

^{14}C

^{10}B

^{231}Pa

^{86}Sr

^{234}U

^{44}Ca

^{230}Th

OCEAN DIGEST



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Research and Development in Operational Oceanography- Indian Scenario

Invited Article

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Ocean is the cradle of life on Earth. They play the most important role in setting the appropriate climate for the existence and survival of life on our planet. Dependence of living beings on the oceans has ever been increasing as they are good source of food, minerals, medicines and many more. Most parts of the oceans are yet to be explored! Several industries such as transport, energy, recreation etc. depend heavily on the oceans for their operations. Natural phenomena which originate from the oceans, such as Tropical Cyclones, Storm Surges, Tsunamis etc., although are different means for the redistribution of energy in the earth system, quite often affect our life and cause extensive damages to our properties. Humans have an instinct to understand the natural processes around us and predict them so that the calamities due to them can be mitigated and the casualties may be reduced. This also helps for the effective utilization of natural resources for the socio-economic uplift of mankind.

Gathering information of weather and climate has been an age-old practice, this has led to the development of techniques, including sophisticated numerical models which can be solved by the most powerful computers, to predict them. It is important to mention here that there have been tremendous improvements in our skills to predict the weather and climate, thanks to steadfast efforts of meteorologists around the world. In earlier days, mariners used to collect and record information on the ocean currents and marine weather en-route their voyages, which helped us to improve our understandings on the global ocean circulations and sea states. Later, reliable data for the world oceans was available through state-of-the-art observation systems including satellites. The availability of data, and skills of the numerical models to simulate the important oceanographic parameters, attempts have been made to develop operational ocean prediction systems in many parts of the world in the recent years. GODAE Ocean View, which is a consortium of the leading operational ocean forecast systems in the world, has been providing a platform for the scientific exchange of information and expertise in developing the operational ocean forecast systems. The leading operational ocean forecast systems such as BLUElink (Australia), FOAM (UK), Mercator Ocean (France), RTOFS (NOAA, USA), HYCOM/NCODA (US Navy), ECCO (JPL, NASA, USA), ECMWF (EU), MFS (Italy), INDOFOS (India) REMO (Brazil), MOVE/MRI.

COM (Japan), CONCEPTS (Canada), NEMFC (China) etc. are the members of GODAE Ocean View (<https://www.godae-oceanview.org/>).

The main objective of the operational oceanography is to provide information/predictions on the behaviour of the oceans, such as circulation, wind-waves or sea state, tides, distribution of temperature, salinity, water quality, sea level variations etc., in different time and spatial scales. While short term predictions of these parameters are important for safe navigation in the seas with lesser fuel consumption, finding out potential fishing zones, making cost-effective operations in the oceans to explore resources, installation of platforms for the generation of off-shore energy and planning the activities in ports and harbours etc, long term projections of sea level and tides are necessary for designing the plans to mitigate any eventualities due to global change. Search and rescue operations for the missing persons/objects in the sea benefit enormously by accurate predictions of the ocean currents and surface winds. Similarly, predictions of oil-spill trajectories proved to be vital for the protection of marine ecosystem. Maritime security forces depend heavily on the operational predictions of ocean general circulation features for their operations. It can be well understood that the information/predictions of ocean features will be very handy, when one venture into the unknown oceans, be it for finding his daily livelihood or for high-tech operations. Another important component of the operational oceanography is the generation of ocean analysis, in which all the data available in real time is assimilated to a suitable general circulation model. Similarly, ocean reanalysis is generated by retrospective assimilation of quality controlled ocean data (including non-real time data) in the ocean models. While the ocean analysis is an important component of the numerical weather prediction, ocean reanalysis is widely used for research and development (R&D) activities in oceanography including process studies.

Essential components of the systems to generate operational oceanographic products are (i) a well distributed ocean observation system to collect data from different parts of the oceans, (ii) numerical models which can simulate the observed features of ocean circulation, waves, tides,

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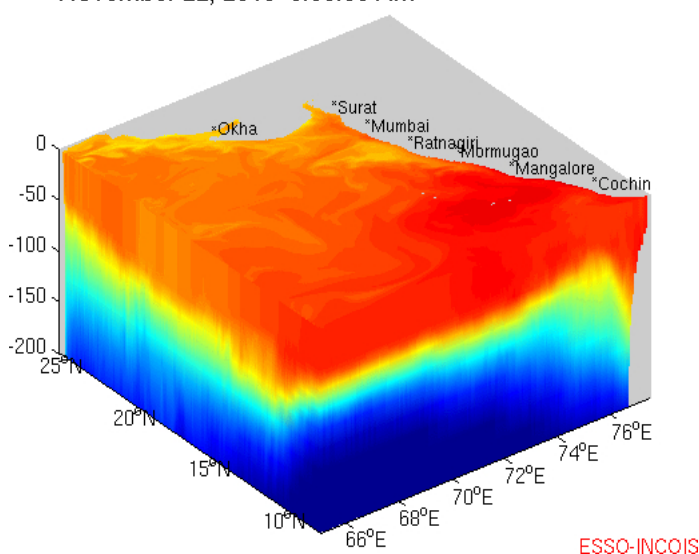


Figure 1: Cross-section of temperature variation in the eastern Arabian Sea predicted by the High-resolution Operational Ocean Forecast and reanalysis System.

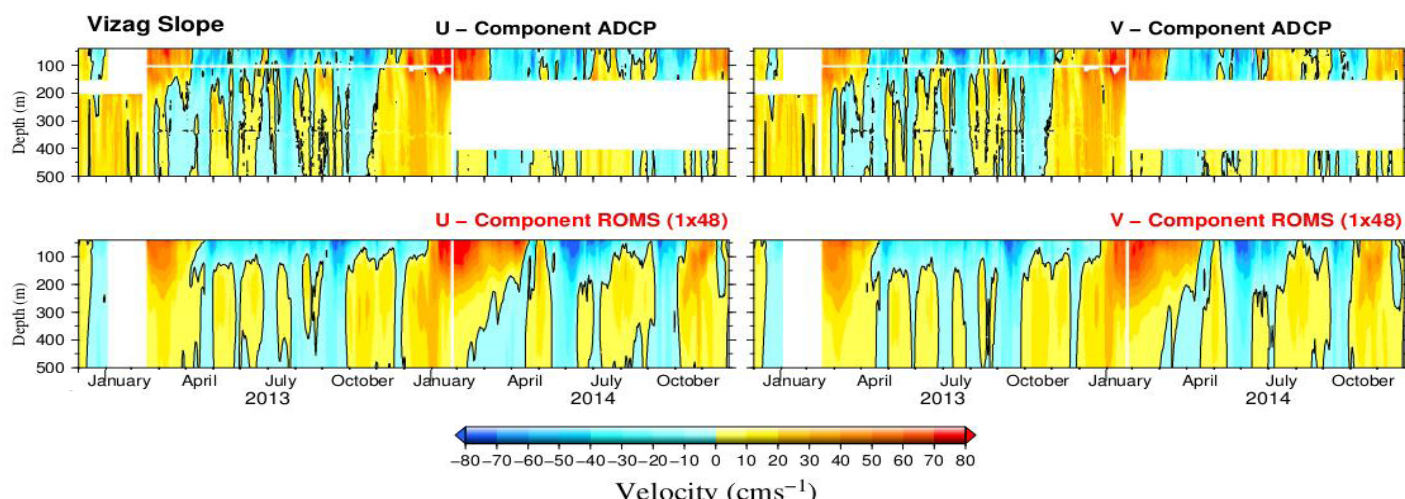


Figure 2: Coastal currents simulated by the HOOFS setup for the Bay of Bengal is compared with the ADCP observations in the slope region off the coast of Visakapatnam. Processed data from the ADCP was provided by Dr. D. Shankar, NIO, Goa.

thermohaline structure etc., (iii) a suitable data assimilation system which can assimilate the ocean observations to the numerical ocean models so that the errors in the model simulations can be minimized, (iv) accurate surface boundary forcing fields such as momentum, heat and fresh water fluxes to force the numerical ocean models and (v) the necessary hardware and software to integrate the numerical ocean models to generate the simulations/predictions. It requires focused research to setup the numerical ocean models and data assimilation schemes which are suitable for operational oceanographic purposes.

