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- Top Five Pricey Red Seaweeds

Ocean Circulation and Debris

Simulation of Indian summer monsoon using the Japan Meteorological Agency's seasonal ensemble prediction system

A Brief History of Physical Oceanography

Baywatch India: Top Five Pricey Reds

Invited Article

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Abstract

With a coastline of ca 7000 km, Indian coastal region is one of the longest in the world and harbors a rich diversity of seaweeds. However, attempts to utilize this economically valuable marine resource have been scanty, or even nonexistent. The primary reason for this is scarcity of competent phycologists from India, and therefore most of the diversity still remain to be explored. Some progress have been made since 2012, having completed five systematic research expeditions targeting coasts of Goa, Karnataka, Kerala, Tamil Nadu, Andaman & Nicobar Islands and West Bengal to profile DNA-based phylogenetic diversity of seaweeds supported by DST-INSPIRE Faculty Award. In this article five of the most important naturally occurring red seaweeds of Indian coastal region (*Porphyra keralensis* Sp. Nov., *Kappaphycus alverazi*, *Eucheuma denticulatum*, *Grateloupia ettikkulensis* Sp. Nov., and *Hypnea valentiae*) are introduced that have great economic potentials spanning across food, pharmaceutical, scientific and hydrocolloid industries. As habitats of these seaweeds are in coastal villages of Kerala, Tamil Nadu, West Bengal and Andaman & Nicobar Islands where fishing is the main source of income for local communities, it is expected that utilizing these seaweed resources efficiently and sustainably will contribute substantially to the livelihood of these rustic communities.

Figure 1. *Caulerpa racemosa* from Palk Strait, Tamil Nadu, a highly invasive algae that spread from Mediterranean throughout the world byanthropogenic means, especially through ballast water.

Introduction

India is blessed with rich oceanic resources that encompass Indian Ocean, Arabian Sea and Bay of Bengal, two archipelago systems (Laccadives and Andaman & Nicobar Islands) and a long coastline of ca 7000 km which ranks 18th in the world. However, we still have not yet harnessed this valuable resource, perhaps except our fishery and hydrocarbon resources, even to a minimal extent. For example, no active programs for harnessing tidal energy or energy from oceanic waves exist in India yet. A number of economically important marine algae occurs in India -some of which are endemic, but we have not yet begun utilizing this important economic resource. There is a dearth of specialists (phycologists) "patrolling" rocky intertidal shorelines –quite slippery and dangerous- in India as well. Botany/Agriculture departments exist throughout Indian universities, but almost entire of them study terrestrial plants- which are far easier to work on.

Fig. 2. *Acetabularia acetabulum* (Mermaid's umbrella) from Andaman and Nicobar Islands. Some of the algae are beauty pageants of plant kingdom.

Marine algae or seaweeds, encompasses marine plants of the divisions Chlorophyta (green), Heterokontophyta (brown algae) and Rhodophyta (red algae) (Bast, 2014b). It was only recently that tools of the modern DNA-barcoding-based molecular systematics have been started applying to the seaweeds of Indian coastal region. In 2012, I received DST-INSPIRE Faculty award to work on phylogenetic diversity of Indian seaweeds. Since then, I sampled seaweeds in five research expeditions. First expedition targeted coastlines of Goa, Karnataka and North Kerala; Second expedition to Coromandel coast of Tamil Nadu-from Ennore to Rameswaram; third expedition to Andaman & Nicobar Islands; fourth expedition to West Bengal coast including Sundarbans; and fifth to Southwest coast, from Central Kerala to Cape Comorin. Two new endemic seaweeds have already been described, *Cladophora goensis* Bast (Bast, John, & Bhushan, 2015) and *Ulva paschima* Bast (Bast, John, & Bhushan, 2014), while a number of novel endemic species have been discovered, formal descriptions are awaited. Endophytic microalgae -that live inside macroalgal host -have been discovered for the first time in the Indian Ocean (Bast, Bhushan, & John, 2014a).

In this article, five of the most economically important red seaweeds that I have collected are introduced. Seaweeds included are: *Porphyra keralensis* Sp. Nov., *Kappaphycus alverazi*, *Eucheuma denticulatum*, *Grateloupia ettikkulensis*, and *Hypnea valentiae*.

Red 1. Red seaweed *Porphyra keralensis* Sp. Nov. (seen brown/dark). Green seaweed seen is *Ulva paschima* Bast. Cheriyazheekkal, Kollam, Kerala.

Red 1. *Porphyra keralensis* Sp. Nov.
The edible seaweed *Porphyra* (Order: Bangiales) is the most economically important red seaweed in the world owing to its use as *nori* (Laver)-the wrapping used in Japanese dish Sushi. While Japanese restaurants are relative rarity in India, there is an ample of scope for its export to the places where nori is consumed the most, including the West (USA, Canada, Europe), South America (Peru, Chile, and Brazil) and East Asia/Oceania (Japan, South Korea, China, The Philippines and Australia). Dry *Porphyra* typically fetch USD 16,000 per dry ton.

R-Phycoerythrin from *Porphyra* is extensively used as fluorophore in applications such as immunofluorescence and Fluorescence-Activated Cell Sorting. While there is an ample of market opportunity exist for this seaweed, no one from India seems to have ventured in its commercialization. *Porphyra* that exist naturally at Cheriyazheekkal, Kollam, Kerala had been confirmed to be a new species as per our DNA-based phylogenetic analyses and been arbitrarily named *Porphyra keralensis* Sp. Nov. (Fig. 1), while a formal description is awaited. Primary habitat of this algae is intertidal splash zones. Lifecycle is haplodiplontic; with macroscopic monostromatic gametophyte stage consisting of haploid foliose (blade-like) thalli. In many species, the gametophytic thalli are monoecious (i.e., having both male and female reproductive structures in one plant). Fertilization occurs when spermatia, the male gametes, lands on the blades and produce a tube that penetrate cell wall of the female gametes. After fertilization, repeated mitotic divisions of zygotes result in packets of diploid zygotospores (carpospores) within the blade phase. Female gametes in some species also undergo a process of parthenogenesis (Bast, 2014a).

Red 2. *Porphyra keralensis* Sp. Nov.
The red seaweed *Kappaphycus alvarezi* (Order: Gigartinales) occurs in natural population at Mandapam, Rameswaram, Tamil Nadu (Fig. 2). This seaweed is commercially cultivated for Kappa-carrageenan-a high value hydrocolloid used in cooking, baking, ice creams, jellies, toothpaste, shampoo, personal lubricants and so on. The lifecycle of this seaweed is triphasic, consists of dioecious gametophyte (N), carposporophyte (2N) and tetrasporophyte (2N) phases,

Red 2. Red seaweed *Kappaphycus alvarezi*, Mandapam, Tamil Nadu

similar to that of *Eucheuma* (Bast, 2014a). Gametophytic thalli is erect filamentous with cylindrical branches that are heavily cartilaginous. Spermatia and carpogonium are produced by male and female thallus, respectively. Gametes fertilize within terminal parts of the female thalli (trichogyne) to form diploid carposporophyte, which subsequently produces diploid carpospores. Repeated mitotic divisions in the carpospores results in the formation of tetrasporophyte and subsequent meiotic divisions within tetrasporangia results in the haploid tetraspores. Released tetraspores develop to respective gametophytes to complete the lifecycle (Bast, 2014a).

Red 3. *Eucheuma denticulatum* from Krusadai Islands, Palk Strait, Tamil Nadu.

