Introduction
The Earth’s climate is already changing, and the changes are particularly marked in the Arctic. The Arctic is undergoing significant transformation as a result of climate change and increased human use including marine transportation, tourism and resource development. The highly uncertain sensitivity of the carbon cycle of the Arctic to the projected climate change is a major issue of global concern. Studies during the 1990s suggest that the Arctic has been a sink for atmospheric CO₂. The impacts of climate change in the Arctic will be felt throughout the world because changes in physical processes here influence the climate on a global scale. Processes of change in the Arctic can therefore provide a unique insight into the climate change that is already taking place and also act as a forewarning of the future regional and global impacts of these changes.

Challenges in continuous data collection
In the Arctic, continuous ocean observations are quite sparse, except for the surface where satellite data collection is possible. It is thus a challenging environment to monitor. The region is not well covered by satellites, and heavy cloud cover often limits their use. Buoy and float systems are a highly promising way to take measurements in the depths of the ocean. Here, the major challenge is to build up expertise and capacity to develop new observing systems suitable for the Arctic environmental conditions.

Abstract
This article describes the first Indian arctic multi-sensor mooring (IndARC) observatory in Kongsfjorden of Arctic waters. The Ministry of Earth Sciences evolved a unique moored observatory ‘IndARC’ with suite of sensors for physico-chemical and oceanographic in situ long-term data collection. The Arctic Ocean plays an important role in governing the earth’s climate and also faithfully records its past climatic history and represents a significant gap in ocean observations. This indigenously designed and installed observatory IndARC, for the first time, collected various parameters from July 2014 to July 2015. The uniqueness of this system, the challenges faced and results from data collected are presented in this article.

Keywords
IndARC, Kongsfjorden, Arctic, current, Dissolved Oxygen, temperature

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A major knowledge gap in this region is due to the lack of long-term, multidisciplinary inter-annual data spanning both the summer and ice-covered winter seasons. In particular, the North Atlantic Oscillation (NAO) and/or Arctic oscillation (AO) are the major components of inter-annual variability in the North Atlantic and Arctic area. Recent studies as reported by Song Feng and Qi Hu (2008) and B.N. Goswami et al.
have shown that there is a physical linking of the multi-decadal and inter-annual variabilities in the Indian summer monsoon rainfall with the Atlantic Multidecadal Oscillation as well as the NAO. This need to continuously monitor ocean parameters for extended periods was a driving force for the development of moorings in the arctic region. Hence it was decided to deploy a multi-sensor mooring within the Kongsfjorden, along with complementary ongoing field surveys. India has now established its first multi-sensor moored observatory in the Kongsfjorden. The IndARC deployment can be certainly considered as a significant achievement and a testimony to the capabilities of the Earth System Science Organization (ESSO) in designing, developing and installing underwater observatories. The data acquired will be of vital importance to the Indian climate researchers as well as to the international fraternity.

India’s first mooring in Arctic

A major milestone in India’s scientific endeavours in the Arctic region has been achieved on 23 July 2014 when a team of scientists from ESSO–National Institute of Ocean Technology (NIOT) and ESSO–National Centre for Antarctic and Ocean Research (NCAOR) successfully deployed the IndARC system, the country’s first multi-sensor moored observatory in the Kongsfjorden fjord of the Arctic, roughly half way between Norway and the North Pole (Figure 1). The fjord lays adjacent to both Arctic and Atlantic water masses. It is an open fjord, without sill, and therefore is largely influenced by the processes on the adjacent shelf. With five tidewater glaciers, Kongsfjorden acts as a natural laboratory to study the climatic impacts of global warming, the local Arctic warming as explained by Yongqi Gao et al. (2009), the consequent glacial melt and the impacts of freshwater discharge. This is also an established reference site for Arctic marine studies as it receives variable Arctic/Atlantic climatic signals between years with measurable effects on the physical and biological systems. With established research facilities available, there is a great potential for international, multi-disciplinary collaborations.

Design of IndARC

The moored observatory included measurements of current speed and direction, salinity, temperature and
dissolved oxygen. Data were measured for a year from July 2014. A key challenge was the presence of ice cover, sea ice, floating ice and drifting icebergs with >20 m draft, which challenged conventional methods of measuring near the surface. This was overcome using a weak link at 25 m separating a surface part of the mooring with a deeper part. If heavy loads are experienced on the mooring due to icebergs, the link will give away and the main mooring will remain safe. Floats fixed above the weak link section will surface the upper delinked portion and a beacon at the top float will emit signal to identify the floating location. This can be monitored from shore and the sensors and data can be retrieved.

Salinity, temperature and oxygen were measured using multiple SEABIRD-SBE37-SMP-ODO with internal batteries, memory and integral pump. Currents were measured using a single-point Nortek current meter and an Acoustic Doppler Current Profiler (ADCP). Both measured three-component (East, North, Up) velocity using Acoustic Doppler technology. All plastic and titanium parts eliminated corrosion. The ADCP is a hydro-acoustic current meter similar to sonar, measuring water current velocities over a 170-m depth range using the Doppler effect of sound waves scattered back from particles within the water column. The unit has no moving parts that can be blocked or damaged.

