Ocean Digest

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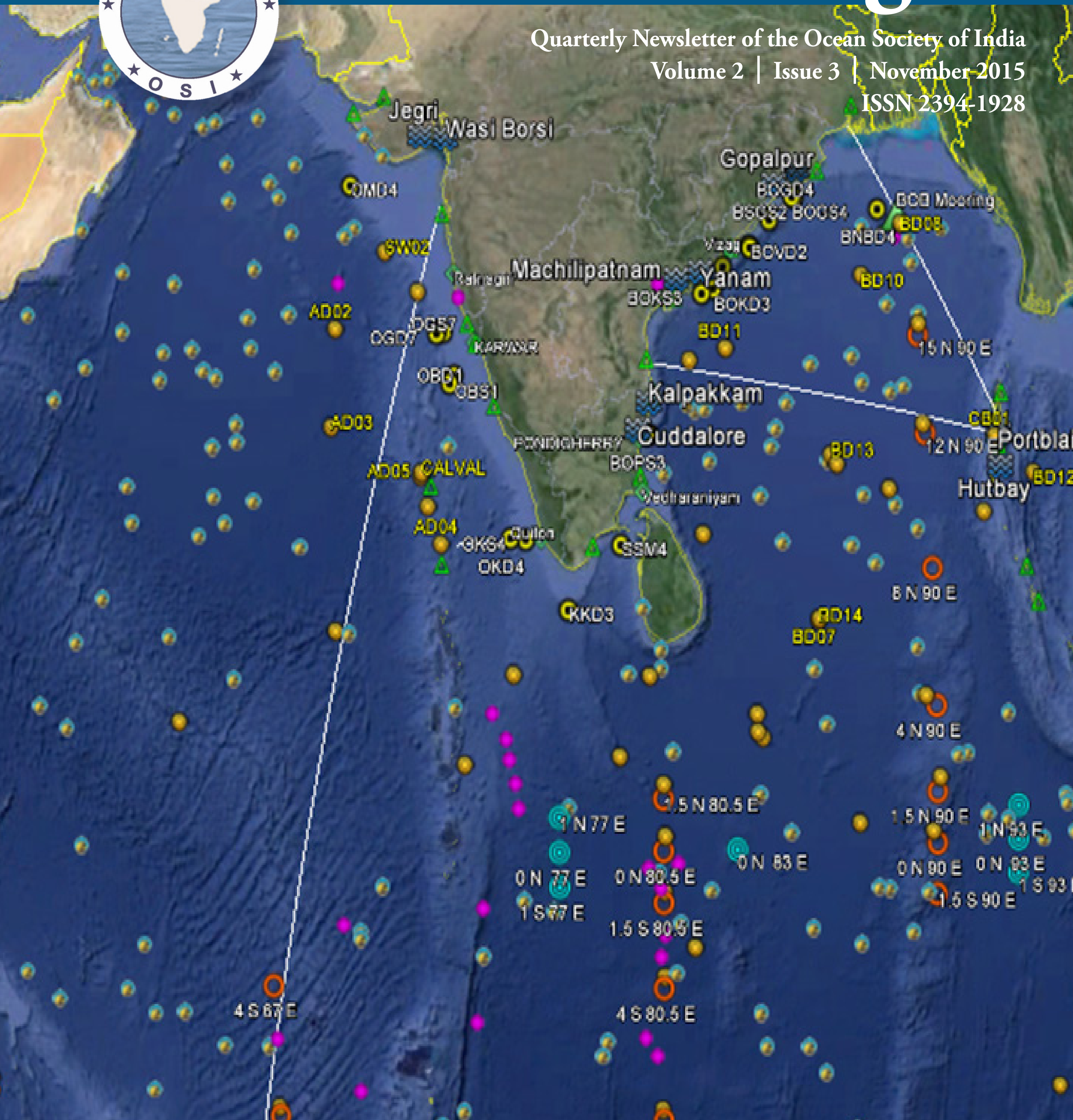
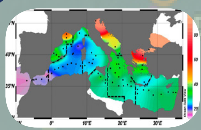



Indian Ocean is no more under-observed!


Can submarine groundwater discharge be a major source of primary marine productivity?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Invited Article

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1. Introduction

Oceans are the lifeblood of Earth, covering more than 70 percent of the planet's surface, driving weather, regulating climate, and ultimately supporting life on earth. Throughout history, the ocean has been a vital source of sustenance, transport, commerce, growth, and inspiration. But we still know very little about our ocean. Systematic and sustained ocean observations are hence necessary to improve our ocean literacy and inspire young people to seek careers in marine science and technology. There are many challenges in this area, young minds with innovative ideas can explore it.

Proper knowledge of the ocean is essential for a range of stakeholders, from ordinary fishermen looking for a livelihood to the value added oil, gas and mineral explorations. Up-to-date and accurate ocean related information is a pre-requisite for the port and harbor operations, coastal zone management, environmental agencies, maritime tourism industry and climate research. Hence Ocean Observing Systems (OOS) have a central role to deliver ocean related services to the society. OOS physical systems typically consist of (a) in-situ measurements using sensors mounted on ships, buoys, moorings, coastal stations etc. to capture changes in time and depth at specific points or tracks and (b) remote sensing systems such as satellites, aircraft, radar, etc. to capture the spatial and temporal variations synoptically. However, data produced by such systems need to be translated into user friendly ocean information services. This is usually done with state of the art analysis systems which assimilate the data in ocean general circulation models to deliver past, present and future state of the ocean.

2. Indian Ocean

Of the three major oceans – Pacific, Atlantic, and Indian – the Indian Ocean (IO) is the only one that is not open to the northern subtropical regions as it is land locked by the Asian landmass. Hence it cannot transport heat gained in the tropics to the higher northern latitudes, as the Pacific and Atlantic oceans do, mainly via their western boundary currents. Furthermore, the Indian Ocean is the only ocean with a low-latitude opening to other oceans. Indian Ocean gains additional heat/mass from the tropical Pacific via the Indonesian Throughflow in its eastern boundary. This unique geography has important implications on the ocean circulation, physics, chemistry, biology and consequently on the climate and biogeochemistry of the ocean. The Indian Ocean consequently has a unique system of three-dimensional currents and interactions with the atmosphere that redistribute heat to keep the ocean approximately in a long-term thermal equilibrium. Further, monsoon systems generate distinct seasonal variations in the upper ocean. Also, previous attempts to measure and simulate the ocean variability reveals rich spectrum of variability spanning from intraseasonal to interannual, decadal, and much longer time-scale, that has important climate impacts. Despite such unique aspects of the Indian Ocean such as the strongest monsoons, rich climate variability and its impact on global climate change through atmospheric and oceanic teleconnections, a long-term, sustained observing system in the Indian Ocean were not available. This had left the Indian Ocean as the least observed ocean among the three major basins.