Red 3. *Eucheuma denticulatum*

Eucheuma denticulatum (Order: Gigartinales) is a red seaweed cultivated for the production of carrageenan. This algae occurs in natural populations at Krusadai Islands, Palk Strait, Tamil Nadu (Fig. 3), however no attempts for the commercialization have ever been made. Morphology varies significantly with the habitat, but in general thalli consists of multiaxial filaments with rigid corticated cylindrical branches. The habitat is typically between low tide mark and upper sub tidal zone of reef system. The lifecycle is already described triphasic polysiphonia-scheme common for many red algae of Gigartinales including *Kappaphycus* (Bast, 2014a).

Red 4. *Grateloupia ettikkulensis* Sp. Nov.

Grateloupia (Order: Halymeniales) is a sub tidal agarophyte seaweed naturally occurring throughout Indian West Coast. *Grateloupia* population that exist naturally at Ettikkulam, Payyannur, Kerala had been confirmed to be a new species as per DNA barcode information and have been tentatively named *Grateloupia ettikkulensis* Sp. Nov. (Fig. 4), while a formal description is awaited. This seaweed is an excellent source of gelatinous polysaccharide hydrocolloid agar-agar, which has a number of uses including culinary, microbiology media, gel electrophoresis, dental impression material, salt-bridges in electrochemistry, and so on. However, no attempts have ever been made to either commercially cultivate this seaweed in India or to export the harvested natural population. Domestic demand of agar is at present met entirely with the imports due to the lack of commercial enterprises specialized on the agar extraction. *G. ettikkulensis* is believed to have a triphasic Polysiphonia-scheme lifecycle as described for *Gracilaria*.

Red 4. Red seaweed *Grateloupia ettikkulensis* Sp. Nov. (seen brown/dark). Green seaweed seen is Chaetomorpha. Ettikkulam, Kerala.

Red 5. *Hypnea valentiae*

Red 5. Red seaweed *Hypnea valentiae* from Bekal, Kerala.

The red seaweed *Hypnea valentiae* (Order: Gigartinales) occurs abundantly in Westand East Coasts of Indian Subcontinent, as well as in Andaman & Nicobar Islands (Fig. 5). Phylogeographical analyses suggest that the natural population of this seaweed on the west coast is evolutionarily more primitive than that of the east coast (Bast, Bhushan, & John, 2014b). This seaweed is an excellent source of agar as well as kappa-carrageenan. The lifecycle is believed to be triphasic, with dioecious gametophyte (N), carposporophyte (2N) and tetrasporophyte (2N) phases, similar to that of *Kappaphycus* and *Eucheuma*.

Conclusion

Albeit abundant marine botanical resources that the India possesses attempts to harvest those have been scanty. This article introduced five most important red seaweeds naturally occurring in the Indian coastal region. Apart from these five important red seaweeds, there are a number of other seaweeds occurring in India - some of which are not seen anywhere else in the world (endemic), with high economic potential. For example, a number of green seaweeds including Bryopsis have potent anti-cancer properties owing to the presence of cyclic depsipeptide Kahalalide-F. Seaweed-derived bioactive substances that have a multitude of biomedical applications include fucoidans, lectins, sulphated polysaccharides and aplysiatoxins. Seaweed derived natural products that are used as vermifuges and insecticides include kainoids, terpenes, diterpenes (Crenulacetal C used in pearl cultivation), sesquiterpenes and polyhalogenated monoterpenes.

All locations from where the seaweeds introduced in this article were collected are located in coastal villages where fishing is the main source of income for local communities. It is therefore expected that utilizing these seaweed resources efficiently and sustainably will go a long way to the livelihood of local communities.

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This study was supported in whole by DST-INSPIRE Faculty award received from department of Science and Technology, Government of India (IFA0LSPA-02). The cover image shows the author collecting Ulva paschima Bast, a new species of green algae from Bat Island, Goa

Oceanic Debris and Circulation

Review

What is ocean/marine debris?

According to National Oceanic and Atmospheric Administration (NOAA) marine debris is any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment. Common types of marine debris include plastic bags, bottles and cans, cigarette filters, bottle caps, and lids. When trash is not recycled or properly thrown away on land, it can become marine debris. Waste enters to ocean through littering by beachgoers, Run-off from rivers and storm drains, direct dumping into ocean and accidental loss from ships. For example, in 1992, a shipping crate containing 28,000 plastic bath toys was lost at sea when it fell overboard on its way from Hong Kong to the United States. Since that day in 1992 when they were unceremoniously abandoned at sea, the yellow ducks have bobbed halfway around the world. Some have washed up on the shores of Hawaii, Alaska, South America, Australia and the Northwest Pacific and others have been found frozen in Arctic ice. Still others have somehow made their way as far as Scotland and Newfoundland, in the Atlantic. Today those flotillas of plastic ducks are being hailed for revolutionizing our understanding of ocean currents [Read More]

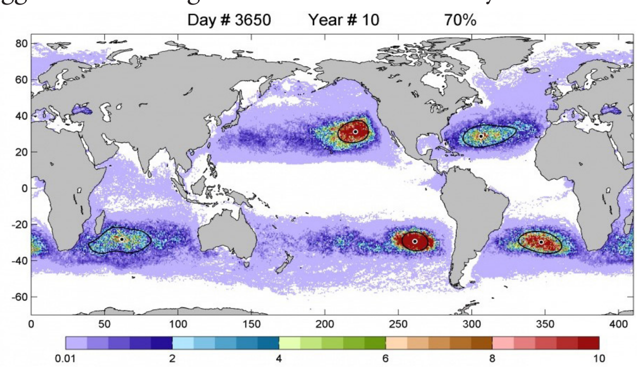
What does the ocean currents do?

Ocean currents may also carry trash, pollutants, or other drifting debris up to thousands of miles. Trash in the seas is carried by currents to a number of areas. The collections of trash in these locations have recently been referred to as marine trash islands. Major ocean surface currents corral trash into "garbage patches". The garbage patch is an area of marine debris concentration in the Pacific Ocean, Atlantic and Indian Ocean. The garbage patches are created by the swirling ocean currents caused by the subtropical zones to the north and south oceans. These subtropical high pressure systems drive ocean currents in particular patterns that create a massive swirling effects, called a gyre. These gyres can be big or small and exist all over the world; however, the particular convergence of the gyres in the Pacific Ocean has created the proper atmosphere for the continuation of the Great Pacific Garbage Patch (see more in http://www.geolounge.com/ocean-garbage-patches). The North Pacific Garbage Patch, a loose collection of drifting debris that accumulates in the northern Pacific, first drew notice when it was discovered in 1997 by adventurer Charles Moore. The five garbage patches occur in each of the north and south Atlantic, the north and south Pacific, and the middle of the Indian Ocean (Figure 1).

Why should we worry about ocean debris?
Birds, fish, and mammals often mistake plastics and other debris for food. Many endangered albatross birds and chicks have been found dead with stomachs full of plastic, including bottle caps and cigarette lighters. With debris filling their stomachs, animals have a false feeling of being full, and may die of starvation (Figure 2). Beach visitors can be injured by harmful debris on beaches, such as broken glass and sharp metals. Toxic pollutants can also be transferred up the food-chain and consumed by humans. Marine debris causes damage to shipping vessels through collision, entanglement in propeller blades, and clogging of water intakes for engine cooling systems [Read More].