With more than 300 million people settled along the coastlines and a large fraction of population depending on oceans for their livelihood, having an operational ocean forecast system is vital for India. Recognizing this requirement, Ministry of Earth Sciences, Government of India entrusted Indian National Centre for Ocean Information Services (INCOIS) to develop a suitable ocean forecast system. In 2010, INCOIS setup the Indian Ocean Forecast System (INDOFOS), which consists of a suite of state-of-the art numerical ocean models (Wavewatch III, SWAN, Modular Ocean Model (MOM) and Regional Ocean Modeling System (ROMS)) to generate information/forecasts of various ocean parameters such as currents, waves, temperature, salinity, tides etc. ranging from global oceans to the coastal waters. More details on the configuration of the ocean forecast system of INCOIS can be seen at <http://www.incois.gov.in/portal/osf/osf.jsp>. Propelled by the demand from the user community for more accurate ocean forecasts at higher spatial resolution, INCOIS has been setting up a series of High-resolution Operational Ocean Forecast and reanalysis System (HOOFS) for the coastal waters of the country. The HOOFS is designed in such a way that very high-resolution (~ 2.5 km for the prediction of circulation and ~ 250 m for the wave predictions) coastal models are nested in the relatively lower resolution (~9.5 km for the prediction of circulation and ~5 km for the wave prediction) models for the Indian Ocean. The Indian Ocean models take boundary conditions from the global model which is of a coarser resolution. Extensive validations of the predictions are also conducted before finalizing the optimal configuration of the ocean forecast systems. HOOFS setups for the west coast of India (WC-HOOFS & SEA-HOOFS) are already made operational and the setup for the Bay of Bengal (BB-HOOFS) is now ready for operational use.

Apart from focused R&D in the numerical ocean modelling, India has also invested considerably in maintaining a good network of ocean observation systems that report data on real time to INCOIS. Hence, there is reasonable amount of data available for assimilating into the numerical models to correct the errors which creep into simulations owing to various reasons ranging from the inaccuracies in the model physics, numerical schemes, external forcing etc. Data from these observation systems are also used for fine-tuning the ocean model setups. Focused research is carried out to develop and incorporate suitable data assimilation systems to assimilate ocean data into the models used for the operational forecasts.

Numerical modelling aiming at the prediction of the marine ecosystem parameters is another important area of research at INCOIS. There has been considerable progress in simulating the variability in biogeochemical parameters such as chlorophyll, oxygen, nitrates etc. Focused R&D is also being carried out to improve the quality of the simulations so that this can be used for forecasting the marine ecosystem parameters in near future.

While the ongoing R&D on numerical modelling and data assimilation in INCOIS is primarily restricted towards setting up the models suitable for the requirements

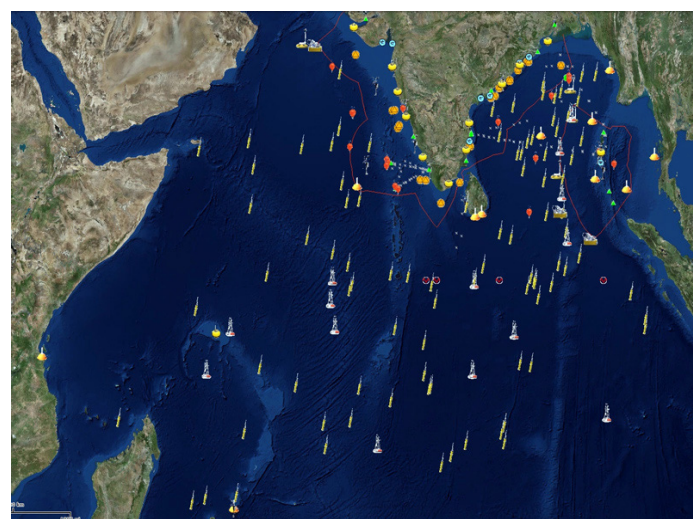


Figure 3: Present status of ocean observation systems in the Indian Ocean. Courtesy: N. Kiran Kumar, INCOIS.

of operational ocean services and fine tuning these setups using the options available in the models, it is necessary that the numerical models themselves have to be improved by defining the most appropriate parameterizations of physical processes for the Indian Ocean. This can be done only by the analysis of data collected from observations, specific to such processes. Hence, it is envisaged that, in the coming years, more observational campaigns and focused R&D will be carried out with the specific aim to improve the numerical ocean models used for the operational oceanography. At the same time, we still have to complete the implementation of data assimilation schemes in all the models used for the operational ocean services. Similarly, more R&D has to be carried out to develop an end-to-end ecosystem model, which can be used for graduating the ongoing Potential Fishing Zone (PFZ) services from 'Advisories' to 'Forecasts'. In short, while the foundation of the operational oceanography has been well laid in the country in the past several years, a more organized structure has been built in the last few years. We will now improve upon this and bring India as one of the most sought place for operational oceanographic services in the coming years.

Coastal Currents from HF Radars along Odisha Coast

Student Article

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Introduction

The Bay of Bengal (BoB), covering the north-eastern part of the Indian Ocean ($76^{\circ} - 100^{\circ}$ E, $4^{\circ} - 24^{\circ}$ N), is a semi-enclosed tropical ocean basin. The current system on the western boundary in the BoB is well known for its unique circulation pattern with high complexity as compared to the rest of the basin. The space-time current variability, northward during spring and southward during autumn, has been studied from various hydrographic datasets (Babu et al., 2003), satellite altimetry datasets (e.g. Gangopadhyay et al., 2013 and references therein) and numerical simulations (e.g. Sil et al., 2014) in the last few decades. Earlier circulation studies are focused mostly on basin scale and are from ocean models and satellites derived data. The observational data were limited along the BoB coast until ESSO-NIOT and ESSO-INCOIS installed five pairs of the long range SeaSonde HF Radar systems along the Indian coastline. They remotely sense the ocean surface currents covering the coastal regions of India and are operating continuously since 2009 (John et al., 2015). In this study, the coastal currents variability has been analysed during 2011 along Odisha Coast, the north western BoB. The sub-mesoscale coastal processes captured by HF radars are validated with other available datasets in this region.

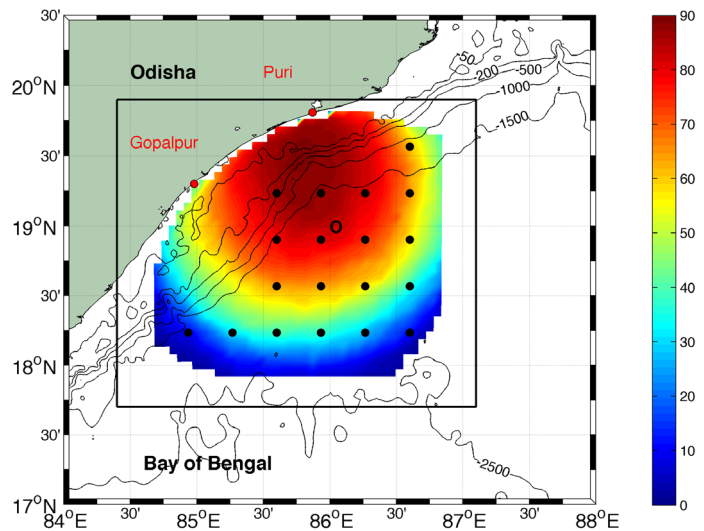


Figure 1: The Data Coverage (shaded) during 2011 in percentage (%). The dots are showing the grid points of the OSCAR data. The location "O" (85.93° E, 18.90° N) is chosen to compare with HYCOM and OSCAR.

