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Climate Change and Oceans – Growing Threat and Implications for India

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The paper focuses on the maritime aspects of climate change. It highlights the regulatory role that the oceans play in the global climate, through its absorptive and buffering capacities. Based on recent reports, the paper presents various observations on ocean warming, sea level rise, ocean acidification and de-oxygenation, and charts out their impacts on the oceans. Based on forecasts for the future, it observes that these changes will continue to degrade marine ecosystems further, unless considerable action is taken now. The paper notes that climate change poses substantial risks to human and natural systems, which have significant implications for India. As this poses challenges to the growth and development of the country, India needs to take action for adaptation as well as for mitigation. The paper also examines India's stand in climate negotiations and suggests that India needs to adopt a flexible approach while championing the cause of an equitable and fair climate deal. The paper concludes that there is a strong case for bringing oceans into the public debate and strengthening India's resilience capacity is the key to face the growing threat of climate change.

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Introduction

Climate change, which is primarily caused by human activities, is the single most important global cause of concern in the 21st century. Global warming is unequivocal and increased concentration of *anthropogenic* Green House Gas (GHG) emissions is leading to most of the observed increase in average global temperatures.[1] The resulting climate change has affected physical systems – glaciers, permafrost, oceans, rivers and lakes; biological systems including terrestrial and marine ecosystems; and human-managed systems such as food production, livelihoods and health of people. It is also predicted that as the global climate changes further, it may affect the delicate equilibrium of the earth's ecosystem, which may lead to mass loss of biodiversity[2,3] on the planet.

The Intergovernmental Panel on Climate Change (IPCC) has been in the forefront of generating consensual opinion based on scientific basis, and it produced the First Assessment Report (FAR) in 1990. As part of its fifth Assessment Report (AR5), the IPCC released the reports of Working Group (WG) I (The Physical Science Basis[4]) in October 2013, WG II (Impacts, Adaptation and Vulnerability[5]) and WG III (Mitigation of Climate Change[6]) in May 2014 and would be releasing its Synthesis Report in end October 2014. AR5 concludes that it is *extremely likely*[7] that human interference with the climate system is occurring and its impact has been observed in the atmosphere, cryosphere and other geochemical cycles.

Despite the increase in scientific understanding, the earth's ecosystem is relatively complex to model and hence the impact of climate change cannot be predicted with certainty. Thus there is a strong case for recording the observations, understanding the science, analysing the risks and assessing the impacts of climate change. Equally important is the need to invest in adaptation[8] and to develop resilience[9] while contributing to mitigation[10] of climate change.

The Role of Oceans

Oceans that transcend national boundaries are integral for supporting life on earth. They create more than 50% of the earth's oxygen[11,12] and drive global weather systems. Oceans also play a crucial role in the process of climate change through its absorptive and buffering capacities, a fact that is poorly understood and even less acknowledged. It is estimated that oceans have absorbed approximately 28% of the cumulative anthropogenic emissions[13,14] released from 1750 to 2011; hence they play a key role in reducing the impact of growing terrestrial CO_2 emissions. It is also estimated that 93.4% of the total heat for the period 1993 to 2003, has been absorbed by the oceans, while only 6.6% was absorbed by atmosphere, continents, glaciers and ice-caps, arctic sea ice, Greenland sea ice and Antarctic ice sheet.[15] Figure 1[16] shows the rising heat content, both in the upper layers (0–700 m) and deeper layers (700–2000 m) of the oceans, land, ice and the atmosphere. This figure clearly shows that the ocean acts as a big buffer by absorbing the growing heat content.

However, a majority of people do not appreciate the threat that this change will have on the earth's climate in the near future. Instead, the focus is mostly on land-based phenomenon such as rising temperatures, melting of polar and glacial ice, and variability in rainfall patterns, as these impacts are more visible and affects terrestrial life.