Estimates
Jambeck et al. (2015) estimated that 2.5 billion MT (metric tons) of municipal solid waste was generated in 2010 by 6.4 billion people living in 192 coastal countries (93% of the global population). This estimate is broadly consistent with an estimated 1.3 billion MT of waste generated by 3 billion people in urban centers globally (Hoornweg and Bhada-Tata 2012). Approximately 11% (275 million MT) of the waste generated by the total population of these 192 countries is plastic. We expect plastic waste to roughly track plastic resin production (270 million MT in 2010) (Plastics: the facts 2013), with differences resulting from the time lag in disposal of durable goods (lifetime of years to decades), for example. Scaling by the population living within 50 km of the coast those likely to generate most of the waste becoming marine debris, we estimate that 99.5 million MT of plastic waste was generated in coastal regions in 2010. Of this, 31.9 million MT were classified as mismanaged and an estimated 4.8 to 12.7 million MT entered the ocean in 2010, equivalent to 1.7 to 4.6% of the total plastic waste generated in those countries.

How about future?
Waste will continue to grow with increased population and increased per capita consumption associated with economic growth, especially in urban areas and developing African countries Jambeck et al. (2015). Historically, waste management by burying or burning waste was sufficient for inert or biodegradable waste, but the rapid growth of synthetic plastics in the waste stream requires a paradigm shift. They suggested that long-term solutions will likely include waste



Computer model simulation that predicts where floating debris in the five subtropical gyres of the ocean due to converging surface currents. Colors indicate relative concentration of debris after 10 years of model integration. *Source*: Maximenko et al. (2012).

reduction and downstream waste management strategies such as expanded recovery systems and extended producer responsibility.


A turtle caught in debris. *Source*: http://greatbigmind.org/great-pacific-garbage-patch/

If you throw plastic waste at some location of ocean and if you want to know how it travels and where it goes and deposited in the ocean see at http://www.adrift.org.au/map?lat=-11.7&lng=108.5&center=0&startmon=Jan

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Review compiled by Jasti Chowdary and Anant Parekh, IITM

Simulation of Indian summer monsoon using the Japan Meteorological Agency's seasonal ensemble prediction system

Student Article

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The world meteorological organization (WMO) designated modeling centers such as ECMWF, NCEP, UK Met Office, Japan Met. Agency (JMA) etc. as Global Producing Centers (GPC) around the globe for generating real time seasonal forecasts based on coupled models. The JMA Ensemble Prediction System (EPS) is one of the skillful atmosphere-ocean coupled model for the monsoon simulation. Detailed evaluation of the JMA model for prediction of Indian Summer monsoon rainfall is carried out in this study. The model has

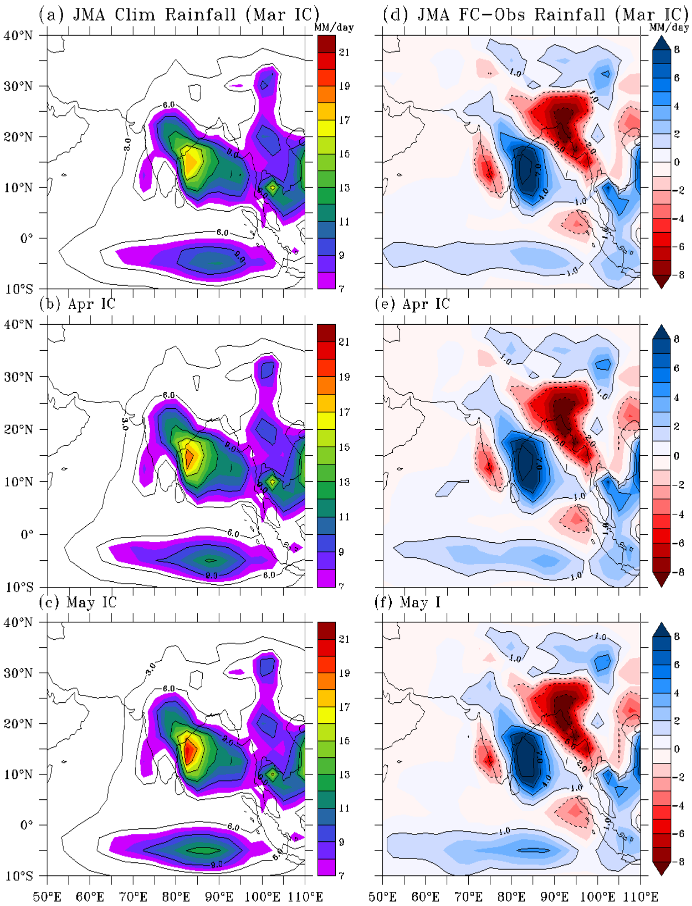

Fig.1. The spatial climatological rainfall (mm/day) obtained from JMA for a period of 32 years from 1979 to 2010 valid for JJAS. Shaded area denotes rainfall of more than 7 mm/day. (a) March ensemble, (b) April ensemble, and (c) May ensemble. The corresponding difference between the forecast and observed climatology is shown in (d–f).

also got a long hindcasts data of 32 years (1971-2010), which can be used for the study of inter-annual variability of Indian monsoon. In view of that we considered the JMA EPS model in our present study to see the performance of JMA EPS model for the Indian monsoon simulation.

The performance of dynamical seasonal EPS of JMA is evaluated for the prediction of summer monsoon rainfall over the Indian region during June–September (JJAS) by using hindcast period of 32 years (1979–2010) based on five ensemble members each of March, April and May initial states. The rainfall climatology from JMA hindcast during JJAS, based on 32 years (1979–2010) with initial conditions of March, April and May, is shown in figure 1(a–c), respectively. The zone of less rainfall over the northern region of the country and the southern state of India (Tamil Nadu) seen in the verification analysis in figure 1 is also captured well in the JMA hindcast (figure 1a–c). The JMA hindcast climatology during JJAS also simulates the rainfall maxima over the west-coast of India and the head Bay of Bengal reasonably well, although, the latter is slightly shifted southwestward with March, April and May initial conditions (Figs. 1a-c). The model bias is calculated by taking the difference between JMA model hindcast climatology of JJAS rainfall with March, April and May ensembles plotted in figure 1(a–c). The JMA model bias is shown in figure 1(d–f) with March, April and May ensemble, respectively. The underestimation of west-coast maximum in the JMA model can also be seen from the difference plot with negative bias over the west-coast region (figure 1d–f).

Since El Nino is one of the major forcing of driving the interannual variability of All India Summer Monsoon Rainfall (AISMR), the forecast skill of El Nino in the JMA model is also investigated. The forecast skill of El Nino during JJAS in the JMA model with March, April and May initial conditions are found to be very well with correlation coefficient significant above 99.9% level (Fig. not shown). In order to investigate the forecast skill of the interannual variability of AISMR during JJAS, the rainfall departure over the Indian landmass during JJAS obtained from IMD is plotted against the hindcast rainfall departure over the Indian land grid points during JJAS with March, April and May initial conditions (figure 2). As seen from figure 2, the contrasting monsoon during 1987 and 1988 are very well captured in the JMA model with all the three lead times based on March, April and May ensembles. In addition, the other deficient years like 1979, 1986, 2002 and 2009 were also reasonably well captured in the JMA model. However, the strongest El Nino year of 1997 associated with slight positive rainfall over India was not captured in the JMA model (figure 2). Thus, associated with better forecast skills of El Nino in the JMA model, the interannual variability of AISMR during JJAS during the 32-year period has also been very well simulated with a significant (99% level) correlation in April ensemble followed by that of March and May ensembles.