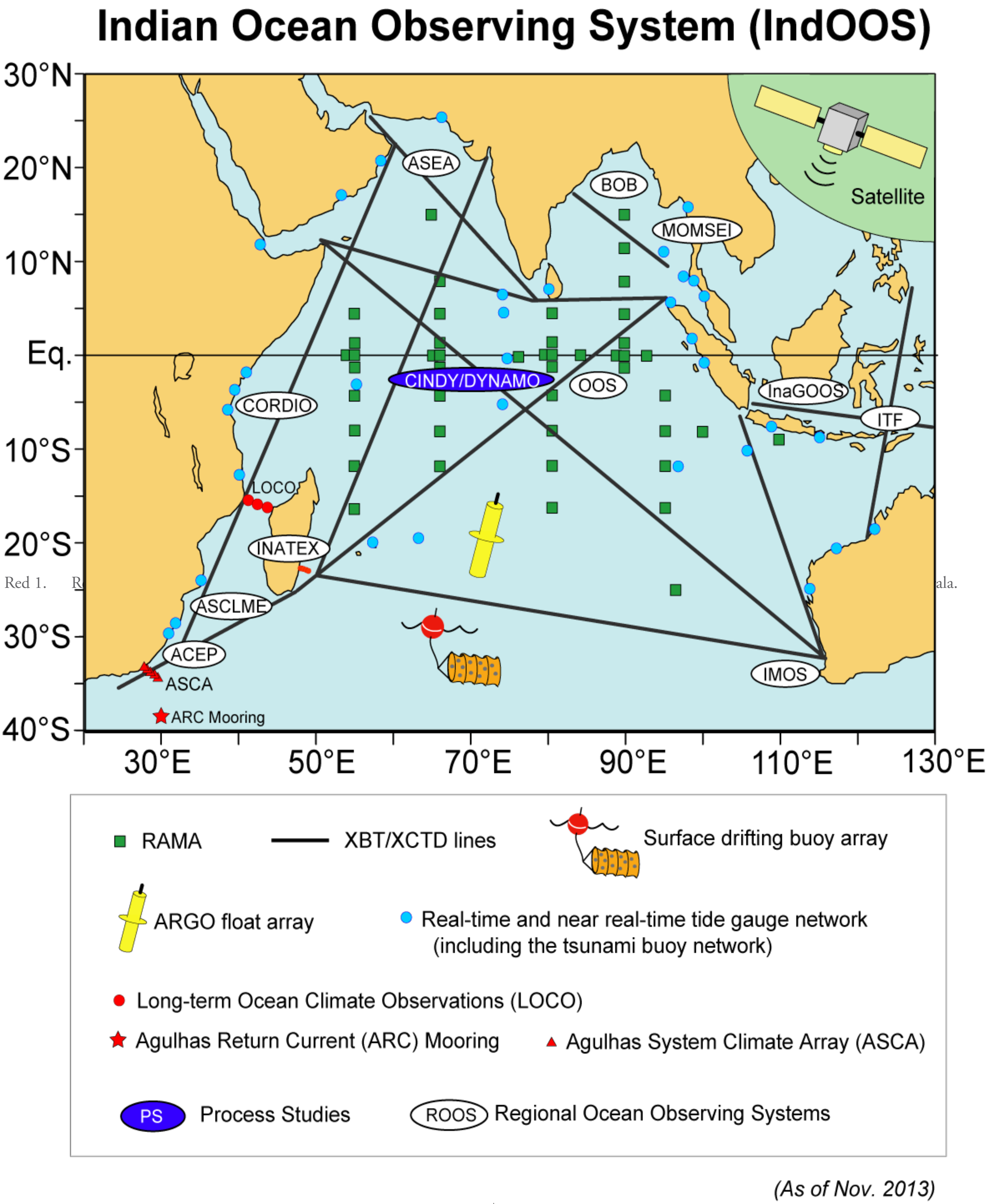
The outstanding research issues that need to be addressed with observations to advance the understanding of the role of the Indian Ocean in the climate system and its predictability are (i) Seasonal monsoon variability and the Indian Ocean, (ii) Intraseasonal variability, (iii) Indian Ocean zonal dipole mode and El Niño–Southern Oscillation, (iv) Decadal variation and warming trends in the upper Indian Ocean, and (v) Southern Indian Ocean and climate variability, (vi) Circulation and the Indian Ocean heat budget (Indonesian Throughflow, shallow and deep overturning cells), (vii) Biogeochemical cycles in the Indian Ocean and (viii) Operational oceanography. All these require a systematic and sustained long term ocean observations.

3. IndOOS

Recognizing this gap, an enthusiastic spirit emerged after the OceanObs99 meeting, resulting in the development of a plan for the Indian Ocean Observing System (IndOOS) under the coordination of the CLIVAR/GOOS Indian Ocean Panel (IOP). IndOOS is a regional contribution to the Global Ocean Observing System (GOOS). IndOOS is a multi-platform long-term observing system, which consists of a surface mooring array, Argo floats, surface drifting buoys, tide gauges, Voluntary Observing Ship (VOS) based XBT/XCTD sections and satellite measurements. The schematic diagram of IndOOS and the regional Observing system is shown in Fig. 1. The system is designed to provide high-frequency, near real-time climate-related observations, serving the needs of climate research, forecasting, and related services. The different components of IndOOS and its present status are furnished below.

Satellites: Satellite remote sensing provides maps of surface variables such as temperature, sea surface height, sea surface winds, sea surface salinity and ocean colour, as well as several meteorological parameters for estimating air-sea momentum, heat, and fresh water fluxes. Availability of real time satellite observations proved its worth in the monitoring and decision making during severe weather features like cyclones, storm surges etc. Our success in managing the recent north Indian Ocean cyclones are to a great extent due to the availability of high quality satellite observations, which (a) helps in the real-time monitoring of the movement of the systems and (b) provides quality observations for assimilating in ocean models to accurately predict the weather systems.

RAMA: The most important platform under IndOOS is the Research moored Array for African-Asian-Australian



Monsoon Analysis and prediction (RAMA, http://www.pmel.noaa.gov/tao/rama/index.html), which is similar to the TAO/TRITON array in the Pacific and PIRATA array in the Atlantic Ocean. The RAMA array consists of 46 moorings, of which 38 are ATLAS/TRITON-type surface moorings. Eight of these surface moorings are surface flux reference sites, with enhanced flux and subsurface ocean measurements. The surface mooring system can measure temperature and salinity profiles from the surface down to 500 m depth as well as the surface meteorological variables. The observed data are transmitted in real-time through the Global Telecommunication Systems (GTS). In addition to these surface buoys, there are four subsurface ADCP moorings along the equator and one near the coast of Java to observe current profiles in the upper ocean, and three deep current-meter moorings with ADCPs in the central and eastern equatorial regions. As of October 2015, 34 RAMA mooring sites have been occupied out of 46 planned locations (i.e. 74% complete, Fig.2). Efforts are underway to occupy the remaining RAMA sites. The publications using RAMA data are available at http://www.pmel.noaa.gov/tao/rama/ramapubs.html