Data and Methodology

The measurements of high radar frequency echoes backscattered from the sea surface can be used to deduce information on both waves and surface currents. These radars are of direction finding type, consisting of one receiving and one transmitting antennae at each of the locations. The two radars at the Odisha coast which are located at Gopalpur (84.96° E, 19.3° N) and the other at Puri (85.86° E, 19.8° N) covering a region of 200 km from the coast (John et al., 2015), the locations are shown in figure-1.

The high resolution (~ 6 km) and high frequency (hourly) surface current from HF Radar during 2011 (source: INCOIS, India) along the Odisha coast are initially used for this analysis. The simulated daily ocean currents for the same time span have been taken from Hybrid Coordinate Ocean Model (HYCOM) with $1/12^{\circ}$ (~ 9 km) spatial resolution (<https://hycom.org/>) and OSCAR surface current datasets which are available on a 5-day scale with spatial resolution of

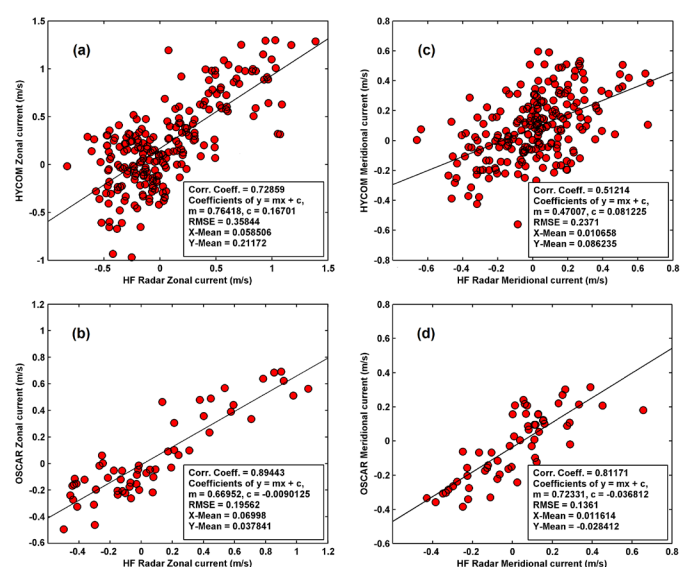


Figure 2: Scatter plots between HYCOM, OSCAR and HF Radar derived ocean currents at O (85.93° E, 18.90° N) location during 2011. The zonal (left) and meridional (right) components of HF radar derived comparisons with HYCOM (top) and OSCAR (bottom).

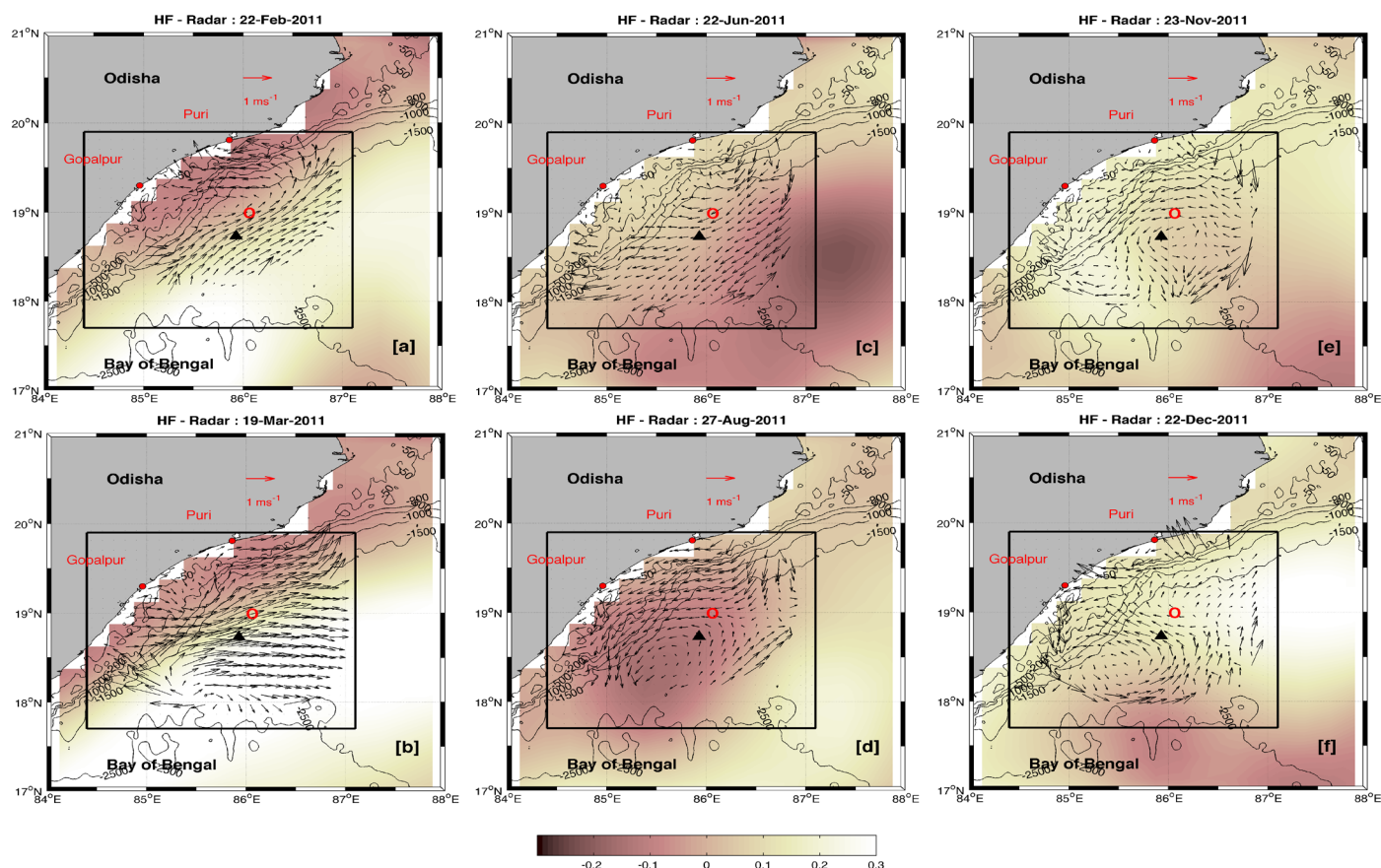


Figure 3: Daily averaged current field (vector) on different dates during 2011. The shaded background is Sea Level Anomaly (in m from AVISO). The pair of HF radar stations are shown as red dots at Puri and Gopalpur. The black contour lines are from GEBCO showing bathymetry. The location chosen for analysis at offshore (O) is indicated by triangle symbol.

$1/3^\circ$ (~ 33 km) have been used (Bonjean and Lagerloef, 2002). These datasets are compared with the HF radar as there are no other surface current observations available during this period in this region.

