Ocean Digest

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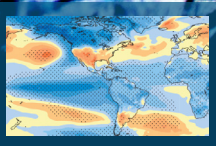
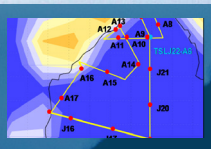
Cover Story: Expeditions to Antarctic and Arctic. **Cover Image**: Air bubbles from several centuries before, trapped in the Antarctic ice.



Global warming hiatus and the oceans - Review



Land-sea CO_2 contrast over the Bay of Bengal region

From Tethys to the Indian Ocean - A journey through the Jurassic and the Late Cretaceous

Poles are not poles apart !

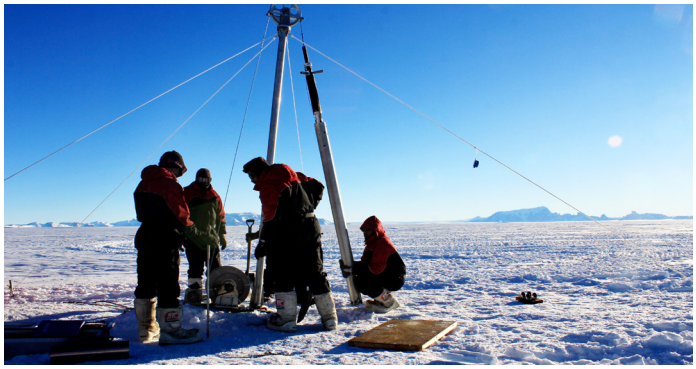
Invited Article

Dr. **Thamban Meloth** is a Senior Scientist at the National Centre for Antarctic & Ocean Research (NCAOR), Goa. He has been to several research expeditions to the Antarctic and Arctic, including the 1st Indian mission to South Pole.

"*Every day some new fact comes to light - some new obstacle which threatens the gravest obstruction. I suppose this is the reason which makes the game so well worth playing.*" – Robert Falcon Scott

Scrawled in the last diary of legendary Robert Falcon Scott, best known for his heroic but fatal attempt to be the first to reach the South Pole more than a hundred years ago, these reflections sum up the excitement and challenges inherent in working in polar regions. The frigid poles have attracted great adventurers since the late 19th century, which is considered to be the 'heroic era' of polar exploration.

Oceans have always fascinated me since childhood with its immense vastness, mysteries and the excitement about the unknown. My own tryst with scientific expeditions and explorations was commenced in 1993 once I joined the National Institute of Oceanography to embark on my doctoral research. Several expeditions to the great expanses of Arabian Sea, Bay of Bengal, Central Indian Ocean and Southern Ocean made me a hardened oceanographer. However, a life altering decision in 2002 to take up a new assignment to set up India's first Ice Core Laboratory at the then fledgling National Centre for Antarctic and Ocean Research brought me to the remote and extreme surroundings of Antarctic, Arctic and Himalayas. It was a sea-change in my life, work, terrain and research!



Setting up of an ice-core drilling camp in Antarctica

Polar Regions consisting of the Antarctic and Arctic offers an enormous expanse of remote, inhospitable and ice covered zones on the planet. While the Antarctica is an immense continent on south surrounded by the ocean, the Arctic is essentially an ocean covered by thick sea ice for large part and includes several larger islands such as the Greenland and Svalbard. Himalayas, considered as the 'Third Pole' stores more snow and ice than anywhere else in the world outside the Polar Regions.

Antarctica is a land of extremes- it is the coldest, driest and windiest continent, and has the highest average elevation of all the continents. Ninety eight percent of Antarctica is covered by thick ice sheets that contains about 90% of the world's 'permanent' ice and 70% of its fresh water. Antarctica has the lowest temperature on Earth (-89.2°C), recorded at the Vostok Station located on the East Antarctic plateau. Compared to this, Arctic climates are moderated by oceanic influences, having generally warmer temperatures and heavier snowfalls than the Antarctica. Antarctica tends to be thermally isolated from the rest of the planet by the surrounding Southern Ocean and the atmospheric polar vortex, whereas the Arctic is influenced strongly by seasonal atmospheric transport and river flows from surrounding continents.

