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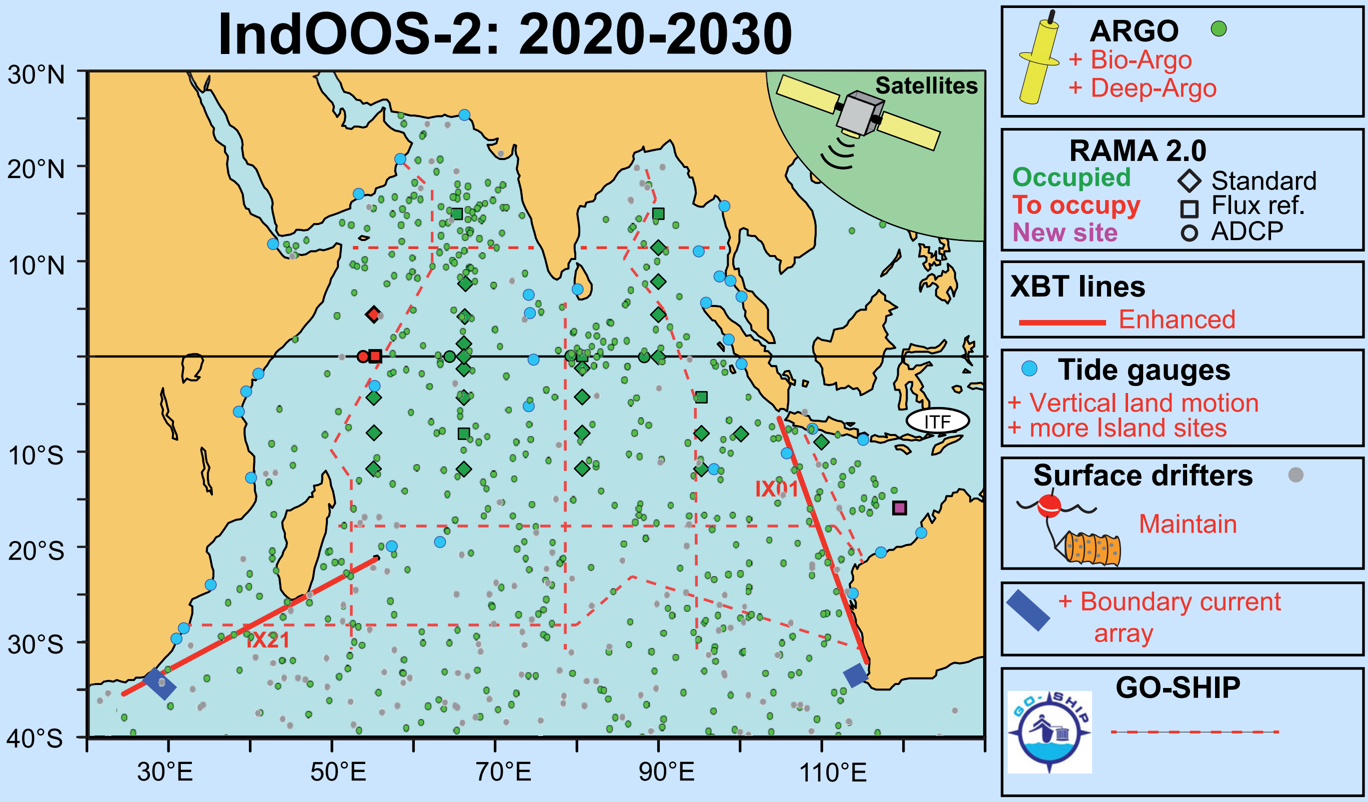
CLIVAR Exchanges

Special Issue: The Recent Decadal Review (2020-2030) of the Indian Ocean Observing System (IndOOS-2) and its Outcomes



CLIVAR (Climate and Ocean - Variability, Predictability, and Change) is the World Climate Research Programme's core project on the Ocean-Atmosphere System

Theme 5. Climate Information and Prediction across Timescales

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THE INDIAN Ocean is home to many different modes of variability ranging from weather to subseasonal to interannual timescales and beyond. Here, we briefly review these modes of variability, their predictability, and influences on regional hydroclimate, and list specific recommendations for IndOOS.

Indian Ocean Observations for Operational Subseasonal and Seasonal Forecasts

INTRASEASONAL VARIABILITY (ISV) is a dominant mode of variability in the tropical Indian ocean-atmosphere system and forms a bridge between weather systems and long-term interannual and decadal climate modes of variability. The tropical ISV influences many temporal and spatial phenomena that include: the diurnal cycle of tropical convection, tropical cyclone activity, synoptic disturbances over the monsoon trough, Asian and Australian monsoons, the El Niño Southern Oscillation (ENSO), and many other weather-climate phenomena. The eastward propagating Madden–Julian Oscillation (MJO) is the most common and energetic mode of ISV in the tropics (Madden and Julian 1994). The MJO represents the planetary scale convectively coupled eastward propagating disturbance of 30–60 day periodicity. In the Indian Ocean region, the monsoon intraseasonal oscillation (MISO) is another manifestation of ISV and refers to a quasi-oscillatory mode that modulates the Asian summer monsoon in the region (Goswami 2005; Waliser 2006).