The HYCOM and OSCAR are of comparably coarse resolution and HF radar data is also not spatially uniform in terms of data availability (Fig. 1). Therefore, we have selected a point 'O' (85.93° E, 18.90° N) where 80% data of the year is available excluding May 1 to June 11, when no data is available.

This location is identified to be very close to the grid points of the other two data sets. In addition, the location is also useful to study the eddy movement in this region. The zonal and meridional component of the ocean currents are analysed at this location and compared with the other data sets at the nearest location. As the HYCOM is available daily and OSCAR is for five days, so the hourly HF radar derived currents are averaged in the corresponding scales.

Results and Discussions

First, the comparison of HYCOM and OSCAR time series data at the location "O" is done with HF radar, to validate the capability of HF radar on capturing the broad scale features like reversal of coastal current and the existence of the eddies in this region. Then, the spatial variation of the HF radar current during 2011 is discussed and the mesoscale eddies in this region is identified.

Validation

The statistical comparison of HF radar current with the

HYCOM and OSCAR include the magnitudes of the correlations, the root-mean-square (RMS) differences, and the regression analysis. The HF radar current matches with both the currents (OSCAR and HYCOM) quite well, with strong correlations of 0.89 and 0.73 for the zonal components (Fig. 2a and 2c) whereas, 0.81 and 0.51 for the meridional components (Fig. 2b and 2d), which satisfy the range as obtained from the previous studies (Cosoli et al., 2010). The respective Root Mean Square Errors (RMSEs) for the zonal components are 0.36 m s^{-1} and 0.23 m s^{-1} (Fig. 2a and 2c) whereas, 0.19 m s^{-1} and 0.13 m s^{-1} for the meridional components (Fig. 2b and 2d). A comparatively less match has been found for the meridional components which agrees with the earlier studies (Cosoli et al., 2010).

The above comparisons for the year 2011 at the location 'O' show the seasonal variability of the circulation pattern, which matches well with HYCOM and OSCAR. But both datasets show lesser magnitude in both components as compared with HF radar derived current.

Current Variability

The major advantage of the HF radars is that it would enable us to study the spatial distribution of surface current circulation patterns with high temporal and spatial resolution in coastal regions (Ramp et al., 2008, Cosoli et al., 2010). During January 2011, the significant southward flow is observed both from HF Radar and OSCAR with higher amplitude along the continental slope (-0.8 m s^{-1}) with a strong meander. In February, the northward boundary currents are observed with magnitude 0.6 m s^{-1} and at the same time a cyclonic eddy is captured with centre at around 86° E, 19° N as supported by

satellite altimetry. This results in a southward current in the northern coastal region of Odisha (Fig. 3).

In March, the northern boundary current is observed to be fully developed but a bit away (~50 km) from the coast. In April, the same current attains its peak strength and as a result an increase in the magnitude is observed from the coast (0.5 m s^{-1}) to the offshore (1.8 m s^{-1}). The formation of the anticyclonic eddy below the 18°N is also observed which takes the main stream of the current away from the coast (Gangopadhyay et al., 2013). From the mid June, the flow reverses and a cyclonic eddy is observed clearly by the end of August which satisfies the earlier studies from altimetry and geostrophic flow. During November, the HF radars captured a mesoscale cyclonic eddy with centre almost at the middle of the HF radar coverage region which provides a southward current along the Odisha coast. This eddy lasted for almost two months till the mid of December.

Summary

The study indicated the usability of the HF radar in this domain as it captured the basin scale as well the mesoscale oceanic processes. The comparison with other available datasets such as HYCOM and OSCAR showed strong correlation and less RMSEs, although HF Radar current magnitude is higher than the others. This study provides an insight of the coastal circulation on the Odisha Coast. The spring time northward flowing current magnitude was observed to be more than 1.5 m s^{-1} . The southward flow is comparative slower around 0.5 m s^{-1} during November. But a high tempo-spatial variability in the coastal currents associated with mesoscale to sub-mesoscale oceanic processes have been observed. The structure and dynamics of these currents could be studied in the future.

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ORV Isotope

Review Article

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A ship sailing across the Bay of Bengal waters on a breezy winter night of December, is about to start its operation of vertical profiling of water samples off the Andaman Islands with an aim to identify the different water masses down to about 2000m of water depth. More than a dozen scientists have geared up, aspiring to delve into the ocean, to understand the marine processes that control the short-term weather pattern to long term climate variability. They are equipped with a variety of sensors and equipment that can measure ocean-atmospheric parameters such as temperature, salinity, surface current, alkalinity, dissolved oxygen, nutrients, wind speed, rainfall, humidity, isotopic ratios and so forth. The CTD sensor (Conductivity, Temperature and Depth of the ocean, Figure 1) goes down to any desired depth of the ocean and collects water which is followed by onboard analysis for its oxygen content, inorganic carbon, pH, micro-organisms, and many more. There is a coring device that can drill sediment cores from the abysmal ocean; the depth ranges from several hundreds to a few thousands of meters. The ship is nicknamed as "Ocean Research Vehicle (ORV) Isotope" - an acronym for the "Indian Scientific Organization for Transatlantic and Pacific Expedition" that explores all the major oceans and applies the isotopic techniques in every operation and endeavors to unfold the mystery of the mighty ocean, understand its enigmatic behavior, peep into its unfathomable abyss and in turn to the distant past. How it is done- is a fascinating story.

We all know that isotopes are the atoms of the same element but have different number of neutrons that give them slightly different physical properties. For example, hydrogen (^1H) has mass 1 while deuterium (^2H or D i.e. deuterium) has mass 2. Similarly, ^{16}O and ^{18}O are two isotopes of oxygen having masses 16 and 18 respectively. A normal water molecule (H_2^{16}O) consists of one ^{16}O and two ^1H . But a 'heavy' water molecule can have one ^{18}O and two ^1H ($^1\text{H}_2^{18}\text{O}$) or one ^{16}O and two ^2H ($^2\text{H}_2^{16}\text{O}$) (See Figure 2). This mass difference makes the heavier molecule little sluggish relative to the lighter molecule when they take part in a physical process or undergo a chemical or bio-chemical reaction. For example, when ocean water evaporates lighter molecules escape faster than the heavier molecules, making the vapor isotopically lighter and the ocean surface water heavier relative to each other. Similarly, when a sea shell (chemical composition

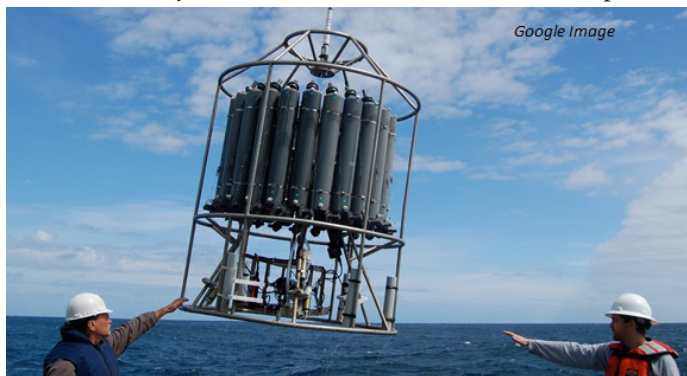


Figure 1:CTD Sensor

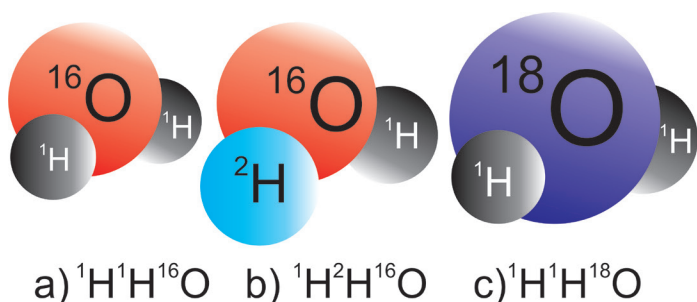


Figure 2: Water molecule consisting of a) lighter isotopes of hydrogen and oxygen, b) one lighter isotope (^1H) is replaced by a heavy isotope (^2H) c) one lighter oxygen (^{16}O) is replaced by a heavy oxygen (^{18}O) with heavier isotopes of oxygen.

