Propagation route and speed of swell in the Indian Ocean

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Abstract The characteristics of swell propagation play an important role in the forecasting of ocean waves as well as on research on global climate change, wave energy development, and disaster prevention and reduction. To reveal the propagation routes, terminal targets and speeds of swells that originate from the southern Indian Ocean westerly (SIOW), an intraseasonal swell index (SI) was defined based on the 45-year (September 1957-August 2002) ERA-40 wave reanalysis data product from the European Center for Medium-Range Weather Forecasts (ECMWF). The results show that the main body of the SIOW-related swells typically spread to the waters off Sri Lanka and Christmas Island, while the branches spread to the Arabian Sea and other waters. The propagation speeds of swells originated in the SIOW were fastest in May and August, followed by November, and were slowest in February. Swells usually required 4-6 days to propagate from the western part of the SIOW to the waters off Sri Lanka and Christmas Island, whereas swells usually required 2-4 days to propagate from the eastern part of the SIOW to the waters off Christmas Island.

Introduction Swells in the ocean can often be surprisingly destructive and lead to phenomena such as hogging and sagging, which can cause serious damage to ships. After being generated by a storm, waves can propagate very long distances with little attenuation until they break and dissipate upon reaching a coast. These characteristics make swells an indicator of various atmospheric phenomena such as tropical cyclones, distant storms, or even large-scale sea breezes such as those related to monsoons. Swells also have significant impacts on the transport and dispersion of oil plumes within the ocean mixed layer, ocean surface roughness, wind stress, and other things. Because of their substantial energy and good stability, energy production from swell waves has received increasing attention. Studies have shown that swells have a dominant status in a mixed wave, which means that swells also have a significant impact on air-sea interactions and global climate change. As a result, in-depth study of the characteristics of swells has practical value for swell wave power generation, ocean wave numerical simulation and forecasting, and studies of global climate change.

Although data on swells are extremely scarce, previous researchers have provided important insights into swell generation and propagation. To date, studies of swell propagation routes, terminal targets and propagation speeds have been relatively rare. In this study, the SIOW was divided into 4 regions. The swell index (*SI*) of each region was then defined to analyze the swell propagation characteristics, primarily their propagation routes, terminal targets and propagation speeds, to provide a reference for ocean wave forecasting, energy development from swells, studies of air-sea interaction, and other applications.

Methods The southern Indian Ocean westerly (SIOW) was first divided into 4 regions as shown in Figure 1. The propagation characteristics of swells that originated in these 4 regions were then examined in the following analysis. Regions T1, T2 and T3 were randomly selected experimental areas chosen to determine if the SIOW-related swell could propagate to regions T1, T2 and T3. Regions E and F were the key regions of swell propagation terminal targets. The sub-daily scale swell index of a certain region was defined. Then, the SI of regions A, B, C and D were calculated to analyze the characteristics of swell propagation. Calculation of the simultaneous, leading and lagging correlations between SI and swell energy in each bin then revealed the propagation route, terminal target and propagation speed.