Observations on Oceans[17]

It is quite natural that oceans that comprise 71% of the earth's surface will be at the forefront of bearing the impact of climate change. IPCC reports the following observations:

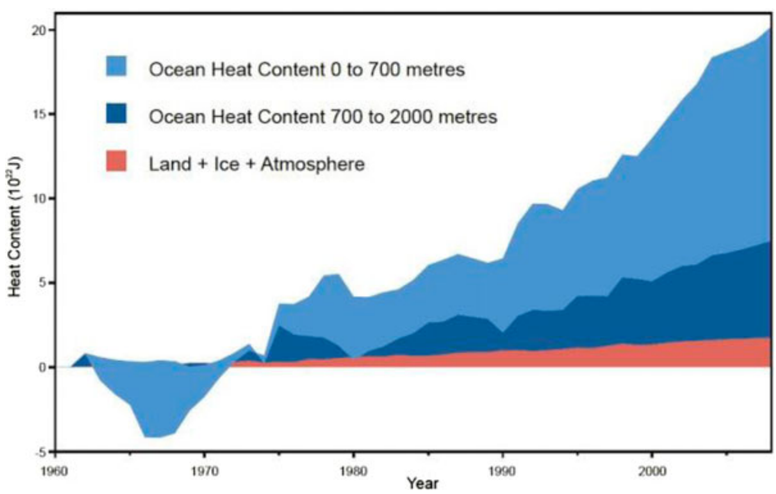

Fig 1. Heat content absorbed by oceans.

Ocean Warming

(a) Oceans account for more than 90% of the energy accumulated in the climate system (*high confidence*).[18]

(b) More than 60% of this is stored in the upper ocean (0–700 m), and about 30% is stored in the ocean below 700 m.

(c) Figure 2[19,20] shows the annual values of upper ocean heat content. The increase[21] in upper ocean heat content (between 1971 and 2010) is *likely*[22] to be 17×10^{22} J.

(d) The upper 75 m of the oceans has warmed by 0.11°C per decade.[23]

Sea Level Rise

(a) Global mean sea level rose by 0.19 m over the period 1901–2010.[24] The change in global mean sea level relative to 1900–1905 is shown in Figure 3.[25,26]

(b) However, this rise was not linear and the rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). It is *very likely* that sea level rise has increased at the rates shown in Table 1.[27]

(c) It is estimated that various factors, as shown in Table 2,[28] have contributed to the rise in sea level.

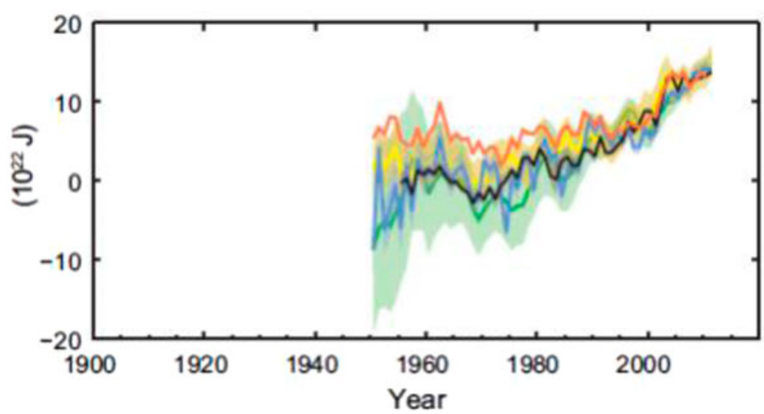

Fig 2. Changes in global average Upper Ocean heat content.

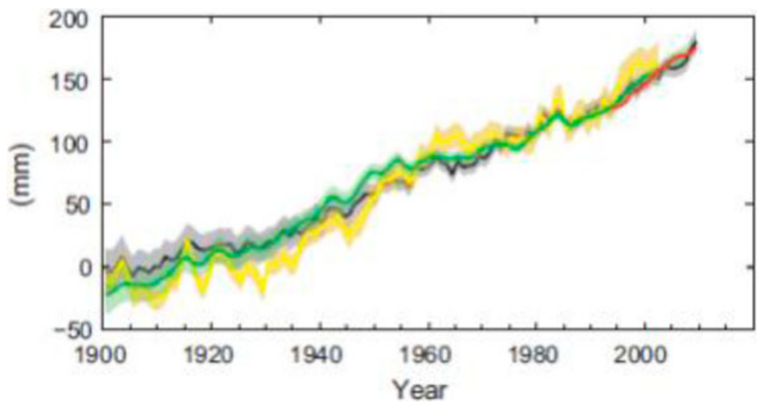

Fig 3. Global average sea level change relative to 1900–1905.