Thus, the present analysis indicates that the JMA seasonal forecast model can prove to be a useful tool for the dynamical seasonal forecast of AISMR.

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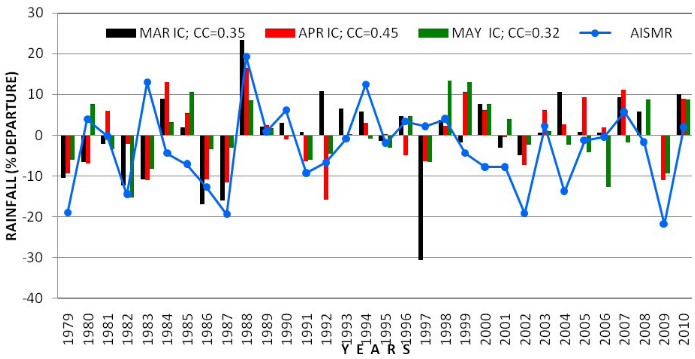

Fig. 2. Year-to-year variations of observed and JMA seasonal EPS forecast rainfall departure with March–May initial conditions for the All India Summer Monsoon Rainfall regions during JJAS along with the correlation coefficient.

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A Brief History of Physical Oceanography

History Article

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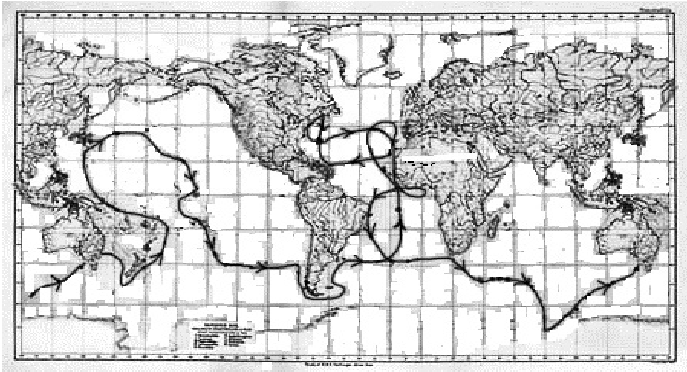
1. Introduction

During early times man had considered ocean as God/ Goddess because of the fear for the furies of nature. At the same time, there were efforts to understand the oceans. As a result of these efforts over centuries, the science of oceans or oceanography emerged, which later on, branched into different disciplines. The present article is not intended to give a comprehensive account all developments in physical oceanography, but aims to touch upon major events during the different phases in its progress. Development of physical oceanography in India is also included.

2. Ancient History

During the Vedic period itself some knowledge about oceans existed. Harappans of this period (3000 B C) had knowledge about tides and there is evidence to show that they had built a tidal dockyard at Lothal (20^{o}31'N, 70^{o}14'E). Also, trade with west Asian countries existed then. During the Buddhist–Jain period (600-325 BC) some information about dimensions and depth of oceans were available. Since the trade by sea had flourished, it can be inferred that necessary ocean knowledge had prevailed. A book by an Arabian author of 10th century have mentioned about the seasonally reversing currents in Arabian Sea.

In the western world also ancient ocean knowledge existed. More than twenty thousand years ago, Polynesians, the great seafarers, started travelling long distances in the sea to east and they occupied many islands in east and south Pacific. It is remarkable that such journeys were accomplished without modern navigational equipment and was based only on celestial navigation. During the Greek civilisation period, Aristotle (384-332 BC) was aware that the evaporation from ocean and precipitation cycle was driven by sun's energy. Herodotus prepared in around 450 BC a map with Mediterranean Sea at the centre. Greeks had travelled out from Mediterranean to Atlantic Ocean. They considered this ocean to be as a vast river and called it Okeanos (Oceanus). Ptolemy (150 AD) prepared a world map which had the markings of latitude and longitude and this map had remained acceptable for about 1000 years. The fact that Greeks and Romans had maintained navies and fought sea battles, indicate that they had the knowledge about oceans that was necessary for such war fare.



Route of Challenger Expedition (*prepared by author combining maps for three oceans from the website by D C Bossard*)

3. Great Voyages

Subsequent to the ancient period, further addition of knowledge of oceans came after 14th century, when long voyages took place. Some of the important voyages are those by Christopher Columbus who crossed Atlantic to discover America in 1492 AD, by Vasco De Gama who circumnavigated the Cape of Good Hope in Africa and reached India in 1498 AD and those by Ferdinand Magellan during 1519-22 AD. During one of the journeys Magellan travelled from Atlantic Ocean through a strait in South America to reach the other side of land. When the ship reached the calm sea after navigating through the strait under very difficult conditions, he exclaimed "mar pacifico", meaning the peaceful water, in Portugese, and thus this ocean came to be known as Pacific Ocean. The strait in South America is now known as Magellan Strait. During 1405-43 AD, seven expeditions from China came to Indian Ocean and in 1469 AD Russian voyager Afanasi Nikitin came to India in an Indian ship. These voyages in different ocean had resulted in getting new information about the oceans.

4. Beginning of scientific study of Oceans

James Cook undertook three voyages during 1768-80 AD and established the seas around Antarctica. Systematic observations on winds, currents and temperature were made during these voyages. Benjamin Franklin, who was a multifaceted personality in North America, which consisted of colonies at that time, was deeply interested in science. While working as the Assistant Post Master General, he wanted to speed up the delivery of postal articles across Atlantic. For this purpose, he acquired knowledge about ocean currents and in 1770 charted the Gulf Stream for the first time. Matthew Fontaine Maury (1806-73) had made some remarkable contributions to this science. When he was appointed as the officer in charge of US Navy Depot of Charts and Instruments, he came across the valuable information that was available in the log books of various ships. Realizing that these were laying unutilized, he analysed information on wind, currents etc and prepared charts that were very useful for navigation and he was hence called "Pathfinder of Sea". Subsequently in 1855 he published a book entitled "Physical Geography of the Sea", which is the first book on physical oceanography.

5. Modern Physical Oceanography

5.1 Organised expeditions

Although a lot of information was obtained during the voyages, the main emphasis of most of these journeys was on discovering new trade routes. Well organized scientific explorations of the oceans started much later and the expedition on board naval ship Beagle (1831-33) was one of the early expeditions. Charles Darwin, who later postulated the Theory of Evolution of Species, had participated in this expedition. The land mark development in ocean science was the Challenger expedition (1872-76). For this expedition, the British naval ship HMS Challenger was modified as a research ship. Under the leadership of Charles Wyville Thomson, this expedition covered different parts of world oceans (see Fig.1) and collected data from about 362 stations on physical, chemical, biological and geological aspects. It took about 20 years to complete the analysis of samples and data and the results were published in 50 volumes. The importance of Challenger expedition can never be overemphasized and this can be considered as the real beginning of oceanography.