Argo: Argo floats provide temperature and salinity profiles down to 2000 m depth with a temporal resolution of 10 days. The build-up of the Argo array in the Indian Ocean began in 2002. The Indian Ocean (north of 40°S) requires 450 floats to meet the Global Argo design of one float per 3x3 deg. The Argo program's unprecedented spatial and temporal coverage of temperature/salinity and hence geostrophic current is opening new perspectives on ocean circulation-research and for seasonal forecasting. At present there are 769 active Argo floats in the IO with 491 floats to the north of 40°S. Since 2006, the Argo array in the IO has been maintained at the nominal Argo design specification of 1 float per 3°x3° box. There are however some gaps where no float exist, especially in the Western Equatorial IO, mainly due to piracy issues. About 50 % of active floats are less than one year old, with most of the new deployments using two way communications to provide higher vertical resolution and longer lifetimes. Many recent IO floats are deployed with biogeochemical sensors such as oxygen, chl-a, backscatter and nitrate. The publications using Argo data are available at http://www-argo.ucsd.edu/Bibliography.html

Ship of opportunity lines: Several Ship Of OPportunity (SOOP) Expendable Bathythermograph (XBT) lines obtain frequently repeated and high-density section data. These XBT lines in the Indian Ocean are narrow shipping routes allowing nearly exact repeat sections. At least 18 sections per year are recommended in order to avoid aliasing the strong intraseasonal variability in this region. The CLIVAR/GOOS IOP reviewed XBT sampling in the Indian Ocean and prioritized the lines according to the oceanographic features that they monitor.

Surface drifting buoys: Surface drifting buoys have also been extensively deployed over the decade after OceanObs99, and the targeted coverage of one drifting buoy per 5-degree box is almost achieved. The key application of surface drifter data is reduction of the bias error in satellite SST measurements. They are also used for documentation of large-scale surface-current patterns. Strong Asian summer monsoon winds drive drifters out of the North Indian Ocean, which is a problem of great concern. A more frequent seeding program is needed to maintain the 5-degree sampling. There are about 115 active surface drifters that provide 2500 observations per day. Many drifters have been deployed with Iridium communication to resolve diurnal variability in recent years. The required number of drifters was maintained in the past, but it has deteriorated during the last five years. Efforts are underway to maintain the required number of drifters in the Indian Ocean.

Tide gauges: Sea level measurement from tide gauges along the coast is another important parameter to study our environment and the physical mechanisms controlling the secular changes in the mean sea level, understanding the physical processes near the coast, calibration of satellite altimeters, improving and validating tidal, storm surge, Tsunami and climate models. Currently about 67 coastal tide gauges and 7 open ocean tide gauges (bottom pressure recorder - tsunami buoys) provide sea level data in real-time in the IO.

Regional ocean observing systems: The various Regional ocean observing systems (ROOSs) that complement IndOOS measurements are India's Ocean Observing System in the Arabian Sea and the Bay of Bengal (ASEA and BoB), Australian Integrated Marine Observing System (IMOS), Indonesian Global Ocean Observing System (InaGOOS), Monsoon Onset Monitoring over Andaman Sea and its Social & Ecosystem Impact (MOMSEI), CORDIO-Coral Reef Degradation in the IO, Long-Term Ocean Climate Observations (LOCO), Agulhas & Somali Current Large Marine Ecosystems (ASCLME), Agulhas Return Current (ARC) mooring, African Coelacanth Ecosystem Program (ACEP), and Agulhas System Climate Array (ASCA).

The IOP has endorsed many field campaign based process studies in the Indian Ocean. In late 2006 and early 2007, MISMO and VASCO/CIRENE were the first ever campaigns that directly observed in-situ atmospheric and oceanic features in the presence of a strong positive IO dipole event. These two process-oriented campaigns also activated a broader interest for this unique Ocean. The coordinated international CINDY/DYNAMO field campaign was also designed to advance our knowledge of the Madden-Julian Oscillation initiation with the goal to improve its simulation/prediction. This campaign attracted researchers from 70 institutes/universities of 16 countries and collected unprecedented observations during October 2011 – March 2012.

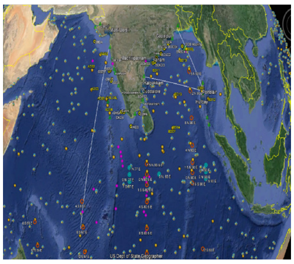
Liaising with SIBER: The IOP has established a unique interdisciplinary relationship with Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER), a regional program of Integrated Marine Biogeochemistry and Ecosystem Research (IMBER). SIBER-motivated deployment of biogeochemical sensors on some of the RAMA moorings, with an ocean color sensor to measure chlorophyll, CO2, PH, Oxygen, etc. in collaboration with the Bay of Bengal Large Marine Ecosystem (BOBLME) program. The IOP/SIBER collaboration has also motivated the deployment of Bio-Argo floats (16 floats with Oxygen sensors and 11 floats with chlorophyll, oxygen and back-scatter sensors) in different parts of the Indian Ocean. Ongoing IOP-SIBER motivated projects include a biogeochemical sensor study of chlorophyll variability in the equatorial IO and efforts to estimate nutrient flux variability through ITF. The interdisciplinary relationship between IOP and SIBER has also been very successful in promoting the development of interdisciplinary programs in the Indian Ocean including the Eastern IO Upwelling Research Initiative.

4. Data portal

A data portal for IndOOS is available at INCOIS from http://www.incois.gov.in/Incois/iogoos/home_indoos.jsp. The main idea is to provide a one-stop shop for IO-related data and data products. The distributed data archives are maintained by the individual groups at their institutes and made available to the community via the web portal. The portal contains data from basin-scale observations from mooring arrays, Argo profiling floats, expendable bathythermographs (XBT), surface-drifters and tide gauges, as well as the data from regional/coastal observation arrays (ROOS). Satellite derived gridded data sets such as sea surface temperature (TMI), sea surface winds (QuikSCAT, ASCAT, OSCAT) and sea surface height anomaly (merged altimeter products) are also available. The agencies contributing to the IndOOS are committed to follow the CLIVAR data policy (http://www.clivar.org/data/data_policy.htm).

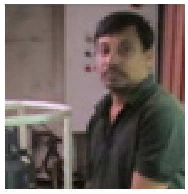
5. Summary

Analysis and interpretation of the ocean observational data require the knowledge of different time and space scales over which each processes characterizes: from the turbulent eddies with durations of few seconds and spatial scales of centimeters (high frequency) to wind-forced and thermodynamically driven ocean currents with time scales of days to centuries and spatial scales of tens to thousands of kilometers (low frequency). The exchange of momentum, heat, salt and other tracers within the ocean and across the air-sea interface occurs in these space and time scales. The observing system should resolve timescales of seconds to decades by measuring continuously without much gap and the spatial scales as close as possible. These observations have to withstand and provide good quality of data during disturbed or extreme weather events. Apart from contributing and building IndOOS observations, India has deployed and maintaining 15 moored buoys in the North Indian Ocean to acquire marine meteorological and oceanographic parameters. These data sets are freely available for the public at INCOIS website. With the description of all the data available in the Indian Ocean, it is clear that the answer to the 'title' question is a BIG NO. So we are now in an era where Indian Ocean is very well sampled. Now it is left to the researchers to use these very useful data sets to the fullest possible way. When we look at the data, several new insights (from diurnal to decadal scales) are emerging from the Indian Ocean data sets. May be the time has come to demonstrate the different (spatial and temporal) variability exists in the IO and its role in modulating global climate variability.



