A Road Map to IndOOS-2
Better Observations of the Rapidly Warming Indian Ocean

This online supplement contains Fig. ES1, as well as a detailed description of the methods used to obtain all the figures in the manuscript.

**Detailed methods of the figures in the main text**

**Methods for Fig. 3.** The datasets used for Fig. 3 climatologies are the World Ocean Atlas 2018 for sea surface temperature and 20°C-isotherm depth (Locarnini et al. 2018), sea surface salinity (Zweng et al. 2018), and oxygen (Garcia et al. 2018); the TropFlux dataset for wind stress (Praveen Kumar et al. 2013); the GPCP dataset for rainfall (Huffman et al. 2009); and the Behrenfeld and Falkowski (1997) dataset for primary productivity.

**Methods for Fig. 4.** Figures 4a–4d were obtained as composites based on the MJO and monsoon intraseasonal oscillations (MISO) bivariate indices of Kikuchi et al. (2012). The displayed composite correspond to phases 2 and 5, with a normalized amplitude larger than 1, of the MJO and MISO as defined in their paper, based on 25–90-day filtered OLR (Liebmann and Smith 1996) and v05.0 Microwave OISST (Wentz et al. 2000) obtained from http://data.remss.com/SST/daily/mw/v05.0/netcdf/ and averaged on the OLR 2.5° × 2.5° grid. In Fig. 4e, the influence of coupled processes on the MJO forecasting skill has been investigated in the European Centre for Medium-Range Weather Forecasts (ECMWF) Extended-Range Forecasting System. A series of subseasonal (extended range) forecasts initialized daily over the Tropical Ocean and Global Atmosphere Coupled Ocean–Atmosphere Response Experiment (TOGA COARE; Webster and Lukas 1992) period were performed using the ECMWF seasonal forecasting system (Molteni et al. 2011) with sea surface temperatures (SSTs) provided by persistence of initial conditions, observed SSTs, and coupling to a full dynamical ocean model with vertical resolution in the upper ocean typical of coupled models (10 m). The subseasonal forecast experiment with the full dynamical ocean model showed improved forecast skill for the MJO compared with the persisted and observed SST experiments, indicating that accounting for coupled processes improves MJO forecasts.

**Methods for Fig. 5.** The SST anomalies (in °C) associated with various climate phenomena in the Indian Ocean are obtained as follows. We use HadISST monthly data (Rayner et al. 2003) over the 1982–2014 period. The monthly climatology and linear trend are removed. SST patterns

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Fig. ES1. As in Fig. 3 in the main text, but for boreal winter (DJFM) observed climatologies of (a) sea surface temperature (colors) and wind stress (vectors), (b) primary productivity estimate (colors) and 200–1,500 m average oxygen (contours), and (c) sea surface salinity (color) and rainfall (contours).
of each mode is then obtained through regression to the normalized indices of the Indian Ocean Basin Mode (IOBM; Fig. 5a), the Indian Ocean dipole (IOD; Fig. 5b), the Indian Ocean subtropical dipole (IOSD; Fig. 5c), and Ningaloo Niño (Fig. 5d). The IOBM index is defined as the first principal component of SST anomalies over the tropical Indian Ocean (20°S–20°N, 40°–110°E). The dipole mode index for the IOD is defined from SST anomalies in the western pole (10°S–10°N, 50°–70°E) minus those in the eastern pole (10°S–0°, 90°–110°E). The IOSD index is defined as SST anomalies in the northeastern pole (18°–28°S, 90°–100°E) minus those in the southwestern pole (27°–37°S, 55°–65°E). The Ningaloo Niño index is defined as area-averaged SST anomalies between 28° and 22°S and from 108°E to the coast. The annotations on the top of these figures summarize the main impacts of these climate modes, obtained from a literature review (see the main text for citations).

**Methods for Fig. 6.** In Fig. 6a, the monthly 0–700-m mean temperature time series is calculated based on a gridded ocean temperature product from Cheng et al. (2017). The Indian Ocean is defined as the oceanic region north of 35°S and between 25° and 125°E, including the Red Sea and Persian Gulf, but excluding the Great Australian Bight. Twelve-month running means are plotted. The shading around the globally averaged temperature time series indicates the 95% confidence interval. In Fig. 6b, the 0–2,000-m heat content is obtained from Argo data as described in Desbruyères et al. (2017). Figure 6c shows the multimodel mean of the projected primary productivity change by the end of the twenty-first century for the 16 CMIP5 (Taylor et al. 2012) models, which provide a primary productivity estimate under the RCP8.5 scenario. The projected change of each models is estimated as the 2080–99 mean from the RCP8.5-scenario run minus the 1986–2005 mean from the historical run.

**Methods for Fig. 7.** This figure is based on six net heat flux at the ocean surface products over the 2001–15 period: Climate Forecast System Reanalysis (CFSR), ECMWF interim reanalysis (ERA-Interim), Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2), NCEP–NCAR Reanalysis 1 (NCEP-1), National Oceanography Centre Surface Flux Climatology, version 2 (NOCv2), and the combination of the objectively analyzed air–sea fluxes–high-resolution analysis of surface turbulent heat fluxes (OAFlux-HR) and Clouds and the Earth’s Radiant Energy System Energy Balanced and Filled (CERES EBAF4.0) surface radiation data product.

**Methods for Fig. 8.** The surface drifters and Argo locations on the map are those in December 2019. The Research Moored Array for African–Asian–Australian Monsoon Analysis and Prediction (RAMA) mooring shows the planned locations in the framework of the RAMA 2.0 design. There are more XBT lines than those shown in Fig. 8, but the map only represents those that have been considered tier I by the Indian Ocean Observing System (IndOOS) review. The tide gauges displayed on the map are those for which data have been reported to the Permanent Service for Mean Sea Level (PSMSL) over the last 5 years (source: www.psmsl.org/products/gloss/status.php).
References