Although the Polar Regions are considered to be the world's most remote and inhospitable region, a combination of isolation and extreme climate has led to a biota rich in endemic taxa and to a strong contrast between marine, terrestrial and freshwater biotas. The 'poles' are home to a range of exotic organisms - from the tiny microorganisms to the large mammals and birds such as polar bears (Arctic) and penguins (Antarctic). Recent studies have revealed that microorganisms dominate the polar environments, with their abundance in the ice sheets estimated to be about 9.61×10^{25} and represent the most abundant cold-adapted life forms on earth. While the effects of climate change on microorganisms in the Polar Regions are less understood, the effect on larger organisms inhabiting these environments is better studied.

The Polar Regions are also important regulators of global climate system. The global climate system is driven by solar radiation, and with 98% of its area covered with snow and ice, the Antarctic continent reflects most of the sun's light rather than absorbing it. This in association with a combination of other factors makes Antarctica, the coldest region on Earth. The large temperature difference between the equator and pole leads to poleward transport of heat which, in association with the Coriolis force imposed by the Earth's rotation, leads to the development of Hadley Cell, a large scale global circulation system. The related pressure gradient at the Earth's surface between subtropics (high pressure) and polar belt (low pressure) forces air to move eastwards under

The first Indian scientific expedition team to reach the geographic South Pole. Thamban Meloth is at the rightmost, standing.

Over-snow convoy to the ice-core drilling camp

the influence of the Coriolis force, creating the mid-latitude westerlies that drive the world's largest and strongest current system, the Antarctic Circumpolar Current. Although the marine Arctic covers a small fraction of the globe, positive feedback between the Arctic Ocean and the climate system has the potential to cause global effects. The thermohaline circulation is the global-scale overturning in the ocean that transports significant heat via a poleward flow of warm surface water and an equatorward return of cold, less saline water at depth. The overturning crucial to this transport in the Northern Hemisphere occurs in the Arctic region. An increase in Arctic outflow (through low saline melt water) will reduce the overturning and therefore the oceanic flux of heat to northern high latitudes.The overturning also moderates anthropogenic impacts on climate because it removes atmospheric CO_2 to the deep ocean.

Ice core lab processing

My own expeditions to the Polar Regions during the past one decade have been very exciting and opened new vistas of scientific opportunities. One of the most interesting studies we undertake includes the drilling into the ice sheets and recovery of long ice cores. Ice cores are long cylinders of ancient ice that are obtained by drilling deep into the polar ice sheets and glaciers. Study of ice core records provide one of the most direct and accurate method to study the climate change beyond the instrumental data availability (typically few decades in Antarctica). Ice cores contain an abundance of scientific information about past climate and climate change. Composition of ice and inclusions in the snow deposit of each year get preserved in the ice and provide quantitiative and/or qualitative information on air temperature, ocean volume, precipitation, chemistry and gas composition of the lower atmosphere, volcanic eruptions, solar variability, sea-surface productivity, desert extent and forest fires. In fact the ice core studies have revolutionized the view of the climate variability and become a cornerstone of climate change detection and attribution studies. We have been successful in drilling several ice cores from multiple sites in Antarctica, with boreholes reaching upto ~100 m.

National Centre for Antarctic and Ocean Research (NCAOR) at Goa is home to India's state-of-the-art Ice Core Laboratory for the exclusive study of snow and ice cores. Our high-resolution ice core studies revealed the utility of ice records to reconstruct the environmental and climate-related processes like the volcanic eruptions, role of microbially mediated biogeochemcial processes, intercontinental

Ice core lab clean analysis

transport of dust and pollution as well as the regional and global climatic teleconnections during the past hundreds of years (see a few references at the end).

Personally, the decision to shift my career to undertake polar studies had been extremely fulfilling and rewarding. It took me to picturesque and exciting places in Antarctica, Arctic and Himalayas as well as to the paths that were untreaded. One such memorable and challenging opportunity was my parctipation in the India's first scientific expedition to the geographic South Pole in 2010. The nearly 4200 km over-snow traverse from the Indian station Maitri to the South Pole was an exceptional odyssey that tested everyone's body and mind.

Indian research facilities in the Antarctic and Arctic

- Dakshin Gangotri (1983) – India's first permenant station in Antarctica. Built on an ice shelf, this was completely lost to the ice by 1990.
- Maitri (1989) – India's second permenant station in Antarctica. Situated on an ice-free area in the central Dronning Maud Land, this facility has been the mainstay of Indian Antarctic research for the past 25 years.
- Bharati (2012) – India's third and most modern permenant research station in Antarctica. Situated in an ice-free area of Larsmann Hills, this facility is separated by nearly 3000 km from the Maitri station.