Present status of RAMA moorings (red hollow circle) including sub-surface current meter moorings, Argo floats (green dots), drifters (pink dots) and tide gauges (green triangle). Also represented Indian mooring (yellow dots), XBT lines (white line), HF radar (waves), yellow circle (coastal ADCP) and wave rider buoys (green Square).

Can submarine groundwater discharge be a major source of primary marine productivity?



Review

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In a simple way, primary production in any ecosystem can be defined as formation of organic compounds from aqueous/atmospheric carbon dioxide (CO2). Primary production in ocean is conducted by microscopic plants called phytoplankton and majorly governed by photosynthesis which uses light energy to fix CO2 into various organic materials. Those plants use part of the synthesized products for their energy and maintenance. The left over is available for plant growth and other marine communities which cannot synthesize foods for their own. This 'left over' is called net primary production (NPP). Although CO2 is the major ingredient, there are many other limiting factors those control the rates and extents of NPP- light, nutrients, iron etc. Nitrate, phosphate and silicic acid are such necessary inorganic nutrients required to build the cells of phytoplankton. For this, NPP is usually more where supply of nutrients is high. Nutrients can be supplied to ocean through river run off. Consequently, estuary and shallow shelf (littoral zone) water usually have high NPP. In calm and stratified ocean, organic nutrients (vig. plankton, dead or fecal material) are lost from surface layer due to gravitational sinking and reloaded only if nutrient rich deeper, dense and cooler water mix with surface warm water (upwelling). Analysis of total organic carbon (TOC), metal content and various diatom assemblages from ocean core sediments suggest that proliferation of phytoplankton are associated with concomitant nutrient supply driven by episodic upwelling or anomalous increase of river discharge also in the past (last 5000 years).

Interestingly, apart from river discharge, a significant amount of fresh water is also added into ocean through submarine groundwater discharge (SGD). Albeit it's potential as a nutrient supplier, is not studied extensively. SGD occurs

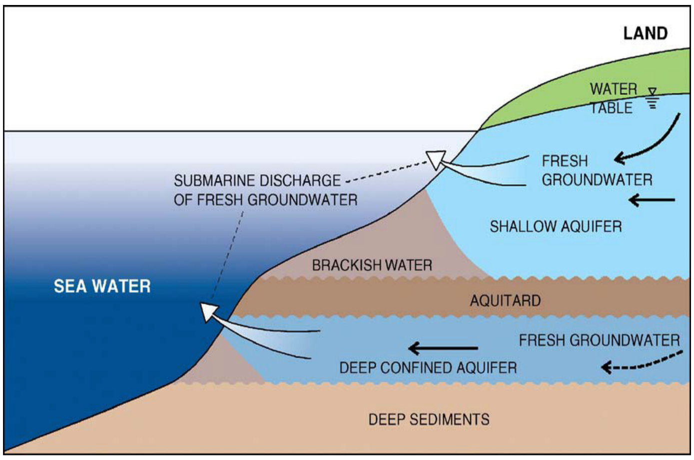

Fig. 1 Schematic of processes associated with submarine groundwater discharge. Arrows indicate flow direction (after Burnett et al., 2006).

in coastal aquifers. It is inflow of fresh/brackish water towards sea/ocean governed by steep hydraulic gradient from land to sea (Burnett et al, 2006; Fig. 1). Studies have shown that episodes of major emplacement of groundwater through SGD correspond to variation of relative sea level. During glaciations, sea level retreats and large parts of shelves are exposed. This results in steeper water table which facilitates groundwater flow towards ocean. Moreover, meteoric recharge in the exposed shelf also stores more fresh water in the coastal aquifers. During deglaciations, the reverse phenomenon occurs. This is supported by the finding that the amount of offshore freshwater are inversely proportional to the sea level.

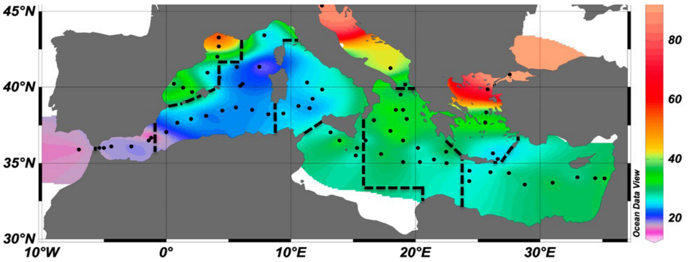

Fig. 2 Distribution of 228Ra (dpm/ m3) in surface waters of the MS. Dots indicate sampled stations. The sub-basin division and the weighted average 228Ra concentration in each sub-basin are indicated (after Rodellas et al., 2015).

In a recent article, Rodellas et al (2015) attempted to assess the role of SGD as nutrient supplier to the Mediterranean Sea (MS). The study is interesting as the MS is a semi closed basin where outflow from the basin is considerably small. Moreover, the sea is rich in oxygen and poor in nutrients. The productivity in this kind of sea largely depends on atmospheric and river borne deposition of nutrients, although the role of SGD is mostly ignored. Rodellas et al., (2015) followed a simple mass balance approach using radium isotope (228Ra) as a tracer assuming a steady state condition in sea where total inflow and outflow fluxes are same. 228Ra is a natural radioactive isotope of radium with a smaller half life of ~5.8 years. 228Ra is produced by the decay of another radioactive thorium isotope (232Th). In freshwater, 228Ra tends to adhere to particles, whereas in seawater, due to high salinity and ionic strength, it is found mostly in dissolved form. Therefore, in the mixing zone of fresh and saline water (estuary), 228Ra is considerably higher than far from the coast (Kim et al., 2005). Once released in ocean/sea, 228Ra behaves conservatively. This means, apart from natural radioactive decay, its concentration in water column will change only due to mixing with water masses of different isotopic composition. The major task for estimation of SGD using mass balance technique is to characterize isotopically all the possible end members/sources of water in the MS.

Towards this, 80 samples were collected from different depths and locations of the sea during various cruises and 228Ra activity (in disintegration per minute, dpm/ m3) was measured using gamma spectrometry. The highest 228Ra concentrations, as expected, are observed in coastal areas (34 dpm/ m3), consistent with radium inputs from continental margins. 228Ra gradually increase from west to east (17-34 dpm/ m3) confirming higher river discharge from the eastern margin of the sea (Fig. 2). 228Ra in the deeper water (depth > 500 m) are much lower (5-13 dpm/m3) suggesting the net 228Ra inventory exists in the top 500m water column. To estimate the inventory, the top 600m of the sea is divided into nine sub basins and each sub basin is divided into three water layers (surface, intermediate and lower). Various input 228Ra fluxes e.g. river (0.40 x 1015 dpm/y), atmospheric dust (0.08 x 1015 dpm/y), advection from deeper water