CaCO_3) forms it has more number of ^{18}O than the ambient water which participates in the reaction. The number of ^{18}O isotope that would be locked in the shell, technically speaking the $^{18}\text{O}/^{16}\text{O}$ ratio in CaCO_3 is determined by two parameters, the sea surface temperature and the $^{18}\text{O}/^{16}\text{O}$ composition (denoted as $\delta^{18}\text{O}$) of the ambient water. Tiny creatures like foraminifera (similar to shell), when forms at the sea surface (called planktonic foraminifera) therefore 'record' the surface temperature. The bottom dwelling species, or the benthic foraminifera, on the other hand, respond to the isotopic composition of the abyss water. Deep ocean temperature usually does not change even for long time, but its isotopic composition could change due to the churning of the ocean, or the ventilation of the deep ocean which takes place in about thousand-year time scale. The life spans of foraminifera are of a few weeks; when they are born, they inherit the temperature information of the sea water; when dead they slowly settle to the ocean bottom and get deposited nearly sequentially in the sediment. The process continues for hundreds of thousands of years and thus the temperature history of the ocean gets recorded in the oxygen isotopic composition of the foraminiferal shell. Corals (Figure 3) are also somewhat similar to foraminifera but are fixed at the sea bottom and usually grow in the warm waters of the tropical region up to a depth of few tens of meters (Sheppard, 2015). Every year a layer of calcium carbonate is deposited, known as annual band; isotopic and elemental concentrations of these bands provide thermal and chemical history of the sea surface up to several hundred years. The western Indian Ocean has been experiencing steady increase in surface temperature which has been very well manifested in an oxygen isotopic record of coral collected from a coastal region of central Africa (Malindi) that provided nearly two hundred years of warming record in this region (Cole et al. 2009). Certain areas of the deep ocean also harbor corals known as deep sea corals, which are solitary in nature. They therefore record the deep ocean properties. For example, the deep water is not well mixed with the surface water, as mentioned earlier; the mixing process takes about thousand years. In other word, in about every thousand year the deep water is replenished by surface water. The timeframe, known as the ventilation age depends on the rate of the deep ocean circulation which changes with the long term climatic condition of the planet.

Apart from oxygen isotope many other isotopes are used to study the oceanic processes. A well-known candidate is radioactive isotope of carbon or ^{14}C which is widely used to determine the age of the archeological artifacts. The ^{14}C isotopes are continuously produced in the upper atmosphere which subsequently get mixed homogeneously in the atmosphere in the form of $^{14}\text{CO}_2$. Eventually they get absorbed



Figure 3: Coral in its natural habitat. The tiny creatures known as 'polyps' are seen on its surface.

by the surface ocean and slowly to the entire ocean. A tiny fraction (1 in 1012) of carbon in foraminiferal or coralline CaCO_3 is ^{14}C . When a sediment core from the deep ocean is collected, its age is determined by analyzing that tiny amount of ^{14}C locked in the foraminiferal carbonate structure. Hence ^{14}C gives time information while ^{18}O provides temperature record. Similarly, if the annual bands of a coral colony are analyzed for ^{14}C it will give the time variation of the surface ocean radiocarbon activity. If a given place of ocean experiences intense upwelling (i.e. bottom water coming to the surface due to ocean mixing process) then the ^{14}C content of that place will be much less than another place which is not subjected to upwelling. This 'information' will be recorded in coral carbonate, thus providing a means to study the past ocean circulation process. This kind of ^{14}C time series for the surface sea and the atmosphere (obtained from tree ring ^{14}C analysis) has been used to estimate the air-sea exchange rate in some coastal areas around the world. Figure 4 shows such an example. The surface water ^{14}C record was obtained from a coral collected from the gulf of Kutch in western India and the tree ring radiocarbon record was derived from a teak tree from Thane in Maharashtra. The y axis in this figure represents the radiocarbon activity denoted as $\delta^{14}\text{C}$ and expressed in permil, meaning 1 part in thousand. In normal circumstances the $\delta^{14}\text{C}$ values of atmosphere remains nearly zero (meaning ^{14}C production and its removal is in equilibrium). But the nuclear testing in the late 1950s by a few countries produced excess amount of anthropogenic ^{14}C , resulting nearly doubling of atmospheric ^{14}C in the atmosphere in mid 1960s. The similar enhancement was also observed in the surface ocean though the peak was subdued and arrived later than the atmospheric peak. This was caused due to ocean mixing processes. The air sea exchange rate was calculated by this method approximately

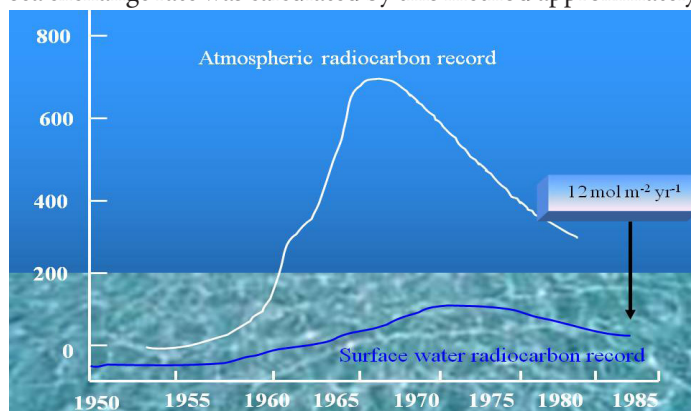


Figure 4: Estimation of air sea exchange rate using the radiocarbon records of air and sea, typically derived from the tree ring and corals respectively.