Technology is the fundamental requirement to make ocean observations, and a reliable platform is an absolute need to undertake long-term in situ observations. The mooring is designed with a buoyancy of 617 kg comprising of steel float of 317 kg and glass floats of 300 kg buoyancy, using OrcaFlex software. The Argos beacon attached to IndARC offers selectable preset frequency channels, along with a range of duty cycle options, resulting in a range of broadcast specifications. Powered with lithium batteries, this miniature recovery aid is designed for long-term ocean deployments. The Mini Beacon housing includes an integrated conductivity sensor that isolates the unit’s power while submerged and activates the device upon surfacing. The Acoustic Release unit has been selected to suit arctic conditions with the capability to withstand the load experienced on the mooring. Two IXSEA Acoustic releases were connected in tandem to serve as a redundant recovery node in mooring.

**Testing of IndARC subcomponents**

In order to ascertain the performance of the sensors and subcomponents, testing of all of the sensors and other accessories at low temperature was carried out using the environmental chamber facility at ESSO-NIOT. The environmental chamber can test components in the temperature range of −45°C to +180°C and a humidity range of 10%–98% relative humidity (RH). Online measurements of the components were executed simultaneously during low temperature condition. The O-rings were also subjected to very low temperature of −20°C and tested. The float with a mechanical fixture for holding the Satellite telemetry beacon was fabricated in-house and tested for stability and upright verticality of the Beacon at Acoustic Test Facility Tank at ESSO-NIOT. The instruments selected for IndARC have been programmed to work continuously for 1 year to collect real-time data. The power source requirements have been specially selected so that data collection is continuous without interruption. The sampling depth is duly selected and the mooring design has been accordingly configured for point and profile sampling.

**Deployment of IndARC**

The IndARC-I moored observatory was deployed and recovered from the Norwegian Polar Institute’s research vessel R.V. Lance at 78°57’N/12°01’E (Figures 2 and 3), about 1100 km away from the North Pole at a water depth
of 192 m. It has an array of 10 state-of-the-art oceanographic sensors strategically positioned at discrete depths in the water column (Figures 4). Seawater temperature and salinity data were collected from discrete depths at 22, 30, 55, 80, 105 and 140 m from July 2014 to July 2015. The moored observatory was successfully retrieved on 15 July 2015. The data from all the sensors were downloaded successfully. Subsequently, the IndARC II mooring with additional sensors to measure photosynthetically active radiation (PAR), nitrate and ambient noise was deployed on 19 July 2015.

Analysis of collected data

The temperature at all depths showed an annual cycle with maximum temperature of 7°C recorded during August and minimum of −1.5°C during February (Figure 5). This phenomenon was also reported by O.M. Johannessen et al. (2004). The salinity varied from 33.6 to 35.1 PSU as shown by Suzanne E. MacLachlan et al. (2007) at all depths, with drastic changes observed during August–September 2014 where the salinity dropped by almost 2.7 PSU (Figure 6). Another lowest salinity was observed during November at 55, 80, 105 and 140 m. The dissolved oxygen at 22 m depth recorded minimum value of 6.6 mL/L during September and peaked during the month of May with a reading of 9.5 mL/L (Figure 7). During May, the oxygen content in the water increased drastically from 7.7 to 9.5 mL/L. The primary findings reveal that the fjord waters are well mixed during December to April. A strong north-westward current during May, suddenly increased the oxygen content of the
region; thereafter, the waters became stratified. This effect is attributed to the freshwater released by melting ice, which confines phytoplankton to the upper sunlit layer, resulting in a biological bloom as reported by Kevin R Arrigo et al. (2012). The zonal, meridional and vertical current obtained from the ADCP showed strong westward currents during September and May as shown by the top panel in Figure 8. This is also reported by F.R. Cottier et al. (2005). The strong westward currents during May also coincided with strong northward and positive entrainment as represented by the middle and bottom panels. Similar strong currents were observed in the fjord during September and May by another mooring deployed by The Scottish Association of Marine Sciences (SAMS), UK. This strong current has also driven the drastic increase of oxygen at 22 m depth during May 2015. Current speed obtained from ADCP at 25 m depth was plotted against current speed obtained from the single point current meter as shown in Figure 9. Both the instruments showed a peak in current speed of 180 mm/s during May. During the last week of September 2014, passage of strong current was recorded by tilt and heading sensors of ADCP too. There was a sudden dip in the surface temperature of 2°C during this period as reported in F. R. Cottier et al. (2007). The preliminary observation shows that the fjord water column is stratified during summer and it is well mixed during winter. The observations also show strong diurnal and intraseasonal variabilities, and these features will be reported in the subsequent article with detailed analysis.

India has become a significant contributor to Arctic scientific advancements. The Arctic Ocean plays a major role in driving the world’s ocean circulation, which impacts the distribution of heat across the globe and the global climate. Success of this study encourages continuing this observation on a long-term basis which would enable India to develop a bio-physical regional model in the Kongsfjorden, Arctic region for better understanding of the system as seen in the website. The performance of sensors under immersed condition is affected by marine fouling organisms. Figure 10 shows one of the most abundant branched
bryozoans *Eucratea loricata* in Kongsfjorden on these underwater sensors. This growth is seen on the sensors which were mounted near to the seabed and abrasion of solid particles from Glaciers would have prevented their larval settlement.

**Closure**

New suite of sensors was added during deployment of IndARC II mooring in the fjord. Data retrieval mechanism for downloading the data at routine intervals during summer is being planned for the upcoming deployments.

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**Author biographies**

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