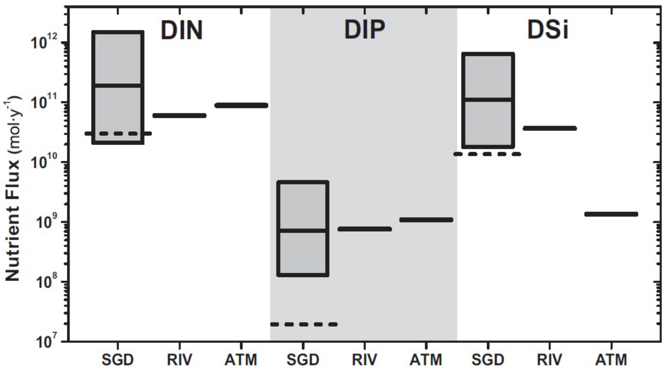

Fig. 3. Comparison of nutrient inputs to the MS derived from SGD to inputs from rivers (RIV) and atmospheric deposition (ATM). (after Rodellas et al., 2015)

(1.1 x 1015 dpm/y) and output 228Ra fluxes e.g. outflow to strait of Gibraltar (0.30 x 1015 dpm/y), natural radioactive decay (4.2x 1015 dpm/y) etc are estimated. Considering all analytical uncertainties, the mass balance show a net positive 228Ra inventory of 1.8 (±1.2) x 1015 dpm/y constituting 9-47% of the total flux which the Rodellas et al., (2015) account for the input from SGD.

As flux from SGD are found significant, the Rodellas et al., (2015) further measured the bioavailable nutrient [dissolved inorganic nitrogen (DIN); (20-1500) x 109 mol/y), phosphorous (DIP); (0.1-4.6) x 109 mol/y) and silica (DSi): (20-650) x 109 mol/y. As evident in the Fig.3, these fluxes are comparable or higher than that from rivers (RIV) and atmosphere (ATM). This study, therefore, demonstrates the importance of SGD in coastal biogeochemical cycle and necessities inclusion of SGD related inputs in coastal and basin wide material balance.

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The status of coral reefs in the Lakshadweep islands

Student Article

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Coral bleaching is a response of corals under stress, the most important being rising sea temperatures. When the temperatures get above normal for a period of weeks to months the corals eject their symbiotic Zooxanthella (a single celled algal plant) which gives the coral its colour. Once ejected the corals appear white as the coral tissue is transparent like a jelly fish. The symbiotic relationship between the host coral and the zooxanthellae is complex but important for corals to survive. The algae live inside the coral and produce food through photosynthesis which it passes on to the coral tissue, the algae in turn gets a place to live and feeds of the waste of the corals (all animal wastes are fertilizers!) and the CO2 that the coral breathes out. When this relationship breaks down under stress, corals can survive only for a while i.e. from weeks to a few months without their zooxanthellae and then perish if the conditions do not return to normal.

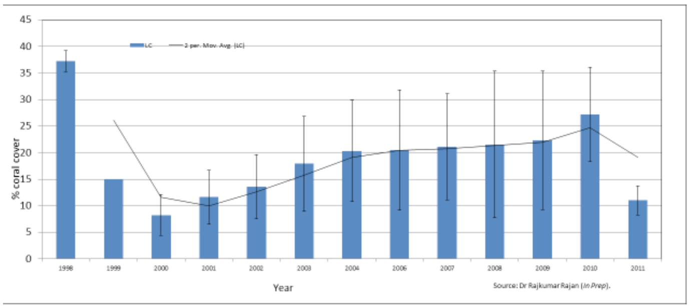

Figure 1: Status of coral reefs in the Lakshadweep Islands from various secondary sources. The graph shows the decline of coral cover after 1998-99 mass bleaching event , the slow recovery thereafter, followed by a second loss in coral cover after 2010.

Global warming and rise in sea surface temperature has been the biggest stress to corals in the last two decades. The Lakshadweep coral reefs have been the most affected by global warming among India's 4 major coral reef regions. These reefs are India's only atoll reefs, located a few hundred kilometres off the coast of Kerala.

Surrounded by crystal clear oceanic waters, there are little anthropogenic threats to the reefs here, except for the impacts of global warming. The 1998 bleaching event was the biggest on record, affecting over 90% of the world's reefs. 16% of the global reefs were lost. Many are yet to recover including the Lakshadweep atolls in India.

During the first mass bleaching event in 1998 live coral cover in the Lakshadweep went down from about 37% to about 8%. Recovery was patchy and coral cover recovered to about 15-25%, before the second mass bleaching event happened in 2010, which again reduced the coral cover to about 5-10%. The most affected corals in both these events were the tabulate (table like) and branching corals (tree like). These corals provide the most structural complexity on a reef, and are important reasons why reefs with these types of corals in abundance have high biodiversity associated with them. Branching and table corals were the most dominant reef forms before 1998. Currently these branching and tabulate corals represent only about 5% of the already low coral cover on the reef.

The Alarming fact about the reefs in Lakshadweep is that bleaching is happening at a rate that the reefs cannot cope with. After the first major bleaching in 1998, it was said that the reefs would take a decade or more to recover, but this time limit was not enough as the second bleaching event happened after 12 years. With predictions that more such events are going to happen, more periodically and more intensely, there seems to be little hope for the reefs of the Lakshadweep islands. Soon most branching forms may disappear throughout and be dominated by large boulder like corals, like the ones from the genus Porites.

There have been studies to show that not all places around the atoll were affected, deeper reefs and lagoonal reefs are showing some resistance. Though these two reef areas showed signs of bleaching in 1998, they showed lesser bleaching in 2010 indicating that corals in these two reef areas could be adapting. This is the only glimmer of hope for the reefs in the atolls, and hopefully these areas can resist future bleaching events. However, the gravity of the situation remains that the biggest threat to our natural resources would need global consensus and action.

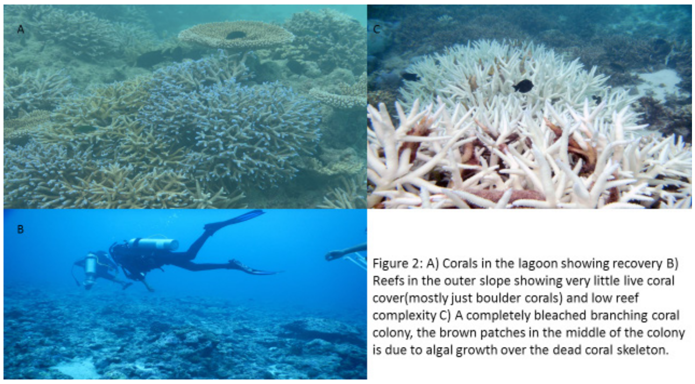

Figure 2: A) Corals in the lagoon showing recovery B) Reefs in the outer slope showing very little live coral cover(mostly just boulder corals) and low reef complexity C) A completely bleached branching coral colony, the brown patches in the middle of the colony is due to algal growth over the dead coral skeleton.

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The Southern Oscillation was discovered in India

History Article

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Introduction

This year's ENSO episode has been very much in the news because of its unusually high intensity and the adverse impact it has had on the Indian summer monsoon rainfall. For the public at large, the warming of the waters of the equatorial Pacific Ocean, is better known as El Nino which is the Spanish word for Baby Jesus, as the warming near the Peru coast generally peaks around Christmas. The pressure component of ENSO, however, is not much talked about, and it is not commonly known that the Southern Oscillation was in fact discovered in India in the 1920s by Gilbert Walker.