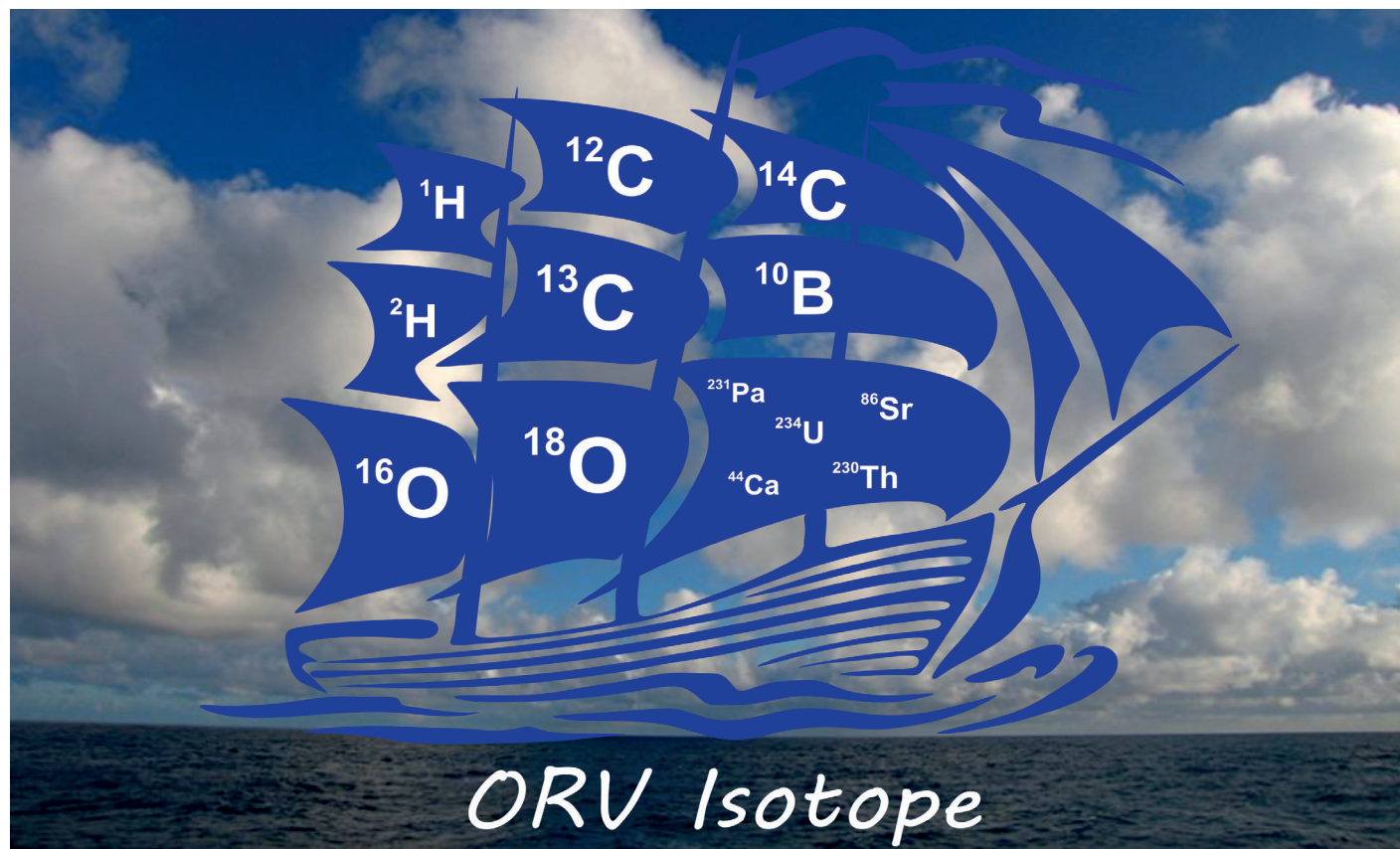


Figure 5: ORV Isotope.

12 mol. $\text{m}^{-2}.\text{s}^{-1}$ in the northern Arabian Sea region.

As mentioned earlier, certain oceanic regions contain deep sea corals, for example the Drake Passage in the Southern Ocean. Since deep sea is cut off from the atmosphere it does not get ^{14}C directly from the atmosphere. The surface ocean supplies ^{14}C to the deep sea at a very slow pace; the rate is governed by the vertical mixing of the ocean. Hence ^{14}C content of the deep ocean is about 8-10% less than that of the surface ocean. So, the 'radiocarbon age' of the deep ocean will be less than that of the surface ocean. If ocean surface has been considered as zero age (actually its radiocarbon age is 400 years due to mixing of the older deep water through upwelling, known as 'reservoir age'), the deep ocean will be about 1000-year-old. This age is however, not constant. If the ocean mixing process is slowed down by whatever means the deep-water age or the ventilation age will be increased. This information can be obtained by analyzing the radiocarbon content of the deep-sea corals. Other isotopes, such as ^{234}U , ^{230}Th , ^{231}Pa also need to be analyzed in the same coral sample to determine the ventilation age. Coral samples collected from the Drake Passage revealed that the ocean circulation or the intensity of the thermohaline circulation of the ocean was significantly down during the most recent ice age, occurred about 20,000 years ago. Since that time the earth has slowly warmed and the paleo record showed that the deep ocean circulation got strengthened. With further intensification of global warming will the ocean circulation be even stronger? Unfortunately, no one knows the correct answer.

Global warming- is a buzzword of the present time. The increased use of fossil fuel and release of excess CO_2 in the atmosphere is causing global temperature to rise at a fast pace. A significant amount of this CO_2 is absorbed by the ocean resulting the surface water more acidic. A lesser

known species- ^{11}B , an isotope of boron locked in the tiny foraminiferal shell records the oceanic level of acidity. Since enhanced supply of CO_2 causes increased level of acidity or decreasing pH of surface water of the oceans, analysis of ^{11}B also helps reconstruct the past CO_2 level in the atmosphere.

There are many such isotopes that the oceanographers use to understand the various marine processes. An important element is strontium whose isotopes, namely the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio has been used to study the rate of chemical weathering and dissolved fluxes in the oceans. Chemical weathering of rocks essentially absorb the atmospheric CO_2 thereby helps cool the planet, albeit on a long-time scale. One of the stable isotopes of carbon, viz. ^{13}C is very useful in studying the carbon dynamics. It is believed that a huge amount of land vegetation was lost to the ocean during the last glaciation. Since the carbon isotopic composition ($\delta^{13}\text{C} \sim 0$) of the dissolved inorganic carbon in the sea water is very different than the mean carbon isotopic composition of the terrestrial biomass ($\delta^{13}\text{C} \sim -25$ permil) it has been possible to estimate how much land vegetation (ca. 530 gigatons) was transferred to ocean during the last glacial time based on the carbon isotopic analysis of foraminifera. Several other isotopes, such as calcium, neodymium, rubidium, etc. are also used by the scientists in their pursuit of oceanic research. The journey of the ORV Isotope is a humble effort toward that noble cause. Figure 5 shows the ORV isotope.

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Cole et al. 2000 Tropical Pacific forcing of decadal SST variability in the Western Indian Ocean over the past two centuries Science 287, 617-619

Sheppard C. 2015 Central Indian Ocean - Effects of Climate Change Ocean Digest Vol. 2 (1) pp. 1-6.

Underwater Acoustic Transducer Test Facility

Contributed Article



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Introduction

Knowledge of underwater acoustics and acoustic based instruments are essential for exploration of ocean and their resources. Underwater acoustic sensors and instruments play a major role in oceanographic applications and their calibration is crucial for deriving fruitful results. Calibration is fundamental for accurate measurements and to estimate the characteristics of hydrophones. A state-of-the-art Acoustic Test Facility (ATF) has been set up at National Institute of Ocean Technology (NIOT) to cater the needs of testing and calibration of marine instruments of NIOT and other National Research Laboratories, Institutes & Industries. The facility has Underwater Acoustic Transducer Calibration systems for characterization of underwater acoustic transducers as per IEC 60565 with the requirement of IEC 17025.

Calibration Methods

Calibration of hydrophones essentially consists of determining important parameters such as receiving sensitivity, transmitting response, directivity and impedance. The most often used electro acoustic parameter is the free field voltage sensitivity of a hydrophone as a function of frequency. The most common absolute methods used in the calibration of electro acoustic transducers depend on the principle of reciprocity. In this method, three standard transducers are paired in three measurement arrangements. The current driving the transducer and the voltage generated by the receiver are measured for each of the arrangement. This method requires three transducers out of which at least



Figure 2: Acoustic Calibration Laboratory.

one must be reciprocal. Reciprocity method is called primary calibration standard since there is no standard or reference transducer required.