The processes controlling MISO characteristics like moisture sensitivity and surface-feedbacks are still not well understood (Goswami 2005 and references therein). Major deficiencies are observed in global models in simulating its spatial structure, northward propagation and scale-selection (Sperber et al. 2013).

The fidelity of general circulation models (GCMs) in representing the MISOs accurately depends on the representation of the air-sea interaction over the tropical Indian Ocean region (Lin et al. 2006). A community effort towards improving MJO simulation in many different global models over the last two decades has helped improve the current generation model physics and hence its representation of the MJO (Kim et al. 2009; 2011). The current generation climate and weather forecasting models are still very limited in terms of prediction skill compared to the potential predictability of the MISO events (Neena and Goswami 2010). Hence, a concerted effort in diagnosing deficiencies in the representation of air-sea interaction processes in the tropical Indian Ocean region is much needed for a similar improvement in MISO representation and prediction in current generation models.

Continuing analyses of these unique in-situ and remote observations will further shed light on the role of air-sea interactions in the regions in modulating the boundary layer dynamics in both the ocean and atmosphere and how this links to MJO and MISO convection.

Observing and understanding the diurnal cycle in the upper ocean and how it couples to the atmospheric boundary layer will require a sustained observing system and would be beneficial for both improving model representations and parameterizations of these processes as well as for providing the data assimilated model states for improvement of initial conditions for subseasonal forecasts.

There is an increasing interest in developing coupled data assimilation methods for initialization of extended range forecast and for reanalyses applications that will require collocated observations across the ocean and atmosphere, and the IndOOS will be instrumental for developing such coupled systems.

Interannual Variability and Predictability of Climate Modes in the Indian Ocean

THE INDOOS has contributed to improved understanding of interannual climate phenomena in the Indian Ocean. Mechanisms and predictability of four climate phenomena are briefly reviewed in this subsection.

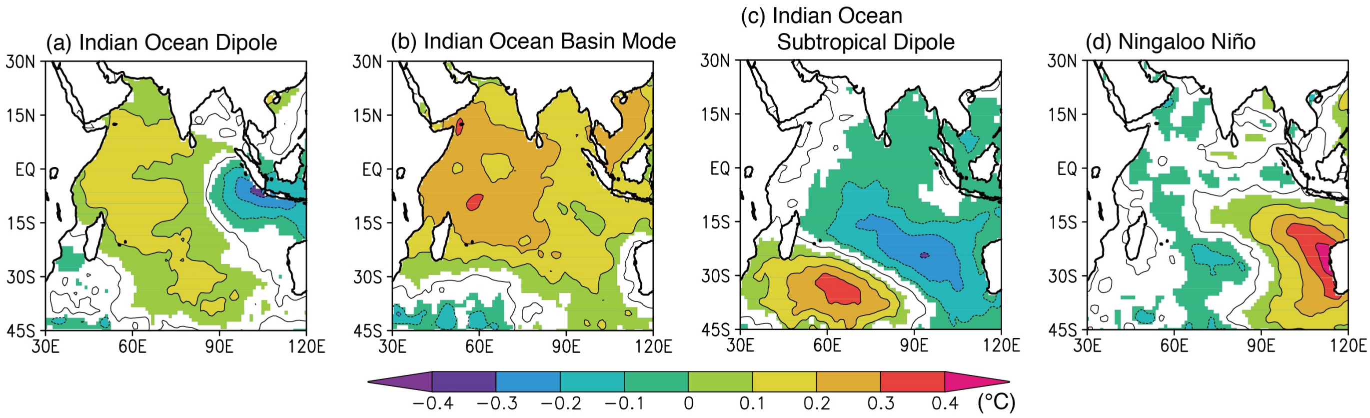

Figure 5.1 Detrended sea surface temperature (SST) anomalies regressed against the normalized time series of (a) the Dipole Mode Index (SST anomalies in the western pole (50°–70°E, 10°S–10°N) minus those in the eastern pole (90°–110°E, 10°S–Equator)), (b) the Indian Ocean Basin Mode Index (the first principal component of SST anomalies over the tropical Indian Ocean (40–110°E, 20°S–20°N)), (c) the Indian Ocean Subtropical Dipole Index (SST anomalies in the southwestern pole (55°–65°E, 27°–37°S) minus those in the northeastern pole (90°–100°E, 18°–28°S)), and (d) Ningaloo Niño Index (area-averaged SST anomalies from 108°E to the coast, and between 28°S and 22°S). HadISST (Rayner et al. 2003) is used to prepare the figure. The contour intervals are 0.2°C, and shading indicates regression coefficients that are significant at the 99% confidence level by a two-tailed t-test. Adopted from the IndOOS Review.