Sir Gilbert Walker

The India Meteorological Department was established in the year 1875 and it was headed by British meteorologists until 1944. Gilbert Walker was the Director General of IMD for 20 years from 1904 to 1924.

Gilbert Thomas Walker was born on 14 June 1868 and grew to be a brilliant mathematics scholar at Cambridge, a Senior Wrangler in 1889, and a Fellow of Trinity College in 1891. Walker worked in many fields, including the path of projectiles and boomerangs, but his main interest was in electromagnetism and one of his papers in this subject got him the coveted Adams Prize in 1899.

Soon after assuming charge as the Director General of IMD, Walker was elected a Fellow of the Royal Society and received the Sc. D. degree from Cambridge University. In 1918, Walker was elected as President of the Asiatic Society of Bengal and President of the Indian Science Congress. Walker had also been a member of the Board of Governors of the Indian Institute of Science, Bangalore. In 1911, Walker was awarded the title of Companion of the Order of the Star of India (CSI) and he was knighted in 1924, the year of his retirement.

Monsoon teleconnections

Gilbert Walker, the mathematician-turned-meteorologist, lived decades ahead of his times. During Walker's tenure the headquarters of IMD were in Simla, a hill station in north India. Communication with the outside world was through postcards and letters, and telegrams were the fastest means of acquiring meteorological data. There were no weather satellites, no computing aids, and no numerical models. Notwithstanding this situation Walker collected and analysed voluminous data recorded over land and ocean from across the world. He was able to establish the fact that the Indian monsoon was not an isolated system but had strong tele-connections with the global climate. He applied statistical techniques to the foreshadowing of Indian monsoon rainfall using antecedent parameters measured in different parts of the world. Walker used parameters as varied as the Himalayan snowfall, Zanzibar rainfall, South American pressure, level of the river Nile, sunspot activity, and icebergs in the southern Indian Ocean, and built sound statistical models for long range forecasting of Indian monsoon rainfall.

Southern Oscillation

During the course of his research on the Indian monsoon, Walker studied the variations of various weather elements worldwide. What he found was that there were see-saw connections of the atmospheric pressure at different places and he gave them the name "oscillations". These oscillations did not have an exact periodicity but they did have an association with global weather. Walker's research brought out the existence of three different oscillations, which he described as the Southern Oscillation, the north Atlantic Oscillation and the north Pacific Oscillation.

Walker described the Southern Oscillation as a tendency of pressure at stations in the Pacific (San Francisco, Tokyo, Honolulu, Samoa, and south America) and rainfall of India (and Java, Australia and Abyssinia) to increase, and the pressure in the region of the Indian Ocean (Port Darwin, Mauritius, SE Australia and the Cape) to simultaneously decrease. By computing the correlation coefficients between various pairs of parameters Walker found that south America was an active centre that controlled subsequent conditions in other regions. Walker observed that conditions in the Indian Ocean also affected each other closely but they exercised comparatively little influence on the region of the Pacific Ocean. He also expressed the need to have data over the Antarctic and also upper air data for more definitive results to be obtained.

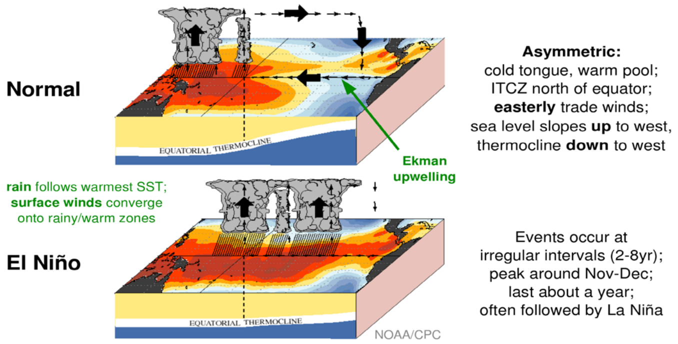
Northern Oscillations

Walker named two Northern Oscillations, one over the north Atlantic ocean and the other over the north Pacific ocean. Even at that time some work had already been done in this field by a few other scientists. The general observation was that an accentuated pressure difference between the Azores and Iceland in autumn and winter was associated with a strong circulation of winds in the Atlantic and a strong Gulf stream, among other things. Conditions in the north Pacific showed a close resemblance to those in the north Atlantic. However, Walker was able to establish strong correlation coefficients between various elements.

Walker's memory

Sir Gilbert, on his retirement from IMD and return to England, worked as Professor of Meteorology at the Imperial College of Science and Technology, London. Here he continued his research on varied subjects like convection in unstable fluids, formation of clouds, and flight of birds. He was the President of the Royal Meteorological Society in 1926-27. Sir Gilbert died at the age of 90, on 4 November 1958.

Walker's memory has been perpetuated by the global meteorological community by naming the east-west circulation over the eastern Pacific Ocean as the "Walker Circulation". In 2006, the University of Reading established a research institute dedicated to the memory of Sir Gilbert Walker, and named it as the Walker Institute for Climate System Research.



Schematic of the El Nino Southern Oscillation

Further Reading

1. Indian Met. Soc. 1986, "The two northern oscillations" and "The southern oscillation", Sir Gilbert Walker Selected Papers Long Range Forecasting of Monsoon Rainfall, 223-240.
2. Royal Met. Soc. at www.rmets.org/publication/classics/cp2.php.
3. Royal Met. Soc. at www.rmets.org/pdf/walkergt.pdf
4. Walker Institute at www.walker-institute.ac.uk/media/GILBERT_WALKER.pdf.

