present regionally averaged H_s across different return periods. The historical hindcast shows relatively small differences among members, whereas the future forecasts exhibit larger variations. Overall, the +2K future climate indicates an increase in extreme wave levels.

Table 1 Source datasets for SST boundary conditions used in d4PDF experiments

Member Name	Institute & organization
COBE-SST2 (HPB-m004, 005, 006, historical)	MRI (Japan)
GFDL-CM3 (GF), +2K, m101	NOAA (USA)
MIROC5 (MI), +2K, m101	AORI, NIES, JAMSTEC (Japan)
MRI-CGCM3 (MR), +2K, m101	MRI (Japan)

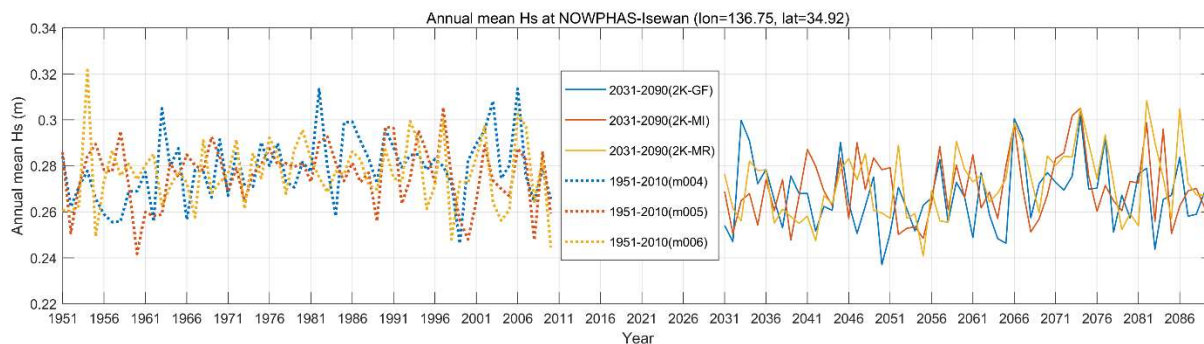


Fig. 1 Annual mean significant wave height at NOWPHAS Isewan station from different d4PDF members

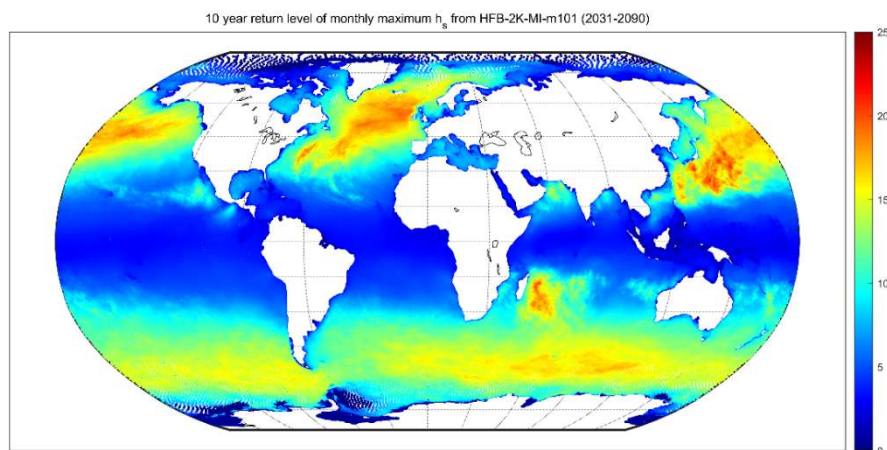


Fig. 2 10-year return level of maximum significant wave height estimated from +2K MI m101 (2031-2090)

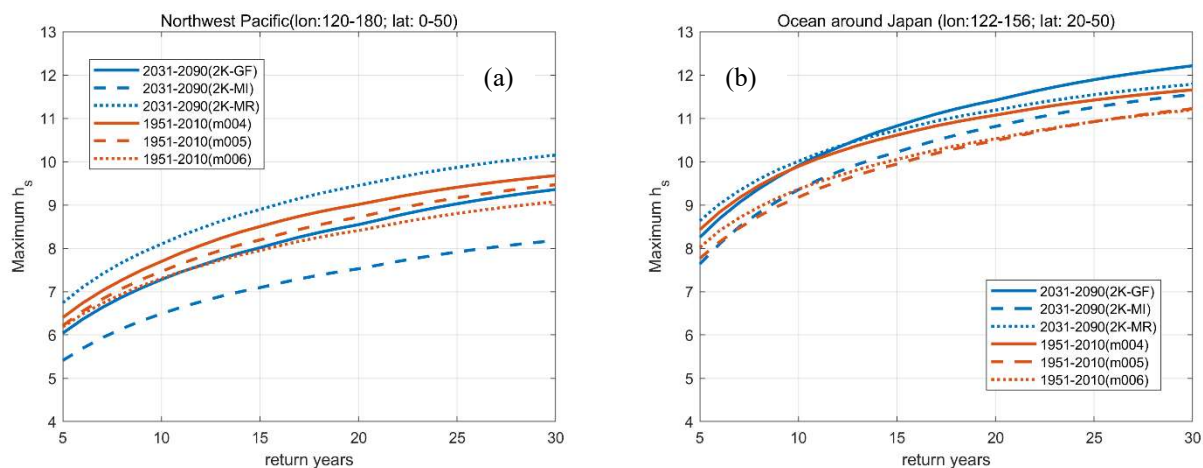


Fig. 3 Regional-averaged significant wave height at different return periods (years) from different d4PDF members.

(a): Northwest Pacific; (b): Ocean around Japan.