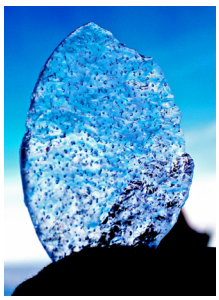
Indian research station Bharati in the Antarctic

- Himadri (2008) – India's first research station in the Arctic. Situated at Ny-Ålesund in the Svalbard Archipelago, this facility is the mainstay of the Indian research activities in the high Arctic.

We live in interesting times! The changing climate is bringing the focus back to the Poles. The Poles have immense scientific importance and offer grand opportunties for young minds, who has an inclination towards new experiences and challenges in life. Poles are no longer poles apart!

References:
1. Antony and others (2012), Diversity and physiology of culturable bacteria associated with a coastal Antarctic ice core, *Microbiological Research*, 167, 6, 372-80.
2. Laluraj and others (2014). Dust and associated goechemical fluxes in a firn core from East Antarctica and its linkages to the Southern Hemisphere climate variability. *Atmospheric Environment*, 90, 23-32.
3. Naik and others (2010). A century of climate variability in the central Dronning Maud Land, East Antarctica and its relation to Southern Annular Mode and El Niño Southern Oscillation. *JGR-Atmospheres*, 115, D16102.
4. Thamban et al. (2006). Aerosol perturbations related to volcanic eruptions during the past few centuries as recorded in an ice core from the Central Dronning Maud Land, Antarctica. *Current Science*, 91, 1200-1207.

Thamban Meloth wrote the article while he was at his research mission in the Arctic station *Himadri*. The cover image, captured by the author himself, depicts gas bubbles in an ice-core, drilled out at a depth of 100m from the Antarctic. These are bubbles which got trapped in the ice several centuries before, and as such tells us about the composition of air and climatic conditions during that period.



Global warming hiatus and the oceans

Review

Over the past century, global average surface temperatures have warmed by about 0.75°C. Much of the warming occurred in the past half-century, over which the average decadal rate of change was about 0.13°C, largely due to anthropogenic increases in well-mixed greenhouse gases. Increasing greenhouse gases have apparently led to an increasing radiative imbalance at the top of the atmosphere (TOA) of order 0.5–1 W m^{-2} in the past two decades, based on observational and model estimates. Over the past 50 years, the oceans have absorbed about 90% of the total heat added to the climate system, while the rest goes to melting sea and land ice, and warming the land surface and atmosphere. However, the trend in global surface temperatures has been nearly flat since the late 1990s despite continuing increases in the forcing due to the sum of the well-mixed greenhouse gases (CO_2, CH_4, N_2O, etc., Fig.1), raising questions regarding the understanding of forced climate change, its drivers, the parameters that define natural internal variability, and how fully these terms are represented in climate models (Solomon, et al. 2010). This global-mean temperature warming rate has slowed to almost zero for more than a decade is called a hiatus.

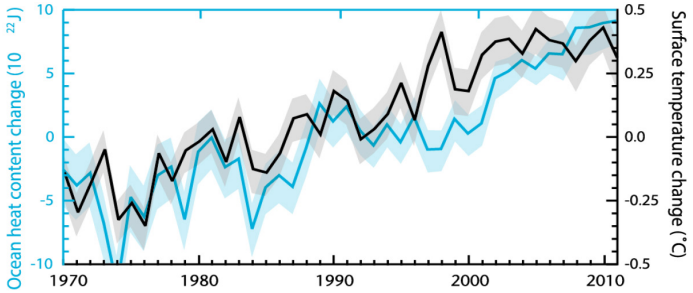


Fig. 1. Change in globally averaged annual ocean heat content (blue) for the upper 700 m of the ocean and global average near-surface temperature (black) relative to 1970-2011. *Source*: HadCRUT4, Met Office.

Analysis based on Coupled Model Inter-comparison Project 3 (CMIP3) reported that the climate over the 21st

century will produce periods of a decade or two where the globally averaged surface air temperature shows no trend or even slight cooling in the presence of longer-term warming. Natural variability of the real climate system can and likely will produce multi-year periods of sustained cooling or at least periods with no real trend even in the presence of long-term anthropogenic forced warming.