Zero : Perceptions Through Ages

Contributed Article

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Zero (हिन्दी में शून्य) was invented independently by the Babylonians, Mayans and Indians although some researchers say the Indian number system was influenced by the Babylonians. The Babylonians got their number system from the Sumerians who were the first people in the world to develop a counting machine. The number 0 is the only number which is neither positive nor negative, neither a prime number nor a composite number, nor a unit. It is however even. The number 0 (zero) is the least non-negative number. There are two uses of zero that are both extremely important but are somewhat different. One use is as an empty place indicator in place-value number system. Place-value number system is the Sumerian number system. In a number like 2106 in place-value system, zero is used so that the positions of the 2 and 1 are correct. Clearly 216 means something quite different. The second use of zero is as a number itself in the form we use it as 0. There are also different aspects of zero within these two uses, namely the concept, the notation, and the name. Name "zero" derives from the Arabic word 'sifr' and the word "zero" came from Italy. Neither of the above uses has an easily described history. It just did not happen that someone invented the ideas, and then everyone started to use them. Also it is fair to say that the number zero is far from an intuitive concept. Mathematical problems started as 'real' problems rather than abstract problems. Numbers in early historical times were thought of much more concretely than the abstract concepts, which are our numbers today. One might think that once a place-value number system came into existence then the 0 as an empty place indicator is a necessary idea, yet the Babylonians had a place-value number system without this feature for over 1000 years. Moreover there is absolutely no evidence that the Babylonians felt that there was any problem with the ambiguity, which existed. Remarkably, original texts survive from the era of Babylonian mathematics. The Babylonians wrote on tablets of unbaked clay, using cuneiform writing. The symbols were pressed into soft clay tablets with the slanted edge of a stylus and so had a wedge-shaped appearance. Many tablets from around 1700 BC survived and we can read the original texts. Of course their notation for numbers was quite different from ours and not based on 10 but on 60. To translate into our notation they would not distinguish between 2106 and 216 as the context would show which was intended. It was not until around 400 BC that the Babylonians put two wedge symbols into the place where we would put zero to indicate which was meant, 216 or 21 '' 6. The two wedges were not the only notation used, however, and on a tablet found at Kish, an ancient Mesopotamian city located east of Babylon in what is today south-central Iraq, a different notation is used. This tablet, thought to date from around 700 BC, uses three hooks to denote an empty place in the positional notation. Other tablets dated from around the same time use a single hook for an empty place. There is one common feature to this use of different marks to denote an empty position. This is the fact that it never occurred at the end of the digits but always between two digits. So although we find 21 '' 6 we never find 216 ''. One has to assume that the older feeling that the context was sufficient to indicate which was intended still applied in these cases. We can see from this that the early use of zero to denote an empty place is not really the use of zero as a number at all, merely the use of some type of punctuation mark so that the numbers had the correct interpretation. The first known calculator, viz. abacus (2400 BC), was probably invented by Babylonians as an aid to simple arithmetic around this date. This laid the foundations for positional notation and other computational developments.

The ancient Greeks began their contributions to mathematics around the time when zero as an empty place indicator was coming into use in Babylonian mathematics. The Greeks however did not adopt a positional number system. It is worth thinking just how significant this fact is.

How could the brilliant mathematical advances of the Greeks not see them adopt a number system with all the advantages that the Babylonian place-value system possessed? Greek mathematical achievements were based on geometry. Greek mathematicians did not need to name their numbers since they worked with numbers as lengths of lines. Merchants, not mathematicians, used numbers, which required to be named for records, and hence no clever notation was needed. There were however exceptions to what have just been stated. The exceptions were the mathematicians who were involved in recording astronomical data. Here we find the first use of the symbol, which we recognize today as the notation for zero, and the Greek astronomers began to use the symbol O. There are many theories why this particular notation was used. Some historians favor the explanation that it is omicron, the first letter of the Greek word for nothing namely "ouden". Otto Neugebauer (1899-1990), Austrian American Mathematician, however, dismissed this explanation since the Greeks already used omicron as a number and it represented 70 (the Greek number system was based on their alphabets). Other explanations offered include the fact that it stands for "obol", a coin of almost no value, and that it arises when counters were used for counting on a sand board. The suggestion here is that when a counter was removed to leave an empty column it left a depression in the sand which looked like O. Zero represents nothingness and emptiness. The idea of nothingness and emptiness has always inspired mathematicians, physicists and even philosophers. Though the humans have always understood the concept of nothingness or having nothing, the concept of zero is relatively new as it only fully developed in the 5th century AD. Before this mathematicians struggled to perform even the simplest arithmetic calculations.

Ptolemy – Greco Egyptian Mathematician, Astronomer, Geographer and Astrologer, in the Almagest written around 130 AD used the Babylonian sexagesimal system (base 60 numeral system) together with the empty placeholder O. By this time Ptolemy was using this symbol both between digits and at the end of a number and one might be tempted to believe that at least zero as an empty place holder had firmly arrived. This, however, is far from what happened. Only a few exceptional astronomers used the notation and it would fall out of use several more times before finally establishing it. Zero was certainly not thought of as a number by Ptolemy who still considered it as a sort of punctuation mark. The idea of zero made its next appearance in Indian mathematics. The scene now moved to India where it is fair to say the numerals and number system were born which have evolved into the highly sophisticated ones which we use today. Of course that is not to say that the Indian system did not owe something to earlier systems and many historians of mathematics believe that the Indian use of zero evolved from its use by Greek astronomers. Some historians seem to want to play down the contribution of the Indians in a most unreasonable way. There are also those who make claims about the Indian invention of zero, which seem to go far too far. What is certain is that by around 650 AD the use of zero as a number came into Indian mathematics. The Indians also used a place-value system and zero was used to denote an empty place. In fact there is evidence of an empty placeholder in positional numbers from as early as 200 AD in India but some historians dismiss these as later forgeries. First use of zero by mathematicians in India is dated around 500BC. Indian Jaina mathematicians invented logarithms around 200AD. Around 200AD, Indian mathematician Brahmagupta was the first to describe the modern place-value numeral system (Hindu-Arabic numeral system). In 1400AD, Kerala School of Astronomy and Mathematics in South India invented the floating point number system. In 300 BC, Indian mathematician, scholar and musician Pingala was the first to described the binary number system consisting of 0 and 1, which is now used in the design of essentially all modern computing equipments. Pingala also conceived the notion of a binary code (collection of bits 0 and 1).similar to the Morse code. Binary codes of numbers are the lifeline of present day classic computers and will perhaps remain so till the design of classic computers is based on digital technology wherein both bits have digital representations of 0 and 1 and will perhaps continue to remain so till the arrival of quantum computers wherein both bits are represented by waves.

The brilliant work of Indian mathematicians was transmitted to the Islamic and Arabic mathematicians further west. Hindu Art of Reckoning describes the Indian place-value system of numerals based on 1, 2, 3, 4, 5, 6, 7, 8, 9, and 0. Ibn Ezra, in the 12th century, wrote three treatises on numbers, which helped to bring the Indian symbols and ideas of decimal fractions to the attention of some of the learned people in Europe. "The Book of the Number" describes the decimal system for integers with place values from left to right. In this work Ibn Ezra uses zero, which he calls 'galgal' (meaning wheel or circle). The Indian ideas spread east to China as well as west to the Islamic countries. In 1247 the Chinese mathematician Ch'in Chiu-Shao wrote "Mathematical Treatise" in nine sections which uses the symbol O for zero. A little later, in 1303, Zhu Shijie wrote "Jade mirror of the four elements" which again uses the symbol O for zero. Fibonacci was one of the main people to bring these new ideas about the number system to Europe. It is significant that Fibonacci was not bold enough to treat 0 in the same way as the other numbers 1, 2, 3, 4, 5, 6, 7, 8, 9 since he speaks of the "sign" zero while the other symbols he speaks of as numbers. One might have thought that the progress of the number systems in general, and zero in particular, would have been steady from this time on. However, this was far from the case. Cardan solved cubic and quartic equations without using zero. He would have found his work in the 1500's so much easier if he had a zero but it was not part of his mathematics. By the 1600s zero began to come into widespread use but still only after encountering a lot of resistance. Of course there are still signs of the problems caused by zero. Recently many people throughout the world celebrated the new millennium on 1 January 2000. Of course they celebrated the passing of only 1999 years, since when the calendar was set up no year zero was specified. Although one might forgive the original error, it is a little surprising that most people seemed unable to understand why the third millennium and the 21st century began on 1 January 2001. Zero is still creating anxieties about its different perceptions through ages.