Ocean Acidification

The pH[29] of ocean surface water has decreased by 0.1 since the beginning of the industrial era (*high confidence*). This is a significant[30] increase in acidity, which corresponds to a 26% increase in hydrogen ion concentration.[31] This trend in ocean acidification is about 30 times greater[32] than the natural variation.[33] Figure 4 shows the surface ocean pH (bottom green line, right hand scale) and surface ocean partial pressure of CO_2 (middle blue line, left-hand scale) recorded at Station Aloha, in subtropical North Pacific, north of Hawaii.[34] The increasing trend of pCO_2 is consistent with the increase in atmospheric concentration of CO_2 observed at Mauna Loa observatory (top red line, left hand scale) and clearly shows the correlation between increased atmospheric concentrations of CO_2 and decreasing pH of ocean surface waters.

Table 1. Estimated rate of sea level rise.

Between the years	Rate of global mean sea level rise (mm/year)	Estimated range
1901 and 2010	1.7	1.5–1.9
1971 and 2010	2.0	1.7–2.3
1993 and 2010	3.2	2.8–3.6

Table 2. Contribution to rate of sea level rise.

Contribution from	Rate of global mean sea level rise (mm/year)	Estimated range
Ocean thermal expansion	1.1	0.8–1.4
Changes in glaciers	0.76	0.39–1.13
Greenland ice sheet	0.33	0.25–0.4
Antarctic ice sheet	0.27	0.16–0.38
Land water storage	0.38	0.26–0.49
Total	2.8	2.3–3.4

De-oxygenation

Ocean de-oxygenation refers to the loss of oxygen from the oceans. Long-term ocean monitoring has revealed that oxygen concentration in the ocean is progressively declining and low oxygen areas are increasing in number, volume and intensity. Oxygen Minimum Zones (OMZs)[35] are also expanding both horizontally and vertically[36] due to climate change.

Other observations include[37] changes in ocean surface fluxes such as ocean precipitation and freshwater flux, wind stress and changes in surface waves, changes in

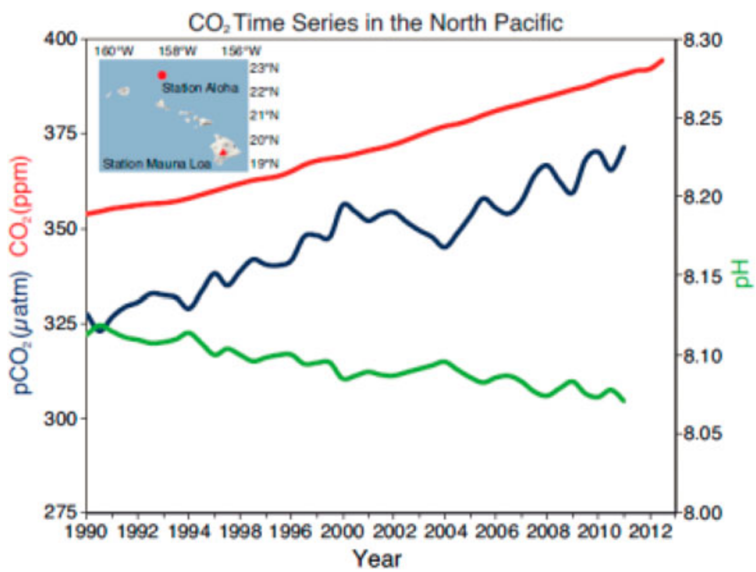

Fig 4. Trends in ocean acidification and atmospheric CO_2 level.

circulation of ocean currents and water exchanges between oceans and changes in the salinity[38] and freshwater content of the ocean.