The Indian Ocean Dipole (IOD) is an intrinsic interannual climate mode with positive sea surface temperatures (SST) anomalies over the western tropical Indian Ocean and negative SST anomalies over the southeastern tropical Indian Ocean during its positive phase (Saji et al. 1999; Webster et al. 1999; Fig. 5.1a). The Bjerknes feedback is shown to play a central role in its development (Saji et al. 1999) and ocean dynamics, including equatorial Rossby and Kelvin waves and coastal upwelling along the Indonesian coast is crucial to the evolution (Rao et al. 2002; Nagura and McPhaden 2010). Also, salinity anomalies are suggested to modify the amplitude of SST anomalies in the eastern pole of the IOD. The RAMA moorings have provided valuable observational data for the studies on the IOD. After Wajsowicz (2005) made the first attempt of the IOD prediction and Luo et al. (2008) made the first successful real-time prediction, many studies were devoted to its predictability. It is shown that the ENSO (Luo et al. 2007; Yang et al. 2015) and subsurface processes (Tanizaki et al. 2017) provide sources of prediction. At the moment, the anomaly correlation coefficient (ACC) of the Dipole Mode Index becomes lower than 0.5 only after 3 months (Liu et al. 2017).

The Indian Ocean Basin Mode (IOBM) is remotely forced by the ENSO with positive SST anomalies typically appearing over the tropical Indian Ocean with one season lag (Yu and Rienecker 1999; Yang et al. 2007; Fig. 5.1b). The IOBM influences climate over the Indo-western Pacific and east Asia, especially in the summer following ENSO events. This prolonged effect is known as the "Indian Ocean capacitor effect" (Xie et al. 2009). The IOBM is the best-predicted climate mode in the Indian Ocean, because it is strongly linked to the ENSO, which is well predicted by coupled models (Luo et al. 2016).

The Indian Ocean Subtropical Dipole (IOSD) is a climate mode in the southern Indian Ocean with positive SST anomalies over its southwestern part and negative SST anomalies in its northeastern part (Behera and Yamagata 2001; Fig. 5.1c). Morioka et al. (2010) clarified its mechanism taking account of changes in the upper ocean heat capacity associated with mixed layer depth (MLD) anomalies; negative (positive) MLD anomalies over the southwestern (northeastern) pole induced by anomalous winds associated with changes in the Mascarene High enhance (suppress) warming of the mixed layer by the shortwave radiation and result in positive (negative) SST anomalies. Yuan et al. (2014) is the only study that focused on predictability of the IOSD, but the dynamical prediction skill is almost the same with the persistence.

The Ningaloo Niño is the most recently identified climate mode in the Indian Ocean with positive SST anomalies along the west coast of Australia (Feng et al. 2013; Fig. 5.1d). Both local air-sea interaction and remote ENSO influences are shown to contribute to the development of this phenomenon (Feng et al. 2013; Kataoka et al. 2014). Salinity anomalies potentially modulate the amplitude of the Ningaloo Niño through their influence on the southward-flowing Leeuwin Current. Using their coupled model, Doi et al. (2013) showed that the ACC for 3-month lead forecast varies from 0.5 to 0.8 and the ENSO is a potential source of predictability.

The Indian Ocean's Influence on Regional Hydroclimate

UPPER-OCEAN CONDITIONS in the Indian Ocean influence regional hydroclimate across a range of timescales, from weather to subseasonal to decadal and beyond. For example, northward propagating MISOs over the Indian Ocean are associated with active and break periods in the monsoon, impacting summer rainfall from India to the Philippines (Annamalai and Sperber 2005). The Bay of Bengal is an area of particularly active northward propagating MISOs, as reflected in strong coupling between SST and intraseasonal summer monsoon rainfall variability (e.g., Wijesekera et al. 2016), with SST warming in the northern Bay of Bengal leading the onset of intraseasonal rainfall by 5 days. The rainfall-SST relationship has strengthened in recent years with an anomalously warm Bay of Bengal, resulting in stronger low-level moisture convergence, as occurs during negative IOD events (Ajayamohan et al. 2008; Jongaramrungruang et al. 2017). Several major flooding events in Indonesia and Malaysia have also been associated with strong easterly winds over the eastern Indian Ocean associated with a Rossby wave-type response to the MJO that allowed for anomalous southward penetration of northeasterly winds from the South China Sea and strong low-level convergence (Tangang et al. 2008). Observing the convectively coupled waves during active MJO phases at sufficient spatiotemporal resolution with measurements, such as upper-air soundings, is therefore important.