News and Views

Recent Updates

Coral worldwide threatened by bleaching
Coral reefs are suffering a severe underwater heat wave this year for the third time on record. 2015 has seen coral

Coral bleaching: Before and After

bleaching occurring in reefs in the northern Pacific, Indian, equatorial Pacific and western Atlantic Oceans. The mass bleaching is caused by rising water temperatures resulting from two natural warm currents and excited by man-made climate change. The record high temperatures in parts of the oceans, is expected to wipe out more than 12,000 sq Km of reefs, or about 5% of the global total. [Read More]

Could 'The Day After Tomorrow' happen?
Scientists from Ocean and Earth Science at the University of Southampton found that, for a period of 20 years, the earth will cool instead of warm if global warming and a collapse of the Atlantic Meridional Overturning circulation (AMOC) occur simultaneously. Thereafter, global warming continues as if the AMOC never collapsed, but with a globally averaged temperature offset of about 0.8°C. The last 15 year climate hiatus witnessed was due to the AMOC collapse which was associated with heat inflow from atmosphere into ocean. [Read More]

The hidden meltdown of Greenland
Scientists working at University of California and NASA's Jet Propulsion Laboratory found the ice cliffs at three outlet glaciers in Greenland can destabilize the ice front and enhance iceberg calving, the process where parts of the glacier break off and float away. They have also found that the melt rates are of the order of few meters a day in the summer months. [Read More]

Oceanic phytoplankton declines in Northern Hemisphere
Diatoms, the largest part of phytoplankton have decreased more than 1 percent per year from 1998 to 2012 globally, with significant loss in northern Pacific, northern and equatorial Indian Ocean. This decline may cause reduction in the amount of CO_2 drawn from the atmosphere. The decline in the diatom population was attributed to the shoaling of mixed layer (ML). Taking into account the seasonal variation, the ML shoaled by 1.8 meters (5.9 feet) over the 15-year study period. [Read More]

Scientists solve the riddle of deep ocean carbon
Scientists from the National Oceanographic Centre (NOC) and the University of Southampton found that the pool of dissolved organic carbon (DOC) is comparable to that of the amount of carbon in atmosphere. Phytoplankton are the primary source of DOC in the ocean, they take CO_2 from the atmosphere and convert them into more complex carbon compounds. [Read More]

Highest tides in 18.6 years
The moon and sun aligning directly over equator at the same time as the moon's 'nodal cycle' reaches a stage which is favourable to high tides. These higher than average tides are called spring tides. The high tides predicted for 2015 are due to a very slow change in the moon's orbit, which is inclined to the plane in which Earth orbits the Sun. [Read More]

New Discovery: First Bio-fluorescent Reptile – A Hawksbill Turtle
Marine biologist David Gruber from City University of New York was in the process of capturing the bio-fluorescence of sharks and corals at Solomon Islands. Accidentally, he found a turtle which was gliding across his camera and observed this amazing characteristic of bio-fluorescence in it. The natural ability of reflecting blue light as a different colour is called bio-fluorescence. There has been no answer yet for why this turtle is exhibiting this characteristic. [Read More]

Compiled by Sandeep Narayanasetti, IITM

Conferences

Upcoming Events

- NIO 50th Jubilee and International Indian Ocean Expedition Symposium which will be held at Goa, India from 30 Nov 2015 to 04 Dec 2015. [Read More]

- CLIVAR/JAMSTEC Workshop on the Kuroshio Current and Extension System: Theory, Observations, and Ocean Climate Modelling will be held at Yokohama, Japan from 12th-13th January 2016. [Read More]

- National Conference on "Climate Change Impacts and Natural Resource Management" 18 & 19th February 2016. [Read More]

Opportunities

Job/Fellowship Opportunities

- Recruitment of Project Scientists at Indian Institute of Tropical Meteorology (IITM), Pune. [Read More]

- Atmospheric Science Faculty Position at Ohio State Univ. Emphasis on Synoptic Met. and Weather Forecasting

- The Climate Simulations and Predictions (CSP) Division, at the Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) invites applications for a position in climate dynamics and modeling. The 2-year position ranges from post-doc to junior scientist, and will be based at CMCC in Bologna (Italy). [Read More]

- PhD position in Mountain Climatology/Glaciology at the University of Fribourg, Switzerland, Department of Geosciences, Physical Geography Unit. [Read More]

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Towards Paris

Spotlight

The 21st yearly session of the Conference of Parties (COP 21) will be held in Paris from Nov 30 to Dec 11, to achieve a legally binding and universal agreement on climate, from all the nations of the world. This time, there is no question on which of the countries will commit to reduce the emissions. The question is on how much will they commit? The focus is on the Intended Nationally Determined Contributions (INDCs), which will determine the path of future greenhouse gas emissions and temperature rise. Will COP 21 provide a window to keep the global warming below 2 degrees Celsius?

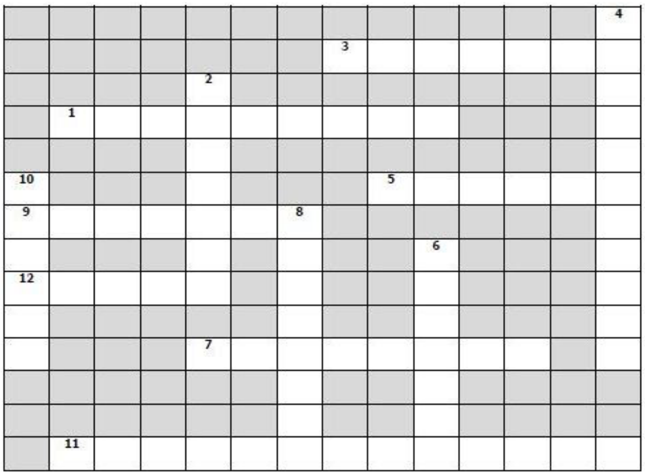
COP21 · CMP11
PARIS 2015

Meanwhile, 2014 was the hottest year on instrument records, and with an ongoing El Nino, 2015 may cross that record. Temperature records and studies point out that the recent climate pause is over-or was never there in the first place!. Time is indeed ticking for climate action!

- Roxy Mathew Koll, IITM

Crossword

The clues for the Earth Science Crossword can be traced to the present and previous issues of Ocean Digest. Enjoy.



ACROSS

1. This wind-driven process brings cooler and nutrient-rich water towards the ocean surface
3. It is India's largest inland salt lake
5. This ocean existed between the continents of Gondwana and Laurasia
7. It is the atomic ratio of carbon, nitrogen and phosphorus found in phytoplankton and throughout the deep oceans
9. This Current is the western boundary current of the southwest Indian Ocean
11. Photosynthesizing microscopic organisms that inhabit the upper sunlit layer of oceans
12. Is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light

DOWN

2. It is the state of the atmosphere during a short span of time
4. The lowest layer of Earth's atmosphere is better known as
6. It is the vast elevated plateau in Central Asia
8. A unit to measure the volumetric rate of transport of ocean currents
10. This cell results due to tropical atmospheric circulation

Compiled by Bhupendra B. Singh

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