5.2 Major contributions by Scandinavian scientists

Many of the early scientific contributions to physical oceanography came from scientists of Scandinavian countries. Fridtjof Nansen, a Norwegian scientist, ventured on a journey to reach North Pole in 1893, on board a ship called Fram, which he had specially designed for this purpose. The ship was allowed to be trapped in sea ice to be carried by favourable ocean currents to the destination. He had to leave the ship and travel in sledges and he could reach close to the Pole. During the period of three years, that the ship was in the sea, valuable information on hydrography, meteorology and currents were obtained. Moreover, some of the observations had led to important theoretical studies. It is interesting to note that Nansen was awarded Nobel Prize for Peace in 1922. One of the observations during the expedition was that under the influence of wind, Fram that was frozen in the sea ice, did not move in the direction to which wind blew but moved at an angle to the right of this. This led to the theory of Ekman Current, called so after Vagen Walfrid Ekman, the famous Swedish oceanographer, who postulated the theory for the current due to steady wind. According to this theory, which was published in the Fram Report in1905, at the surface the current flows at 45 degrees, cum sole, in northern hemisphere and as depth increases the current speed decreases and the angle increases. The resulting vertical distribution of current is known as 'Ekman Spiral'. Ekman current is of great importance in oceanography. Another observation during Fram expedition was what had been referred to as "dead water phenomenon", which the seamen sometimes encounter. Nansen noticed that his ship would not move even when engine was working at full power, during the season of melting of ice, when thin layer of fresh water formed above sea water. By theoretical and laboratory studies on this problem, Ekman showed that when the propeller was at the sharp density gradient layer, the energy of the propeller is utilized for the generating undulations of the interface, leaving little energy to move the ship. This finding, in due course, led to the study of internal waves. It was Ekman who made an ingenious instrument for measuring ocean current and this is known as Ekman current meter (Fig.2).

Ekman making current measurements using the current meter designed him. *Source*: Bergen University.

Another important step was the development of a method for computing the ocean current from vertical density distribution. The first attempt for this was by H.Mohn in 1885. Later, in 1903, the dynamic method of current computation .was developed by J W Sandstrom and B Helland-Hansen from Bergen University. This method for getting the geostrophic current at different levels in ocean, from routine hydrographic cast data was based on Bjerkne's circulation theorem. Because of its wide application, this had revolutionized the knowledge of ocean circulation. In 1916, B Helland-Hansen devised the Temperature-Salinity diagram, which even now continues to be a powerful tool in the study of water masses.

5.3. Further expeditions and studies

The first expedition that gave prime emphasis to physical oceanography was the Meteor Expedition in Atlantic Ocean during 1925-27. One of the objectives of this expedition was to confirm the hypothesis on thermohaline circulation, put forth by George Wust and Alfred Merz. Data were collected from 312 stations and current measurements were also made from some deep stations. In subsequent periods many expeditions like John Murrray Expedition during 1933-34 on board research vessel Mabahiss to Indian Ocean, Galathea Expedition (1950-52) were undertaken. Side by side with field observations, theoretical studies also progressed. Harald Sverdrup and Walter Munk of Scripps Institute of Oceanogaphy and Henry Stommel form Woods Hole Oceanographic Institution published pioneering works during 1947- 51 to provide theoretical explanations for the observed variability of ocean currents. The theory proposed by Stommel for westward intensification of currents, examples of which are the Gulf Stream and Kuroshio Current, by invoking the β-effect (latitudinal variation of Coriolis force) is a land mark development. Sverdrup theory tries to relate the mass transport to the wind stress curl, to explain the situation on the eastern side of the basins. This theory was subsequently refined by Munk.

The International Geophysical Year (IGY) in 1957-58 was the beginning of the large scale cooperation in ocean research. Some of the problems addressed during IGY were the deep ocean circulation, the strong ocean currents and the region of Gulf Stream where it meets the cold northern water. Subsequent major cooperative efforts were International Indian Ocean Expedition (this is dealt in another section), Global Atmospheric Research Programme (GARP) and World Climate Research Programme (WCRP). GARP sub progrmmes were GARP Tropical Atlantic Experiment (1974) and Global Weather Experiment (GWE) in 1978-79 and the sub progrmmes under WCRP were World Ocean Circulation Experiment (1990-98) and Tropical Ocean Global Atmosphere (1985-94). These have resulted in deep understanding of large scale ocean- atmosphere interactions, including El-Nino and other phenomena. The important spin off of these is the quick data retrieval methods for scientific community. There are also regional level cooperative efforts.

6. Ocean Wave Studies

6.1 Wave Theories:

The first wave theory developed by G.B Airy in 1841, under the small amplitude assumption, gave linear solution for sinusoidal waves. This has the advantage that it is applicable for waves in all regions i.e., deepwater to shallow water regions. When the small amplitude assumption does not hold, then the waves, referred to as finite amplitude waves, will have peaked crests and broad troughs. Because of the difficulty in getting analytical solution for the nonlinear equation, more than one theory is found to be necessary to cover all depth regions. G.G Stokes in 1847 presented a theory applicable for deep water regions and F.Gersterner in 1802 gave trochoidal wave theory for the same region. It may, however, be noted that trochoidal wave is not irrotaional. The Stokes theory is used for getting higher order solutions. For shallow water regions, cnoidal wave theory, developed in 1895 by Korteweg and DeVries, is applicable. The Jacobian elliptic function (cn) is used in the theory and hence this name cnoidal is used. In very shallow waters, cnoidal wave becomes solitary wave, in which there will not be trough and solitary crest moves forward. Solitary wave was first observed by John Scott Russel in 1834 in a canal. He saw that the water that accumulated in front of a moving boat, subsequently left the boat and moved forward in the canal as a single crest. In the following period, the efforts to find one finite amplitude theory that would be applicable for the entire depth region had continued. Notable among this is the method of getting Fourier solution numerically, using computer programme. J D Fenton has done pioneering work in this direction in early 1980s.

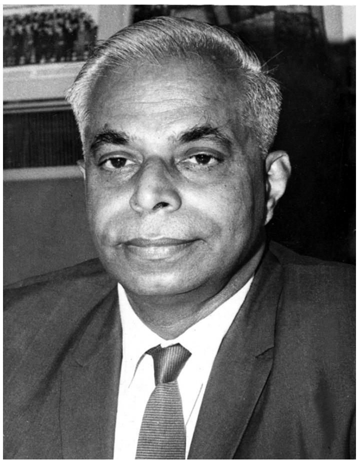
6.2 Wave generation and wave forecasting

The first effort to formulate a theoretical frame work for the generation of wind waves was that by H.Jeffreys in 1925. According to this theory, which is also known as sheltering theory, it is the difference in the wind force between the windward and leeward sides of a wave crest that enables energy transfer from wind to waves. Theoretical value of the sheltering coefficient did not match experimental results. During 1957-58, O.M Phillips postulated resonance theory. Normal pressure due to wind is not uniformly distributed everywhere on sea surface because of the presence of small eddies in turbulent wind. If the distance of separation of eddies equals the wave length, then waves will grow. The hypothesis in the shear flow model, put forth by J W Miles in 1957, is that the transfer of energy to waves is proportional to the curvature of the wind profile at the height from sea surface that is equal to wave length. Subsequent studies indicate that in the beginning of wave generation, Phillips theory is applicable and in the growing stage, Miles theory becomes important. Jeffrey's theory and the non- linear interaction between wave components in the generating area also have a role in wave growth.