The secondary calibration standard or comparison method is more generally used for routine calibrations. This method consists of subjecting the hydrophone being calibrated and the reference hydrophone to the same free field pressure, and then comparing the electrical output voltages of two hydrophones. Calibration of hydrophones in the low frequency range i.e. from 100Hz to 1 kHz is performed by using vibrating water column method. In this method the hydrophone under calibration is immersed in the water column, the position of the transducer is kept constant while the fluid column is moved sinusously in vertical axis with the known acceleration level by using vibrating shaker. The sensitivity of the hydrophone is obtained from the calculated pressure at the depth of the hydrophone and the measured open circuit voltage. To characterize the directionality, response of an electro acoustic transducer is measured as a function of angular direction at specified frequencies.

Calibration Facility

The calibration facility at NIOT consists of an acoustic test tank of 16 x 9 x 7m (length x breadth x depth) for free-field calibration from 1 kHz to 500 kHz. The test tank is equipped with Acoustic Transducer Positioning System (ATPS), which was exclusively developed for positioning the transducers as shown in Figure 1. The ATPS is an integrated system consisting of mechanical, hydraulic and instrumentation equipment. ATPS has two special purpose trolleys which are operated in long travel, cross travel and hoist with rotary.

In order to overcome low frequency limitation in the acoustic test tank, a state of the art low frequency calibration facility based on vibrating water column methodology is established at ATF. Calibration of the transducers from the frequency range 100Hz to 1kHz is performed using this facility. This facility consists of the water filled test vessel with shaker assembly. Hydrophone under test and the reference hydrophone are placed in the test vessel. The frequency response calibration is performed with both the hydrophones exposed to the same sound pressure level in the water filled



Figure 1: Acoustic test tank with transducer positioning system (ATPS).

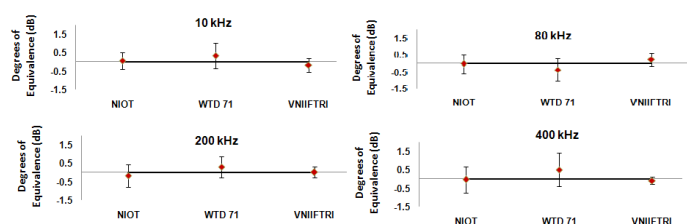


Figure 3: Degrees of Equivalence (D.O.E) in dB among institutes participated in ILC.



Figure 4: Tsunami Bottom pressure recorder and Ambient noise measurement system being tested at ATF.

test vessel. The open circuit sensitivity is determined by comparing the sensitivity of hydrophone under test with that of known reference standard. All the correction factors are considered in order to reduce the measurement uncertainty. State of the art acoustic calibration laboratory used for acoustic calibration and measurements are shown in figure 2.

Calibration Services

The Acoustic Test Facility provides a range of calibration and measurement services to meet the measurement needs of the user.

- Free-field calibration of hydrophones by the reciprocity method from 1 kHz to 500 kHz.
- Free-field calibration of underwater acoustic transducers and hydrophones by comparison method from 1 kHz to 500 kHz.
- Calibration of hydrophones by the vibrating water column method from 100 Hz to 1 kHz.
- Directional response measurement of hydrophones and transducers in the frequency range up to 500 kHz over 360 degrees of rotation with 1 degree resolution.
- Transducer electrical impedance in the frequency range 100 Hz to 1 MHz.
- Power and source level linearity measurement.
- Sound pressure level measurement and frequency analysis.

NABL Accreditation

The facility is accredited for calibration and testing of underwater acoustic transducers in the year 2005 by National Accreditation Board for Testing and Calibration Laboratories (NABL) and the accreditation is continued by periodical

surveillance and re-assessment as per ISO/IEC 17025:2005. Measurements are performed in accordance with IEC 60565-2006 and ANSI / ASA S1.20-2012 in the frequency range from 100Hz to 500 kHz.

Inter-Laboratory Comparison (ILC)

In order to bring the ATF as a Nationally Designated Laboratory in underwater acoustics in India, and as part of the accreditation program, NIOT ATF, coordinated Inter-laboratory Comparison (ILC) Calibration with the support of Ministry of Earth sciences, Government of India with the participation of Russian National Research Institute for Physicotechnical and Radio Engineering Measurements VNIIFTRI, Russia and Bundeswehr Technical Centre for Ships and Naval Weapons (WTD 71), Germany (Figure 3). The ILC was successfully completed in October 2014.

These results establish that the calibration at ATF confirms with the international standards and on par with the internationally acclaimed laboratories.

Other devices being tested at Acoustic Test Facility

Apart from the calibration of transducers and hydrophones, ATF is also being utilized for testing of underwater systems such as prototype Remotely Operable Vehicle (ROV), Bottom Pressure Recorder (BPR) of Tsunami warning system (Figure 4), Ambient noise measurement system, Buried Object Detection Sonar (BODS), Drifter buoy, Fish cage culture system, prototype gliders, variable buoyancy system, Acoustic pingers, Acoustic modems, current meters, tide gauges etc.

News and Views

Recent Updates

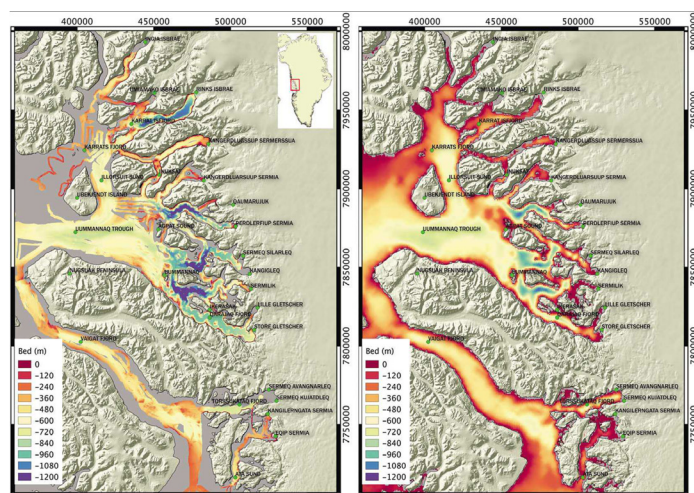
Warmer West Coast ocean conditions linked to increased risk of toxic shellfish

Domoic acid, produced by certain types of marine algae, can accumulate in shellfish, fish and other marine animals. Public health agencies and seafood managers closely monitor toxin levels and impose harvest closures where necessary to ensure that seafood remains safe to eat. [\[Read More\]](#)

Reference: McKibben et al., 2017: Climatic regulation of the neurotoxin domoic acid. *Proceedings of the National Academy of Sciences*, 201606798 DOI:10.1073/pnas.1606798114.

Release of a new detailed Greenland glacier data

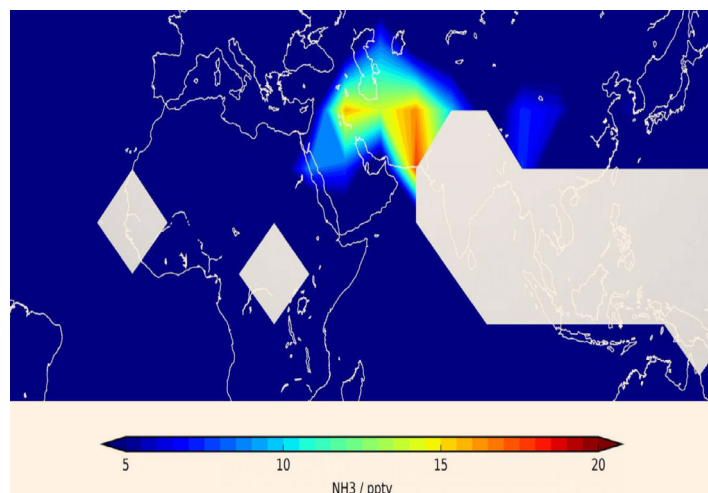
From its first airborne campaign in March 2016, NASA's Oceans Melting Greenland (OMG) mission has released preliminary data on the heights of Greenland coastal glaciers. The new data shows the dramatic increase in coverage that the mission provides to scientists and other interested users. Finalized data on glacier surface heights, accurate within three feet (one meter) or less vertically, will be available by Feb. 1, 2017. [\[Read More\]](#) [\[Glacier Data\]](#)



The Oceans Melting Greenland campaign has released new, more accurate maps of Greenland's coastal glaciers.