Possible mechanisms

Solomon et al (2010) reported that stratospheric water vapor concentrations decreased by about 10% after the year 2000. This acted to slow the rate of increase in global surface temperature over 2000–2009 by about 25% compared to that which would have occurred due only to carbon dioxide and other greenhouse gases. More limited data suggest that stratospheric water vapor probably increased between 1980 and 2000, which would have enhanced the decadal rate of surface warming during the 1990s by about 30% as compared to estimates neglecting this change. These findings show that stratospheric water vapor is an important driver of decadal global surface climate change. Meanwhile, other studies found that hiatus in warming coincides with a period of little increase in the sum of anthropogenic and natural forcing. Declining solar insolation as part of a normal eleven-year cycle, and a cyclical change from an El Nino to a La Nina dominate our measure of anthropogenic effects because rapid growth in short-lived sulfur emissions partially offsets rising greenhouse gas concentrations.

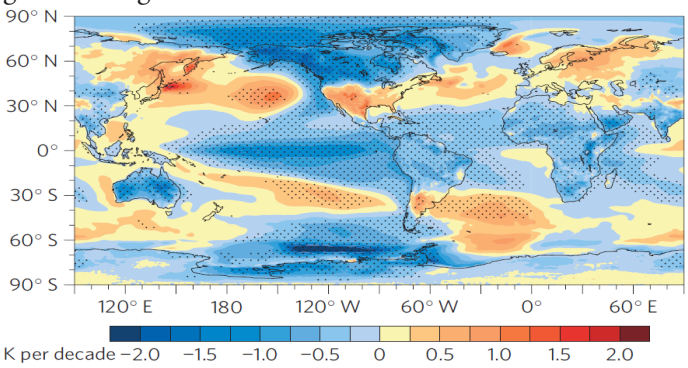


Fig. 2. Composite average global surface temperature trends for hiatus decades, (from the climate models); stipling indicates 5% statistical significance. Orange-coloured ocean areas represent regions where OHC is converging and being driven down into the deep. Soure: *Nature Publishing Group*.

Meehl et al. (2011) analysis of Community Climate System Model version (CCSM4), a global coupled climate model (RCP4.5) showed that the ocean above 300 m takes up significantly less heat whereas the ocean below 300m takes up significantly more compared with non-hiatus decades and indicates that a hiatus period is a relatively common climate phenomenon and may be linked to La Niña-like conditions (Fig.2). Kosaka and Xie (2013) have very recently performed some novel experiments that highlight the importance of the Pacific Decadal Oscillation (PDO) in the apparent hiatus. They used a climate model with radiative forcing and prescribed SSTs over the central and eastern Pacific Ocean. Yet they were able to reproduce many aspects of the observed changes from 1970 to 2012, including the changes in global mean temperature and the recent pause in warming, and several regional and seasonal aspects. Accordingly, the key indeed seems to lie in the Pacific and the decadal tendency for more La Niña events (associated with Pacific decadal variability), as suggested by Meehl et al. (2011). Further Kosaka and Xie (2013) conclude that the recent cooling of the tropical Pacific and the current hiatus are probably due to natural internal variability rather than a forced response. If so, the hiatus is temporary, and global warming will return when the tropical Pacific swings back to a warm state.

Similar hiatus events may occur in the future and are difficult to predict several years in advance owing to the limited predictability of tropical Pacific SST. Trenberth et al (2014) suggest that the hiatus has been strongly influenced by the negative phase of the PDO. The planet is still warming, but the changes in atmospheric circulation and surface winds, in particular, have changed ocean currents and more heat is being sequestered at greater depths. In northern winter, teleconnections via quasi-stationary atmospheric Rossby waves forced from the tropical Pacific influenced the Arctic and predisposed the North Atlantic Oscillation. Accompanying the recent negative phase of the PDO has been striking changes in tropical and subtropical winds and ocean currents, with profound effects on ocean heat content (OHC) and sea level. Some of these aspects appear to be unique to the past decade and raise questions about whether natural internal variability itself is being altered by climate change.