Wave forecasting efforts got impetus because of the amphibious operations during World War II. For successful operations it was necessary to have prior knowledge of the possible wave conditions. In this connection, H. Sverdrup and W. Munk in a report to US Navy in 1947 presented a method for wave forecasting. Based on empirical data, the charts for getting significant wave height and significant wave period from wind fetch, duration and speed have been presented. With additional work on this by Bretschneider, this is known as SMB method. Another wave forecasting method known as PNJ method, presented by W J Pierson, G Nuemann and R W James in 1955 is based on wave spectrum. They had presented charts of co-cumulative spectra, from which the wave characteristics can be estimated using the information about wind. This was followed by Pierson-Markov (PM) spectrum in 1964 and an improved one, the JONSWOP (Joint North Sea Wave Observation Program) spectrum, by Hasselman in 1973. Wave forecast by modelling has become very common now. There are many agencies that provide wave forecasts, on a routine basis using this method. Wave models basically solve numerically, the energy balance equation. The initial model called WAVEWATCH has given way for advanced models called as third generation wave models. WAM (WAve Model), Simulating WAve Nearshore (SWAN) are amongst such models.

7. Physical Oceanography in India

First important development for Indian oceanography was the establishment of marine Survey Department in Calcutta, 1874. Survey vessels Investigator I and Investigator II were commissioned in 1881 and 1908, respectively for the department. Due emphasis for physical oceanographic observations was given after Col. S.B.S Sewell took over as the Head of the Department in 1910. After independence, with the formation of Central Marine Fisheries Research Institute, some physical oceanographic studies were also initiated. Naval Physical Laboratory was established in Kochi naval base in 1952 and subsequently .the Oceanography Research Wing of Central Board of Geophysics started functioning in the same premises. These were later merged to form Naval Physical and Oceanographic Laboratory (NPOL). The realistion that the Indian Ocean was the least explored one had led to the International Indian Ocean Expedition (IIOE) during 1961-65 by UNESCO, as a multidisciplinary, multinational programme. The Director of the Indian prograamme in this was Dr.N.K.Panikkar, who was an expert in biological oceanography and fisheries. Active participation of India in (IIOE) culminated in the establishment of National Institute of Oceanography under the Council of Scientific and Industrial Research, on January 1966, with Dr.N.K.Panikkar as the founder director. The institute initially comprised of divisions of physical, chemical, biological and geological oceanography and a data division. The first ocean research vessel of India was commissioned for the institute in 1976. Taking into consideration the contributions of Dr.Panikkar for oceanographic research and the development of oceanography,



Dr. N K Panikkar. *Source*: NIO, Goa

the Intergovernmental Oceanographic Commission under UNESCO conducts regularly Dr N K Panikkar memorial lecture in Paris.

In 1973, ISMEX, an experiment to study monsoon, as collaborative effort of India and Russia was conducted and this was followed by MONEX-77 and the multinational MONEX-79. An expedition on board INS Darshak (OCENOVEX) was organized during November 1973-Jnuary 1974, to northeast Arabian Sea, which was not adequately covered earlier, Some of the other studies were Bay of Bengal Monsoon Experiment (BOBMEX) in 1999 and Arabian Sea Monsoon Experiment (ARMEX) in 2002 and 2003. The first Indian expedition to Antarctica took place in 1981 and India established a permanent station there called Dakshin Gangotri in 1983. Because of the wear and tear of first station, another one, Maitri was set up in 1988, followed by the latest one Bharati in March 2012. Another important step was the establishment of Department of Ocean Development by Govt. of India in 1981. Dr.S.Z.Qasim, because of his long years of standing in oceanography, became the first Secretary of the Department. This gave a boost to the development of this science. Many new institutes were established, new research ships have been acquired and support for research has increased. The institutes started under the department are Indian National Centre for Ocean Information Services, National Institute of Ocean Technology, National Centre for Antarctic and Ocean Research and Centre for Marine Living Resources and Ecology. The department has been upgraded as Ministry of Earth Sciences in 2005, by including India Meteorological Department. It must be mentioned that physical oceanography also got very good support through these developments. At present there are several other institutes and university departments that carry out research in this subject and some of these institutions have research vessels also.

Although the currents of the east and west coasts of India and its seasonal reversal were known since long time, in around late 1980s and early1990s the terms West India Coastal Current (WICC) and East India Coastal Current (EICC) were used for these currents, which are similar to names of some well known coastal currents. These names are now widely used. Subsequently, the study of coastally trapped Kelvin waves and the formation of Lakshadweep high and low in sea surface topography were pursued. It must also be mentioned here that in the after math of the killer tsunami of December 2004, India has taken several steps like deploying tsunami warning buoys, increasing the number coastal sea level measurement locations, and capacity building to gather near real time information from different sources and to issue timely tsunami warnings.

A post graduate course in physical oceanography was first started in 1952 by Andhra University which was followed by Kerala University in 1965. During 1952-55, the famous Oceanographer, Professor E C LaFond worked in Andhra University as Visiting Professor. His leadership in organizing the course, his research efforts during the time, and the guidance that he gave to the upcoming physical oceanographers had immensely helped in the development of this science in the country. As of today, there are several universities, institutes of national importance that offer educational programmes in physical oceanography.

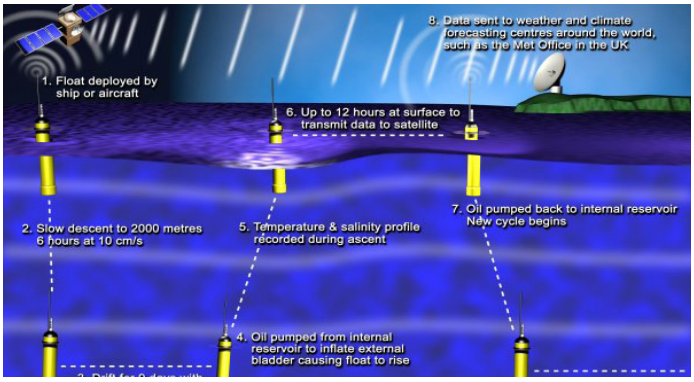
8. Latest trends in Physical Oceanography

8.1 Instruments

Like in all branches of science, the development of electronics had brought in sea changes in oceanographic instruments. In the place of hydrographic casts using Nansen bottles and reversing thermometers, the CTD, which gives continuous profiles of temperature and salinity with depth, is widely used these days. The mechanical bathythermographs, which were in use since it was invented by A.Spilhaus in 1938, gave way to Expendable Bathythermographs (XBT). XBT became very popular because of the convenience in its operation and in data processing. Similarly, the Ekman current meters that were earlier essential for physical oceanographic studies, have also become obsolete. In its place direct reading current meters came and this became popular because of the ease to use. Self recording current meters were developed for continuous measurements by mooring them at required locations. Some of the recording current meters additionally record temperature and salinity also. One of the important developments is the use of the concept of Doppler effect for current measurements. Acoustic Doppler Current Profiler (ADCP) measures speed of water particles from the difference in frequency of sound pulse emitted by the instrument and that received back, after reflection from water particles.

8.2 Remote sensing in physical oceanography

Remote sensing technique has revolutionized many branches of science that require repeated data collection, covering vast areas. Oceanography has greatly benefitted by this method. The first satellite for ocean studies SEASAT 1 was launched by NASA in July 1978. It worked only for about couple of months. It had synthetic aperture radar (SAR) also in the payload and demonstrated the ability for observing several oceanic phenomena, including surface waves and sea surface height anomaly. The US and France joint ocean satellite TOPEX/Poseidon that worked for about 24 years from 1992, was followed by successor Jason-1.The altimeter on board measures sea surface height with sufficient accuracy to deduce ocean circulation. The volume of data generated by remote sensing is enormous and this has led to a quantum



ARGO Float. *Source*: JCCOMMOPS

jump oceanographic studies and results. Now there are many satellites by different countries for ocean observations. India launched OCEANSAT-1 in 1998 which had an ocean colour monitor also. In 2009, OCEANSAT-2 was put in orbit. With French collaboration, satellite Megha-Tropiques that is useful for ocean studies also was launched in 2011. An important satellite under the same collaboration for ocean study is the Satellite with ARgos and ALtiga (SARAL) that was launched in 2013.