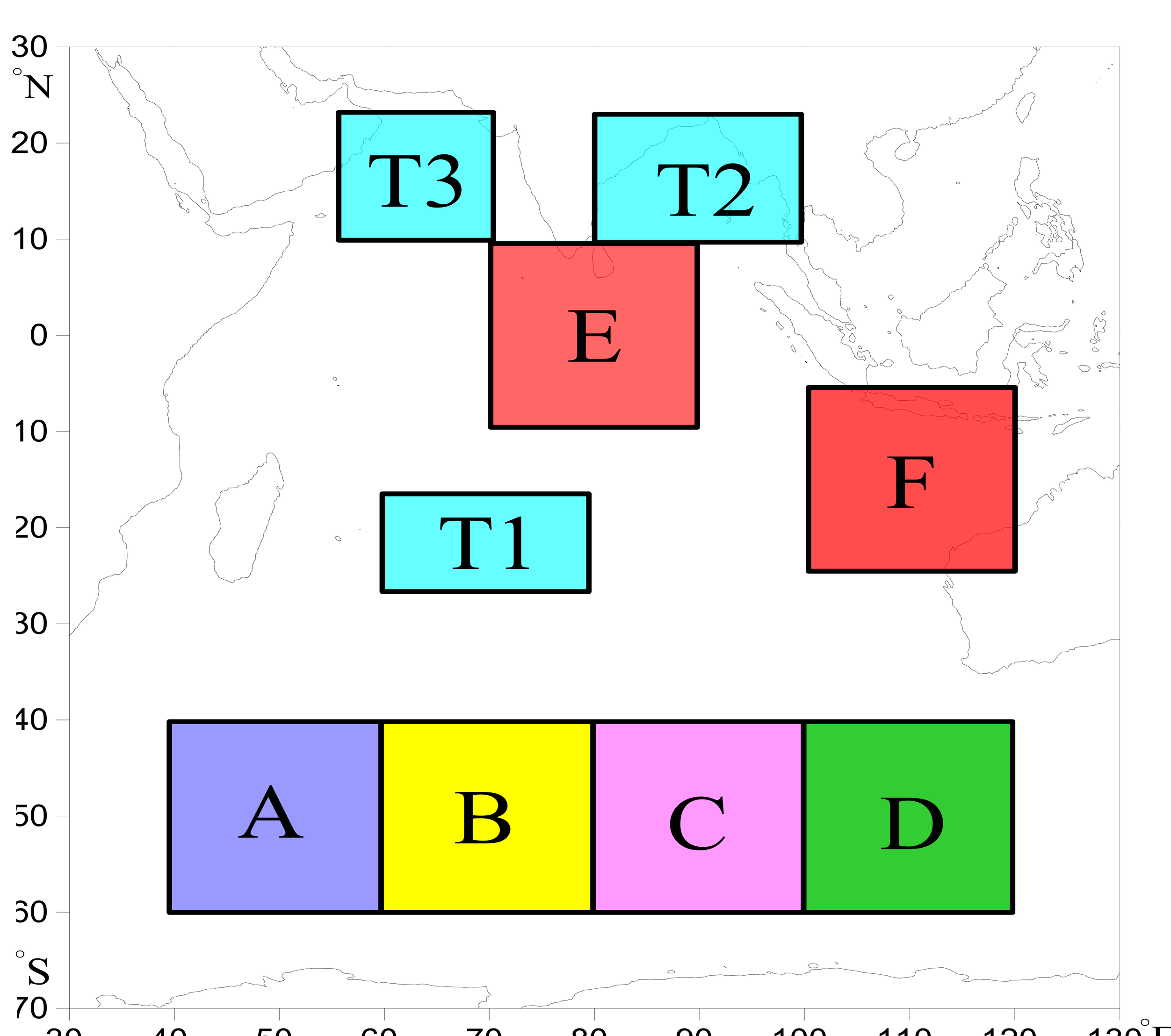

Figure 1. Geographical features of the Indian Ocean and the important regions in this study.

Results The 6-hourly values of sea surface wind speed (WS), wind sea wave height (H^w), swell wave height (H^s), and mixed wave height (H_s) for July 2001 and January 2002 were selected. A 6-hourly zonal average for each element was then calculated to exhibit the northward propagation phenomenon of each element, as shown in Figure 2.

Obviously, the 2.0-m contour of H^s in January exhibits an obvious northward propagation and southward shrinkage characteristic. Similar phenomenon can also be found in July through the 2.5-m contour of H^s. However, the H^w does not exhibit this phenomenon.