Chen and Tung (2014) recently analyzed in-situ and reanalyzed data to trace the pathways of ocean heat uptake. They found that in addition to the shallow La Niña–like patterns in the Pacific, the slowdown is mainly caused by heat transported to deeper layers in the Atlantic and the Southern oceans, initiated by a recurrent salinity anomaly in the subpolar North Atlantic. They also hinted that future El Niño events may temporarily interrupt the hiatus, but, because the planetary heat sinks in the Atlantic and the Southern Oceans remain intact, the hiatus should continue on a decadal time scale. When the internal variability that is responsible for the current hiatus switches sign, as it inevitably will, another episode of accelerated global warming should ensue.

According to recent research, scientists suggest that a slowdown of global warming is temporary– "let us wait and see".

References:

1. Chen and Tung, 2014, Varying planetary heat sink led to global-warming slowdown and acceleration, *Science*, 345 (6199), 897-903.
2. Kosaka Y. and S.-P. Xie, 2013, Recent global-warming hiatus tied to equatorial Pacific surface cooling, *Nature*, 501, 403–407.
3. Meehl G. A., J. Arblaster, J. Fasullo, A. Hu, and K. Trenberth, 2011, Model-based evidence of deep ocean heat uptake during surface temperature hiatus periods, *Nat. Clim. Change*, 1, 360–364.
4. Solomon S. et al., 2010, Contributions of stratospheric water vapor to decadal changes in the rate of global warming, *Science*, 327, 1219–1223.
5. Trenberth K.E. et al., 2014 "Seasonal aspects of the recent pause in surface warming", *Nat. Clim. Change*.

Review compiled by Anant Parekh and Jasti Chowdary, IITM

From Tethys to the Indian Ocean

History

The history of Indian Ocean is inevitably tied up with the history of the Indian subcontinent, and also the monsoon. About 200 million years ago, during the Jurassic period, the Indian landmass was part of the larger Gondwana in the southern hemisphere, along with Africa, Madagascar, Australia and the Antarctic. The wide, open ocean engulfed which between the Eurasian and Gondwana continents was the Tethys Ocean.

Tethys during the Late Jurassic. *Source*: Scotese 2000, Paleomap Project.

Mythologically, Tethys is the sister (and wife) of the Greek god Oceanus. The English word 'ocean' is derived from the Greek Oceanus (Ōkeanós). While Oceanus was considered as the great equatorial-encircling river, Tethys was supposed to distribute his water to the earth via subterranean streams.

About 100 million years ago (mya), between the Jurassic and Late Cretaceous periods, the Gondwana started splitting up, pushing Antarctic to the south, and Africa and India to the north. This lead to the formation of the Indian Ocean in its present state. About 70 mya, the Indian plate drifted northward at an accelerated pace, and collided with the Eurasian landmass some 1.5 mya, resulting in the uplift of the Himalayas. The geological separation resulted in India having its own biological species including the Indian dinosaur, *Rajasaurus narmadensis*, a contemporary of the North American *Tyrannosaurus rex*. Evidences of the tectonic movement can be seen in the ocean ridges along the seafloor, especially the ninety east (90°E) ridge in the Indian Ocean.

The location of the Indian landmass and uplift of the Himalayas in turn lead to a shift in the climate of the region. The moisture-laden winds which are drawn to the subcontinent were forced to rise over the Himalayas, resulting in enhanced convection, rainfall and the present day monsoon. The alignment of the Indian subcontinent in its present state, and the subsequent strengthening of monsoon over the region is supposed to have resulted in subsidence of dry air and expansion of the deserts over Africa.

Today, Indian Ocean plays a major role in deciding the climate and its variability of the surrounding countries. Though it is the smallest among the tropical oceans, it is also the warmest. While the Pacific and the Atlantic are well connected to the higher latitudes at both ends, the Indian Ocean is land-locked on the northern side, resulting in its unique oceanic circulation and hydrology. The strong monsoon winds during northern summer force intense upwelling and deep mixing along the western coastline of the Indian Ocean, making it one of the most biologically productive regions in the tropical oceans. The oceans and continents on the Earth keep on changing throughout its geological history. New oceans form, and the old ones disappear, on a timescale of several million years. The Indian and Atlantic Oceans are getting wider by a few inches every year, while the Pacific is shrinking at a similar pace.

References:
1. Copley A. et al., 2010, India–Asia collision and the Cenozoic slowdown of the Indian plate: Implications for the forces driving plate motions, *J. Geophys. Res.*, 115.
2. Stampfli G.M. and G.D. Borel, 2002, A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrons, *Earth Planet. Sci. Lett.*, 196(1), 17–33.