On interannual timescales, the IOD widely impacts climate in surrounding countries, such as rainfall and flooding in East Africa (Behera et al. 1999; Saji et al. 1999; Webster et al. 1999; Manatsa and Behera 2013), droughts, wildfires, and streamflow in Indonesia (Abram et al. 2003; D'Arrigo and Wilson 2008) and Australia (Ashok et al. 2003; Cai et al. 2009; Ummenhofer et al. 2009; 2011b); and the IOD modulates the well-known teleconnection between ENSO and the Asian monsoon systems (Ashok et al. 2001; Gadgil et al. 2004; Ummenhofer et al. 2011a).

The Indian Ocean is particularly influential for regional hydroclimate on decadal timescales, as found for droughts and wet spells in Australia and East Africa (Ummenhofer et al. 2009; 2011b; 2018). Changes in the tropical atmospheric circulation across the Indo-Pacific on multi-decadal timescales (Vecchi and Soden 2007; L'Heureux et al. 2013) modulate the relationship between Indian Ocean SST and regional rainfall. After 1961, the Pacific Walker cell weakened, the Indian Ocean zonal overturning cell strengthened, and the East African short rains became more variable and wetter (Nicholson 2015) being associated with the IOD (Manatsa and Behera 2013).

In recent decades, the eastern Indian Ocean has sustained considerable sea surface salinity (SSS) changes, with implications for halosteric impacts (Llovel and Lee 2015; Hu and Sprintall 2016). Over the past decade, rainfall over the Maritime Continent has increased, potentially as a regional manifestation of decadal trends in the Walker Circulation (Du et al. 2015). This freshwater input, in conjunction with Indo-Pacific equatorial wind trends, likely contributed to the strengthened ITF transport (Feng et al. 2015; Hu and Sprintall 2017) playing a key role in the global ocean freshwater and heat distribution. Sustained surface and upper-ocean in situ observations, as provided by the long-standing IX01 line (Liu et al. 2015) and more recently the Argo program, need to be maintained to assess variability and change in upper-ocean properties of importance for the Indian Ocean hydrological cycle.

Observations of precipitation, riverine input (runoff), and evaporation at daily resolution are also warranted. The high riverine input and rainfall make the Bay of Bengal surface waters the freshest of any tropical ocean (Mahadevan et al. 2016). Yet, uncertainty in the freshwater distribution and mixing pathways for riverine input is high, and shallow, salinity-controlled MLD significantly affects upper-ocean heat content and SST (Wijesekera et al. 2016). Since 2010, the Soil Moisture and Ocean Salinity (SMOS) satellite provides SSS measurements consistent with *in situ* observations of the equatorial and southern Indian Ocean from the RAMA array; however, large biases in the Bay of Bengal and Arabian Sea are likely caused by errors in the SSS retrieval due to land contamination and strong winds (Sharma et al. 2016). With new satellite missions, remotely sensed SSS measurements will hopefully improve in their utility for marginal seas and coastal regions (Sharma et al. 2016). Satellite remote sensing of surface ocean and atmospheric variables of interest to the hydrological cycle crucially depends on *in situ* observations for calibration.

Specific Recommendations

Specific recommendations for IndOOS include:

A Maintain the current IndOOS.

B Complete and maintain RAMA-2.0 buoy network. Establish a RAMA surface mooring and flux reference site on the northwest shelf off Australia.

C Sustain observation system and process-oriented field observations in the Indian Ocean region targeting timescales from diurnal cycles to longer time periods to help inform and improve coupled prediction systems in improving their upper ocean representation as well as air-sea interaction processes. These observations will also be highly useful for coupled data assimilation to help improve initial conditions for subseasonal and seasonal forecasting over the entire globe.

D Enhance near-coastal observations so that anomalous coastal current and upwelling associated with the IOD and Ningaloo Niño can be monitored.

E Maintain the current IX01 XBT line to monitor the oceanic teleconnection from the Pacific.

F Maintain existing satellite observations for relevant variables at the air-sea interface with basin-scale coverage over the Indo-Pacific region.

G Maintain and replace SSS-sensing satellites with improved capabilities over marginal seas and coastal regions (cf. SMAP, Aquarius, SMOS).

H Maintain and improve river gauge network to observe runoff and riverine input from Indian Ocean rim countries.

I Maintain current coverage with surface drifter network, especially for drifters equipped with surface barometric pressure sensors; expand drifter coverage in eastern equatorial Indian Ocean and between Australia and Indonesia.

J Maintain surface meteorological measurements and ocean observations from commercial shipping (VOS programme).

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