

## Mechanism of long-term change in the Indian Ocean subtropical dipole mode

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The Indian Ocean subtropical dipole (IOSD) is a climate mode in the Southern Indian Ocean associated with negative sea surface temperature (SST) anomalies in the southeastern tropical Indian Ocean and positive SST anomalies in the southwestern part of the southern Indian Ocean during its positive phase. In this study, the long-term change in the IOSD is investigated for the first time using observational data and outputs from an ocean general circulation model. It is found that the frequency of the IOSD has become higher in the recent decade because of a decreasing trend in the mixed layer depth (MLD) over the southwestern pole in January and February. Positive (Negative) SST anomalies associated with the IOSD are generated when the mixed layer becomes anomalously shallow (deep) and the warming of the mixed layer by the climatological shortwave radiation is enhanced (suppressed). The thinner mixed layer in the recent decade amplifies this effect and even weak atmospheric forcing may trigger the IOSD. Based on a diagnosis of the Monin-Obukhov depth, we show that an increasing trend of surface heat flux is the cause of the decreasing trend in the MLD. On the other hand, it is found that the amplitude of the IOSD has become smaller. This is because the IOSD generally starts to develop in December, but the thicker mixed layer in December in the recent decade is unfavorable for its development. Also, the thinner mixed layer in January and February amplifies the negative feedback processes that damp the SST anomalies, as well as the positive effect on generating the SST anomalies. Since no long-term change in atmospheric forcing corresponding to that in the IOSD is observed, the long-term change in the MLD is essential in that of the IOSD.