History Article compiled by Roxy Mathew Koll, IITM

On understanding the land–sea CO_2 contrast over the Bay of Bengal region: A case study during 2009 summer monsoon

Student Article

Ravi Kumar K

IITM, Pune

The total greenhouse gas (GHG) emission in India is estimated to have increased at a rate of 3.3% per year during 1994-2007. Estimates of total fossil-fuel CO_2 emissions from the Indian subcontinent indicate an alarming annual rate of increase of 7% in recent decades. The CO_2 source-sink mechanisms over the subcontinent are of ongoing interest in carbon cycle research. Recent studies indicate that the GHG emissions over the Indian subcontinent are likely compensated by the local biospheric sink. Most of the atmospheric CO_2 investigations conducted over the subcontinent are based on surface monitoring, aircraft measurements, or from model simulations, and not based on ship-based observations.

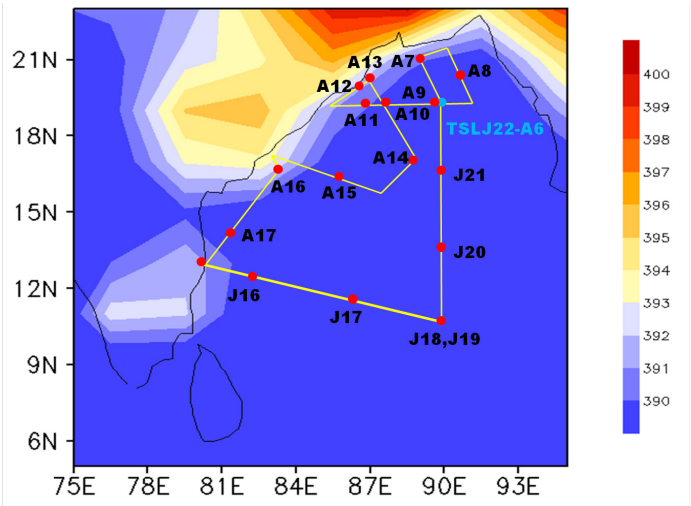


Fig. 1. Mean data for the entire cruise period, from Carbon Tracker simulated daily data. Red dots indicate the position of the cruise, J/A represents July/August.

In this study, we report observations of surface atmospheric CO_2 over Bay of Bengal (BoB) during a research cruise conducted from 17 Jul - 18 Aug, 2009. CO_2 observations over the ocean during a cruise that is limited to one month duration may not be sufficient for detailed process studies or even for inverse modeling. However, it does offer an opportunity to examine the land-sea contrast of atmospheric CO_2 from this data sparse region. This certainly adds value in terms of evaluating the contrasts in the surface fluxes of CO_2 in a region where the ocean warming is rapid, and the land experiences dramatic seasonal variability due to monsoonal forcing. This is the motivation for this analysis, and the results clearly indicate that the observed surface CO_2 variability over BoB as the contrast in the magnitudes of surface fluxes over land and ocean itself.

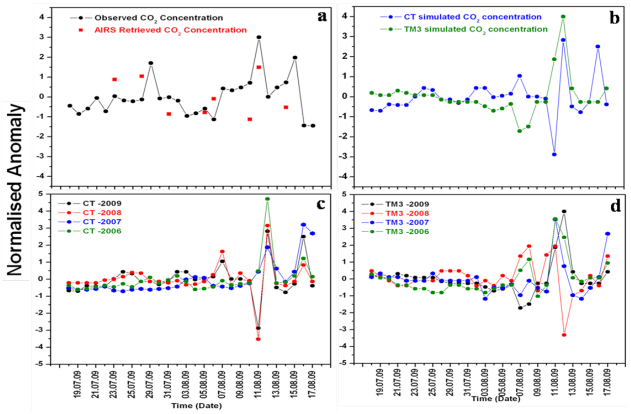


Fig. 2. (a) Comparison of CO_2 observations with the satellite retrievals, (b) CT and TM3 model simulations during ship observations, (c,d) model simulated CO_2 during the years 2006-2009.