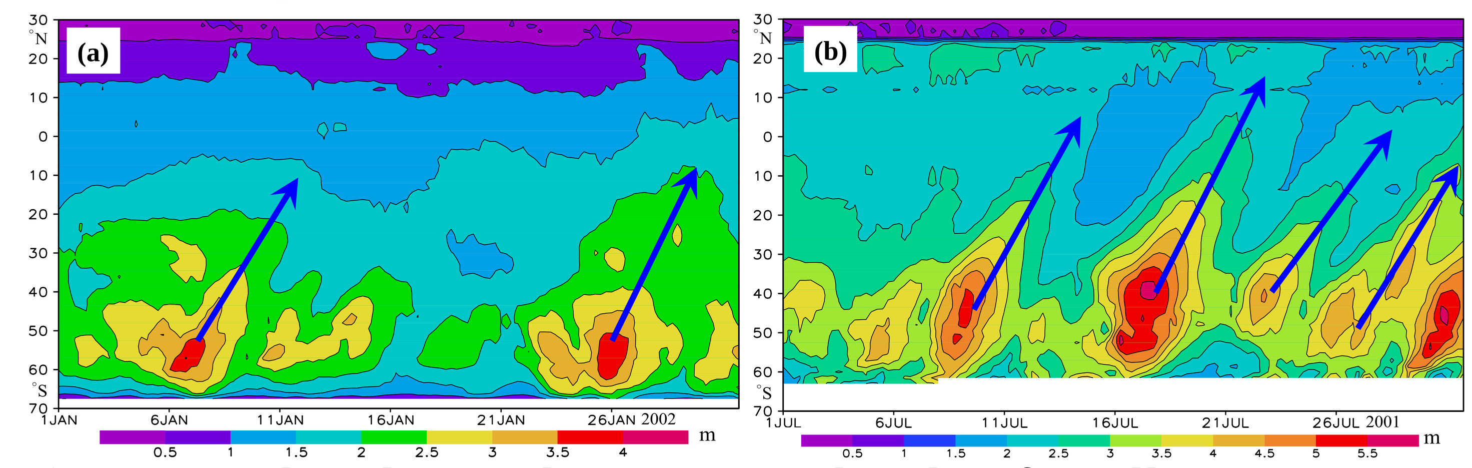

Figure 2. 6-hourly zonal mean wave height of swell waves in January 2002 (a) and July 2001 (b).

The correlation coefficients (CC) between 6-hourly SI_A and simultaneous H^s at each bin in JJA 2001 was calculated. The CC between the 6-hourly values of H^s at each bin for a lag of 48, 96, 120, 144, and 168 hours separately and SI_A in JJA 2001 were calculated. The relatively large areas in each panel were highlighted and then connected with a single line, as shown in Figure 3, where the red arrow represents the main propagation route. Similarly, the propagation routes of swells that originated in regions A, B, C, and D in JJA and DJF are obtained.