Since the remote sensing data is largely limited sea surface, another important instrument called ARGO float is used very widely in world oceans. This also uses satellites in an indirect way. Once deployed in the ocean, these feely floating buoys make vertical excursions up to 2000m (Fig.3). It records temperature and salinity at different levels and whenever it reaches surface, the data are transmitted to shore stations through satellites. In this way wealth of data form all oceans are being obtained on continuous basis.

8.3 Numerical Modelling

Theoretical studies of ocean circulation and other phenomena are based on idealized situations because the complex and non linear nature of governing equations are not amenable to analytical solutions, unless these are simplified. The way out is to adopt numerical solution for the governing non linear differential equations. The advent of computers made this possible. It can be seen that numerical modeling capabilities grew with the speed of computers. The early general circulation model was by Bryan K and Cox M.D in 1968. Considering the limited computational capabilities available at that time, the resolution of the model had to be hundreds of kilometres, so as to ensure the computational stability. As the observations brought out the importance of mesoscale eddies, it became imperative to use finer resolution. This became possible with the increase of computing power. Resolution of few tens of metres is now possible even for basin scale models. Based on new observational and theoretical knowledge improved prameterisaion, more suitable methods of numerical solution and other improvements are being incorporated in models. In early 1980s, isopicnal vertical coordinate was used in models. In order to resolve the near bottom features, terrain following vertical coordinate (sigma coordinate) is found to be more suitable. Princeton Ocean Model (POM) that came in 1980s and the subsequent Regional Ocean Model System (ROMS) are terrain following type. Since these and some others are community models that are freely available for use, these are very widely used. Another attraction for such models is internet sites that provide help about respective models. As the observational capabilities increased it became necessary to use in models the newly arriving data during the model run, to get more realistic results. By the beginning of 21st century, different techniques for the assimilation of such data are being incorporated in the models. Ocean atmosphere coupled models are used widely for weather predictions. Such models are the essential tools for the global warming and climate change research. The effects of different scenarios of the processes that cause global warming are quantified by coupled models to generate the essential inputs for actions to reduce global warming.

9. Conclusions

From the foregoing account it can be seen that physical oceanography form its rudimentary level of knowledge in ancient times has grown, through different phases, as an important and independent discipline. It is the urge to know the unknown that led the earlier workers to go in ships with limited facilities and to make observations with rather crude instruments, that too braving the fury of the rough seas. Theoretical pursuits of many stalwarts have unraveled the mysteries of various physical phenomena of the oceans. As the data collection and analysis have become easier, the demand is for better sophistication in theory. Although India is late entrant into this science, it has caught up fast and has established its position in the world arena.

Further Reading

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Parts of this article was published in the book "Alayazhiyile Chalanangal", authored by Prof. K K Varma. The book is available for purchase at the National Book Stall or the online store: http://www.indulekha.com/alayazhiyile-chalanangal-popular-science-dr-k-k-varma

Email: varmacochin@yahoo.com

News and Views

Recent Updates

Icebergs have 'sound signature'

An innovative way to determine melting of ice and its effect on global sea rise is by identifying the icebergs' own acoustic signature as they calve away from the ice, researchers in Poland, the UK and US have found. Currently, satellites

Icebergs break off from the glacier Perito Moreno, P. C. *Source*: http://formyhour.com/amazing-icebergs monitor the glaciers. But while they can spot huge ice break-ups, smaller blocks of ice are easily detectable by their 'sound signature' [Read More].

Fragment of continental crust found under south east Iceland
Scientific analysis shows that South-east Iceland is underlain by continental crust, ruling out the long-accepted theory that Iceland consists of very thick oceanic crust. The implications of this discovery can be extended to how mantle plumes interact with plate tectonics [Read More].

Bigger thunderstorms are bringing more rain to the tropics
Scientists from Australian Research Council Centre of Excellence for Climate System Science (ARCCSS) and NASA showed that there is a strong correlation between large, well-organized thunderstorms and increasing rainfall. These storms make up about 5 percent of the weather systems in the tropics but are responsible for about 50 percent of tropical rainfall. This idea was supported by recent satellite observations which showed strong precipitation increases in the wettest tropical regions [Read More].

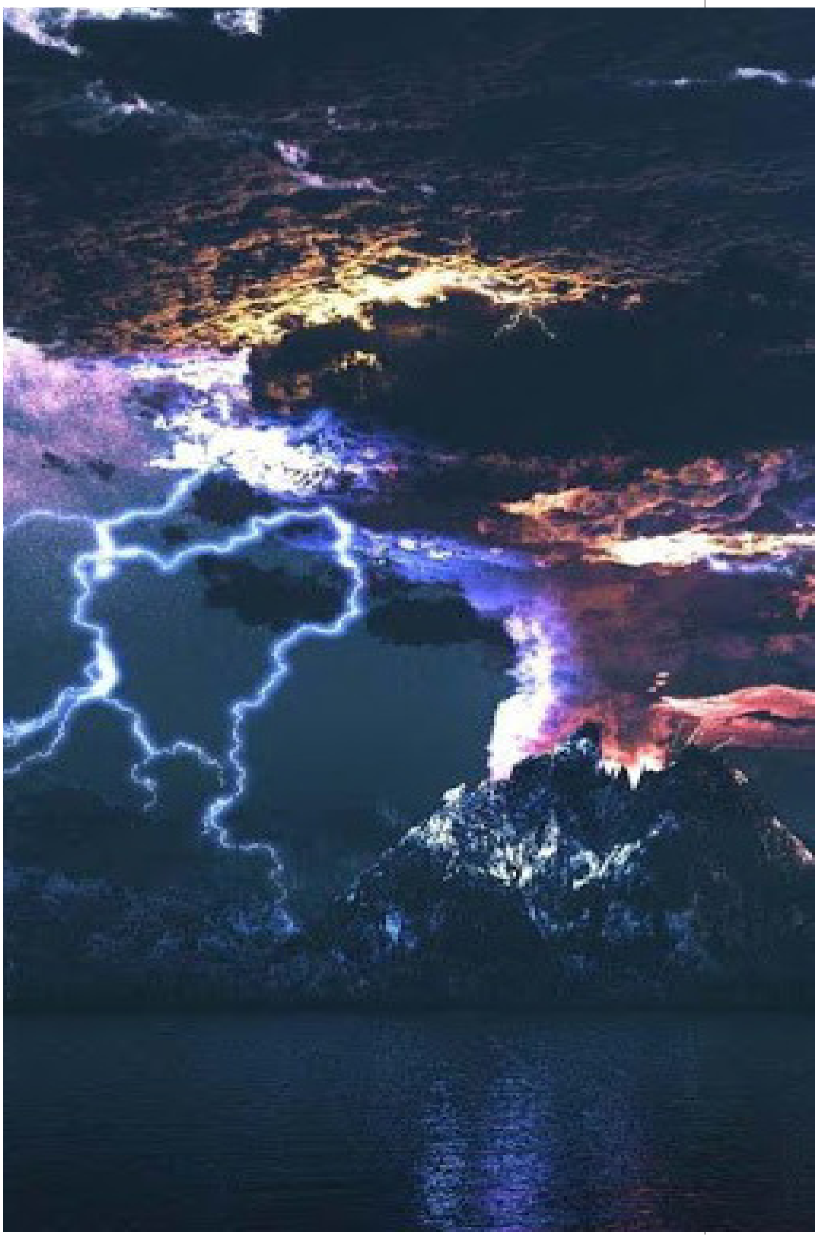
Strong currents promote release of Arctic greenhouse gas
Recent studies reveal that ocean currents have a major control on how much methane escapes to the atmosphere. Fast ocean currents promote escape of methane into the atmosphere as they inhibit the growth of methane consuming marine bacteria. However, coastal waters have slow flowing waters; hence the population of such bacteria is more there [Read More].