Mean CO_2 data for the cruise period simulated from Carbon Tracker model and cruise track are shown in Fig.1. In Fig.2a, CO_2 concentrations measured along the cruise track shows high values when the ship was relatively close to the land. Land fluxes can be expected to have contributed to these large values of CO_2. Over the open ocean observed CO_2 values are relatively lower. Occasional highs and lows of atmospheric CO_2 observed by the moving ship says that there is a large contrast in the ambient CO_2 values between land and ocean. The remarkable similarity between AIRS satellite retrieved and ship-observed CO_2 indicates a more or less uniform concentration in the atmospheric column over the BoB. During the summer monsoon, deep convection over South Asia can carry the surface CO_2 vertically, which makes it detectable by satellite retrievals in Fig.2b. Fig.2(c,d) shows that land–ocean CO_2 contrast are well represented in the CarbonTracker (CT) and Transport Model (TM3) simulations during observation period (2009) and other years. This clearly indicates that models faithfully capture this seasonal land–ocean contrast in CO_2 concentration. With our limited data, we show that over the monsoon regions like BoB, the troposphere may be heavily affected by surface concentrations of CO_2, likely by the uplift due to deep convective episodes.

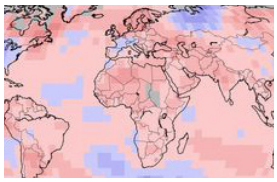
Reference:

1. Ravi Kumar et al. 2014, On understanding of land-ocean contrast of atmospheric CO_2 over Bay of Bengal: A case study during 2009 summer monsoon. *Env.Sci.Poll.Res.*

Acknowledgements: This work was carried as part of CTCZ cruise over the Bay of Bengal. Co-authors Tiwari YK, Valsala V and R Murtugudde are acknowledged.

News and Views

Recent Updates



Hottest summer

According to NOAA, summer 2014 was hottest summer and the global temperature was 1.28°C above the 20th century average. [Read more]

Pacific Northwest blob

The "blob" is another big pool of warmer than normal water, off the Washington coast and goes north, filling the Gulf of Alaska. In 2014 summer, its warmest point is five degrees warmer than normal, and as the air blows across it, that air also becomes warmer as it heads over land. [Read more]

Indian coast was hit by a sea surge some 1,000 years back

New evidence suggests that the Indian coast was hit by a sea surge 1,000 years back, before the tsunami of 2004 which caused massive destruction in the country. [Read more]

Zooplankton migrations may affect global ocean currents

Like other zooplankton, brine shrimp vertically migrate in large groups throughout the day in response to changing light conditions. New research suggests that the collective movement of small marine organisms could affect global ocean circulation patterns on a level comparable to the wind and the tides. [Read more]

New topographic map of Earth's mysterious ocean floor

A new topographic map of Earth's mysterious ocean floor reveals thousands of towering volcanoes, hidden gashes where supercontinents ripped apart and never-before-seen features once veiled by miles of water and thick sediment. [Read more]

Ocean Health Index

Researchers have helped produce the first Ocean Health Index that includes all the Earth's oceans. For the first time, the report assessed the Antarctic and 15 ocean regions beyond national jurisdiction - all critical regions for maintaining a healthy climate, safeguarding biodiversity and providing sustainable food sources. [Read more]

Future changes in coral reefs

National Center for Ecological Analysis and Synthesis reports that there will be winners and losers among coral species facing increasing natural and human-caused stressors. They suggest that a subset of the present coral fauna will likely populate the world's oceans as water temperatures continue to rise. [Read more]

The world is warming faster

Warming in the southern hemisphere oceans since 1970 could be more than twice what has been inferred from the limited direct measurements we have for this region. This means that together, all the world's oceans are absorbing between 24-58% more energy than has previously been estimated. [Read more]

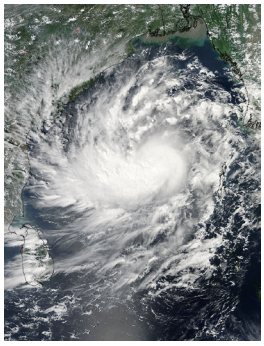
Compiled by Jasti Chowdary and Anant Parekh

Hudhud and Nilofar

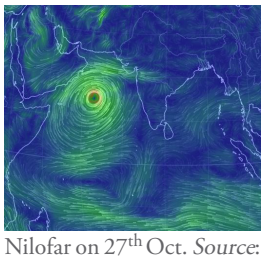
Spotlight

This October, the Indian subcontinent confronted two cyclones, each from either side of the subcontinent - *Hudhud* from the Bay of Bengal which lashed on Visakhapatnam in the east coast and *Nilofar* from the Arabian Sea which is currently en-route to Kutchh in the west coast.