First detection of ammonia (NH₃) in the Asian summer monsoon upper troposphere

An international research team led by Karlsruhe Institute of Technology scientist Dr. Michael Höpfner analyzed data collected from June 2002 to April 2012 by the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) instrument, an infrared spectrometer on the European environmental satellite ENVISAT. MIPAS recorded highly resolved spectra in the middle infrared range, from which gases can be identified clearly. Every gas emits specific infrared radiation. The researchers found enhanced amounts of ammonia (up to 33 pptv, or 33 ammonia molecules per trillion air molecules) within the region of the Asian summer monsoon at 7.5-9.3 mile (12-15 km) altitude. This suggests that the gas is responsible for the formation of aerosols, smallest particles that might contribute to cloud formation. The authors have presented the first evidence of ammonia being present in the Earth's upper troposphere above 6.2 miles (10 km) by an analysis of MIPAS infrared limb-emission spectra. [\[Read More\]](#)



Distribution of the atmospheric ammonia concentration in June, July, and August 2008 at 9.3 mile (15 km) height as observed by MIPAS. Bright areas are measurement gaps due to high cloud cover. Source: Michael Höpfner / Karlsruhe Institute of Technology.

Reference: Höpfner et al., 2016, First detection of ammonia (NH₃) in the Asian summer monsoon upper troposphere, *Atmos. Chem. Phys.*, 16, 14357-14369, doi:10.5194/acp-16-14357-2016.

Short-lived greenhouse gases cause centuries of sea-level rise

In a paper published this week in the Proceedings of the National Academy of Sciences, the researchers report that warming from short-lived compounds, greenhouse gases such as methane, chlorofluorocarbons, or hydrofluorocarbons, that linger in the atmosphere for just a year to a few decades can cause sea levels to rise for hundreds of years after the pollutants have been cleared from the atmosphere. The researchers' estimates for carbon dioxide agreed with others' predictions and showed that, even if the world were to stop emitting carbon dioxide starting in 2050, up to 50 percent of the gas would remain in the atmosphere more than 750 years afterward. Even after carbon dioxide emissions cease, sea-level rise should continue to increase, measuring twice the level of 2050 estimates for 100 years, and four times that value for another 500 years. [\[Read More\]](#)

Reference: Zickfeld et al., 2017, Centuries of thermal sea-level rise due to anthropogenic emissions of short-lived greenhouse gases. *Proceedings of the National Academy of Sciences*, DOI:10.1073/pnas.1612066114.

Rapid Arctic warming has shifted Southern Ocean winds in the past

In a paper published in the January 2017 issue of *Nature Geoscience*, the researchers report that, the Antarctic ice core shows that Southern Ocean winds shifted at the same time, or at most within a few decades, of each rapid Greenland warming event. Antarctic air temperatures, on the other hand, are connected through the slower-moving oceans and took about two centuries to respond. [\[Read More\]](#)

Reference: Markle et al., 2016, Global atmospheric teleconnections during Dansgaard-Oeschger events. *Nature Geoscience*, 10 (1): 36 DOI:10.1038/ngeo2848.

Future of coral reefs under climate change predicted

New climate model projections of the world's coral reefs reveal which reefs will be hit first by annual coral bleaching, an event that poses the gravest threat to one of the Earth's most

important ecosystems. These high-resolution projections, based on global climate models, predict when and where annual coral bleaching will occur. The projections show that reefs in Taiwan and around the Turks and Caicos archipelago will be among the world's first to experience annual bleaching. [\[Read More\]](#)

Reference: Hooidonk et al., 2016, Local-scale projections of coral reef futures and implications of the Paris Agreement. *Scientific Reports*, 6: 39666 DOI: 10.1038/srep39666.

Conferences

Upcoming Events

- OSICON 2017, the 5th National Conference of the Ocean Society of India, will be held at ESSO-NCESS, Thiruvananthapuram, during 28-30 Aug 2017 [\[link\]](#).
*Note the change in dates from the earlier announcement.
- 5th International Conference on Oceanography and Marine Biology will be held at Seoul, South Korea from October 16-18, 2017. Theme: Contemporary challenges and innovative solutions for sustainable oceans.
- A Short Course on Dynamic Data Assimilation: Theory and Applications" will be conducted at Indian Institute of Tropical Meteorology, Pune during 26 June - 7 July 2017

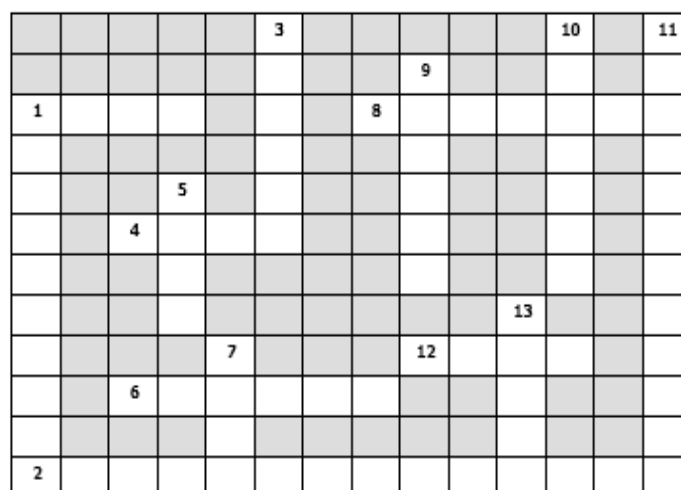
Opportunities

Fellowships

- PhD in Arctic storm risk at the University of Reading [\[See More\]](#)
- PhD studentships on aerosol effects on precipitation at Atmospheric, Oceanic and Planetary Physics, Department of Physics, University of Oxford [\[See More\]](#)
- One Research Scientist and Three Postdoc Positions Open in Ocean Data Assimilation, Forecasting and Visualization at KAUST. To apply, please send curriculum vitae and a letter of interest with the names and contact information of at least two references to ibrahim.hoteit@kaust.edu.sa and omar.kio@kaust.edu.sa.

Crossword

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



ACROSS

- A phenomenon of small droplets suspended in air
- Excessive richness of nutrients in large body of water is termed as
- It is the only landlocked country in Southeast Asia
- The most common form of high-level thin and often wispy cloud is
- The oldest known world maps date back to this ancient region from the 9th century BC
- The meteorological term for crystalline or granular snow, especially on the upper part of a glacier, where it has not yet been compressed into ice

DOWN

- It is the atmospheric layer in which most meteors burn up after entering Earth's atmosphere before reaching Earth's surface
- This Cyclone caused the worst natural disaster in the recorded history of Myanmar during early May 2008
- The Madden-Julian oscillation is a traveling pattern which propagates in this direction
- It is a global array of free-drifting profiling floats that measures the temperature and salinity of the upper ocean
- This is the layer between the crust and the outer core of the Earth
- It is the deepest part of the Mediterranean Sea
- The process through which the physical state of the matter changes from gas phase into liquid phase.
- It is the interface or transition zone between two air masses of different density and temperature.

Compiled by Bhupendra B. Singh

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