Sea rise forces thousands out of Sunderbans
Rising sea-level and salinity is affecting the socio-economic conditions of the people of Sunderbans - the world's largest mangrove forest. The people are deprived of their sources of livelihood – agriculture and fishing, and hence migrating to different places [Read More].

Wind bursts strongly affect El Nino severity
To have a skillful El-nino prediction, it is very important to understand the westerly wind bursts. These wind bursts are intraseasonal. Addition of these westerly wind bursts to ocean-atmosphere coupled model showed three "flavours" of El-nino - extremely strong events with the largest warming near the South American coast, a cluster of weak warm events centered near the dateline, or moderate warming in the central-eastern equatorial Pacific [Read More].

The "Pause" in Global Warming is finally explained
The SST of the Pacific and Atlantic oceans, goes through a natural cycle of warming and cooling, which is driven by large circulations of water across these and the rest of the world's seas. For the past decade, the northern Pacific cooling has been greater than that of Atlantic warming; hence a net slowdown in temperature rise was observed. We have thus been saved in the past decades from rapid atmospheric warming, to an extent, by the oceans, but when the current ocean effect reverses, our emissions will come back to haunt us [Read More].

Compiled by Chaitri Roy, IITM



Thunderstorm. *Source* : http://www.appszoom.com/android_applications/photography/spectacular-thunderstorms_fazpe.html

Conferences

Upcoming Events

- SERB School on "Fundamentals of Oceanic Processes and Modelling" to be held in IIT Delhi from May 19 to June 11, 2015
- AOGS 2015 on Tropical Ocean / Monsoon Sessions at, to be held in Singapore from August 2 to August 7 2015 [Read More]
- Modeling Coastal Marine Circulation and Physics and the Environmental Processes that they influence, to be held at University of New England Biddeford, ME, from 7 June to 12 June, 2015 [Read More].

Opportunities

Upcoming Events

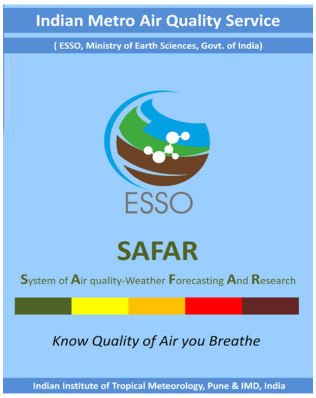
- Recruitment of Teaching Associates on contract basis, Kerala Agricultural University, Academy of Climate Change Education and Research. Visit: http://www.kau.edu/Jobs/accer_teaching_asst.pdf
- PhD opportunity in physical oceanography, University of Bergen, Norway. The position is within the physical oceanography research group. Visit: www.uib.no/en/gfi
- ESSO-INCOIS, Hyderabad is providing Scientist post, both temporary and regular positions. Visit: http://www.incois.gov.in

Compiled by Gibies George *and* Chaitri Roy, IITM

Unified air quality monitoring system for Delhi

Spotlight

The MoEF announced, amidst the growing concern about the air pollution in Delhi, that all the air quality monitoring systems in Delhi will follow a uniform scientific calibration protocol and validation process. Up till the announcement, the Delhi's air quality was being monitored by three different agencies - Central Pollution Control Board (CPCB), Delhi Pollution Control Committee (DPCC) and IMD to meet specific requirements of their operations. It was also stated that data for notified monitored parameters from all the monitoring stations will be seamlessly sent to CPCB for their analysis and authenticated air quality information will be communicated to DPCC on daily basis for further dissemination to public. The MoES-IITM/IMD will provide air quality forecast for Delhi.



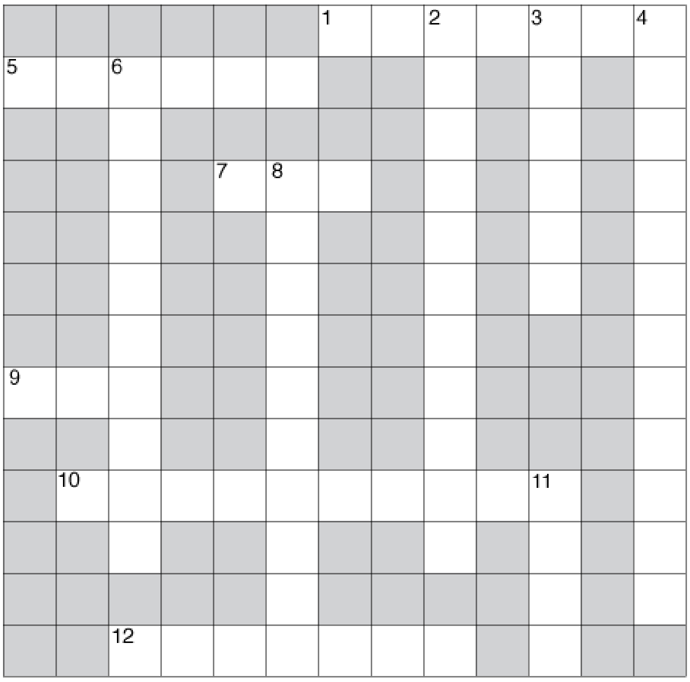
Click on the image above to download the SAFAR-Air App on your Phone!

- Ashok Karumuri, Univ. Hyderabad

Send your correspondence and contributions to:
OSI Pune, Indian Institute of Tropical Meteorology, Pashan, Pune 411008, India.
oceandigest@tropmet.res.in
www.oceansociety.in/oceandigest/

Crossword

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



ACROSS
1. According to this hypothesis universe formed 15 bya
5. It is smallest of the world's five ocean regions
7. An aggregate of minerals from which a valuable constituent can be profitably mined or extracted
9. Ultimate source of energy for Earth
10. Position in which Earth is closer to the Sun
12. Ancient Greeks considered the ocean to be a vast river called

DOWN
2. This wind tends to move parallel to isobars under the influence of pressure gradient and Coriolis force
3. Fraction of solar energy reflected from the Earth back into space is known as
4. The Indian Ocean was formed by fragmentation and dispersal of this continental assemblage
6. A land mark development in ocean science was the ____ expedition
8. Red marine algae are marine plans which belongs to this division
11. During ____ tides the daily tidal variations on the Earth are at their least

Keys to the Crossword in January 2015 issue:
ACROSS 1. venus 4. igneous 5. himalayas 9. indian 11. lima 12. fifteen 13. isobar DOWN 2. sial 3. loess 5. hudhud 6. antarctica 7. mascarene 8. richter 10. tethys

Compiled by Bhupendra B. Singh and Roxy Mathew Koll