Hudhud formed under the influence of an upper-air cyclonic circulation over the Bay, which rapdily intensified to a "Very Severe Cyclonic Storm" by 9th Oct 2014. Rainfall totals were highest over the open ocean at 550 mm; over land, the highest totals were 200~250 mm along the east coast. The remnants of Hudhud continued to move closer to the Himalayan foothills, bringing heavy rains to parts of northern India and snowfall in Nepal.



Satellite image of Hudhud. *Source*: NASA



Nilofar on 27th Oct. *Source*: earth.nullschool.net

The deep depression over Arabian Sea has intensified into "Cyclonic Storm" *Nilofar*. According to the IMD bulletin on 26th Oct 2014, it would intensify further into a "Very Severe Cyclonic Storm" by 28th Oct, and move northeastward reaching north Gujarat and adjoining Pakistan coast by 31st Oct morning.

- Ashok Karumuri and Roxy Mathew Koll

Conferences

Upcoming Events

- OSICON 2015, the 4th biennial conference organized by the Ocean Society of India will be held during 22-24 Mar 2015 at NIO, Goa. Details will be updated on the OSI website: http://www.oceansociety.in
- World Ocean Science Congress, Kochi, during 5-8 Feb 2015. url: http://www.wosce.org/
- TROPMET 2015 conference on Weather and Extremes organized by Indian Meteorological Society will be held at Chandigarh during 15-18 Feb 2015. url: www.tropmet2015.org

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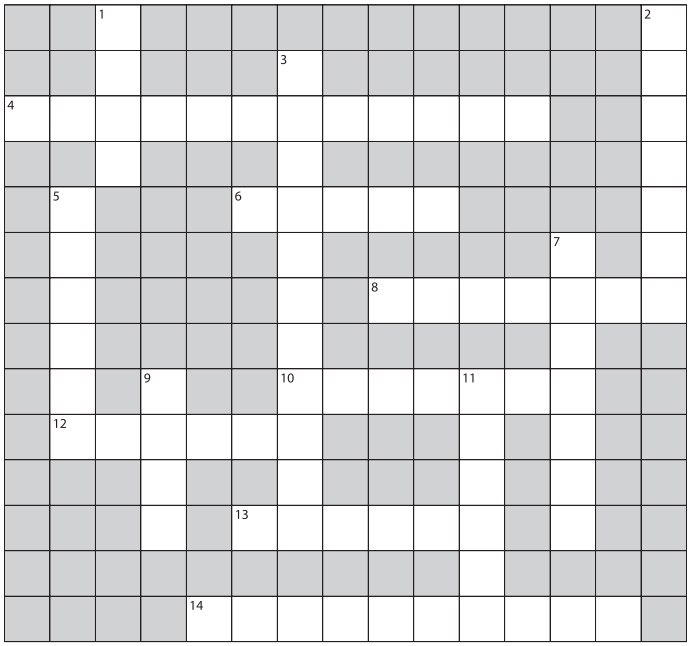
Crossword

Here is an Earth Science Crossword for our readers. Some of the clues can be traced to the present and previous issues of Ocean Digest. Enjoy.



ACROSS

4. The oceanic circulation that distributes thermal energy from the tropics to the polar regions (12)
6. Instrument to identify objects in water using sound waves (5)
8. This supercontinent existed 300 million years ago (7)
10. India's first Arctic research station (7)
12. Planetary waves that are generated due to the change in Coriolis force with latitude (6)
13. Ocean-atmosphere coupled phenomenon which develops as warmer than usual ocean waters over the east Pacific (6)
14. Instrument used for measuring humidity (10)

DOWN

1. The manmade canal connecting the Mediterranean and the Red Sea (4)
2. Driest place on Earth (7)
3. Green pigment which assists the phytoplankton to absorb energy from sunlight (11)
5. German astronomer who laid out the laws of planetary motion (6)
7. Largest of all major tectonic plates of Earth (7)
9. The fourth space agency to reach Mars recently (4)
11. The Indian Ocean _____ manifests as warm surface waters in the west and cool waters over the eastern part of the Indian Ocean (6)

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