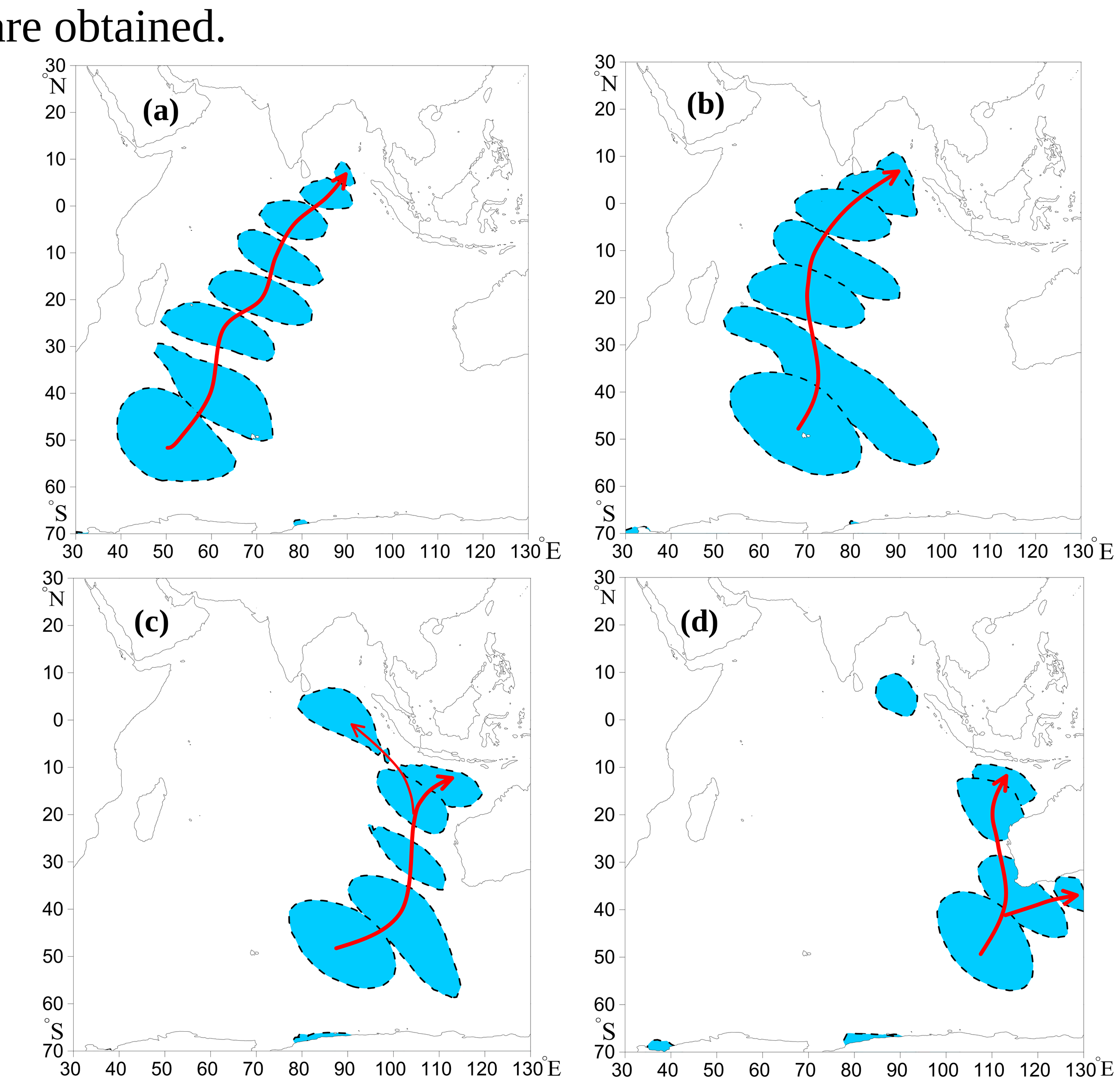

Figure 3. Main propagation routes of swells that originated in regions A, B, C and D in JJA 2001.

It can clearly swells that originated in SIOW often propagated to two areas: the waters off Sri Lanka and Christmas Island. The multi-year average CCs from January to December between swells of the above regions were calculated; only the CCs between regions C and F are presented in Figure 4. SI_C clearly plays a leading role in each month. The correlation coefficient (CC) usually reaches the peak value and SI_C leads by 10-20 intervals (60-120 hours). In July, the CC reached its peak value of 0.53 (significant at the 0.001 level) when SI_C led by 14 intervals (84 hours). This result means that the propagation of swells from region C to region E required approximately 84 hours. The swell propagation speed from region C to region E in each month could be obtained in the same way.

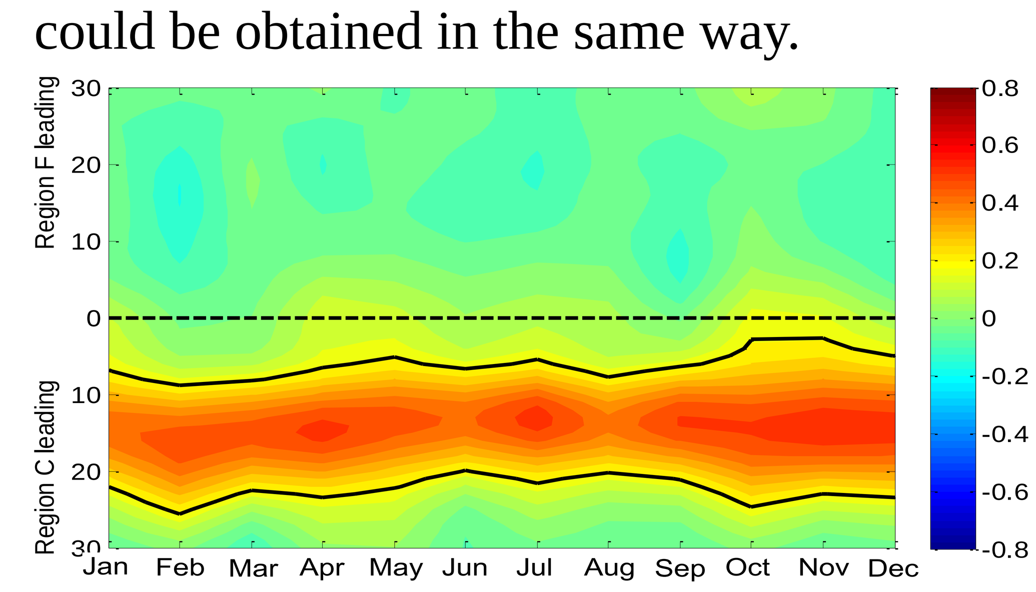

Figure 4. Monthly characteristics of leading and lagging correlations between swells in regions C and F.

Conclusions The propagation routes, terminal targets, and propagation speeds of SIOW-related swells were analyzed. Results were as follows:The main body of the SIOW-related swells mainly spread to the waters off Sri Lanka and Christmas Island.

The swell propagation speed in the Indian Ocean was fastest in May and August, followed by November, and was slowest in February. Swell usually required 132-144 hours to propagate from region A to regions E or F, 108-132 hours to propagate from region B to regions E or F, 78-90 hours to propagate from region C to E/F, and 54 hours to propagate from region D to region F.