Impacts on Oceans

As is evident by various observations, climate change is altering the physical and geochemical properties of the oceans, which is affecting the role of the ocean in the global climate system. Physical impacts on the oceans include modification of ocean currents and its circulation[39] and increased El Niño Southern Oscillation (ENSO)[40,41] events. Warming oceans are also contributing to melting of polar ice sheets due to "a change in the flux of oceanic heat which is transmitted to the undersides of the floating ice shelves".[42]

The deadly trio of ocean warming, de-oxygenation and acidification of the oceans is impacting marine life in the ocean. Evidence also suggests that a suppression of parts of the marine carbon and heat sink is already underway. This is leading to the following cumulative effects:

(a) Lowering ocean productivity: Lowering of nutrient and oxygen supply in the ocean has resulted in lowering of ocean productivity.[43,44]
(b) Habitat changes: Many marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change (*high confidence*).[45]
(c) Increasing hypoxic[46] zones: Hypoxic waters are stressing bottom-dwelling organisms. A shallower OMZ also brings organisms, closer to the surface during daytime, which makes them more susceptible to predators.
(d) Impact on coral reefs: Coral bleaching[47,48] is on the rise and there is a significant impact[49] on coral reefs, which are already among the most endangered marine ecosystems.

It is therefore evident that climate change is impacting oceans in a major way and certain studies suggest that the damage has already been done and is irreversible.[50,51]

Forecasts for the future[52]

AR 5 has made various forecasts of global and regional climate using different models. These climate models simulate changes based on a set of scenarios[53] of "anthropogenic forcing". Results for all scenarios predict that climate will continue to change until around the middle of the century, regardless of any action taken now, to reduce emissions. The following are the forecasts for the maritime domain.

- *Ocean warming:* It is estimated that ocean warming may be between 0.6° and 2.0°C (at 0–100 m depth) and between 0.3° and 0.6°C (1000 m depth) by the end of the 21st century. Figure 5[54] shows the results of two scenarios, RCP 2.6 and RCP 8.5, of the projected changes in average surface temperature over oceans for 2081–2100, relative to observations from 1986–2005 to highlight the impact of ocean warming.
- *Sea level rise*: It is forecasted that global mean sea level will continue to rise and the rate of sea level rise will *very likely* exceed the current observed rates. This rise will not be uniform, but by the end of the 21st century, it is *very likely* that sea level will rise in more than about 95% of the ocean area.[55] It is also projected that about 70% of the coastlines worldwide will experience sea level change within 20% of the global mean sea level change. Figure 6[56] shows the projections of global mean sea level rise relative to 1986–2005 for various RCPs. Global mean sea level rise for 2081–2100 will *likely* be in the range of 0.26–0.82 m (*medium confidence*). In the extreme case (RCP 8.5), the rise by the year 2100 is predicted to be between 0.52 and 0.98 m.
- *Acidification*: Global increase in ocean acidification is projected for all scenarios. As shown in Figure 7,[57] the corresponding decrease in surface ocean pH by the end of 21st century is in the range of 0.06–0.32 for the four RCPs.

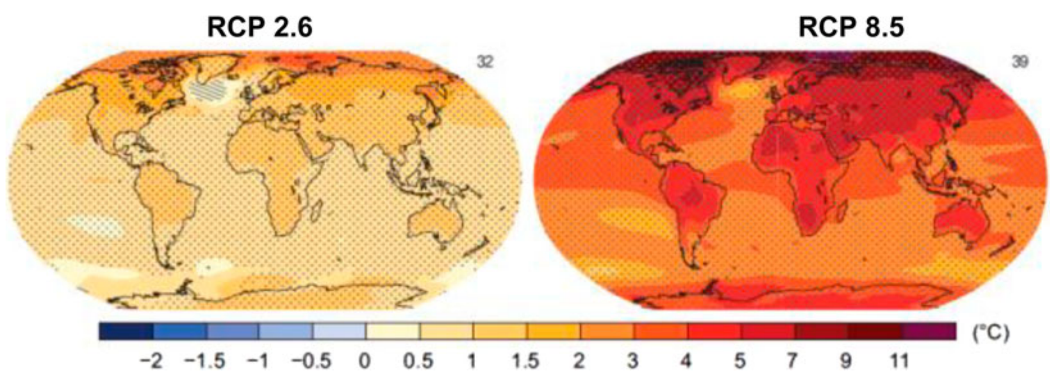

Fig 5. Forecast of change in average surface temperature.

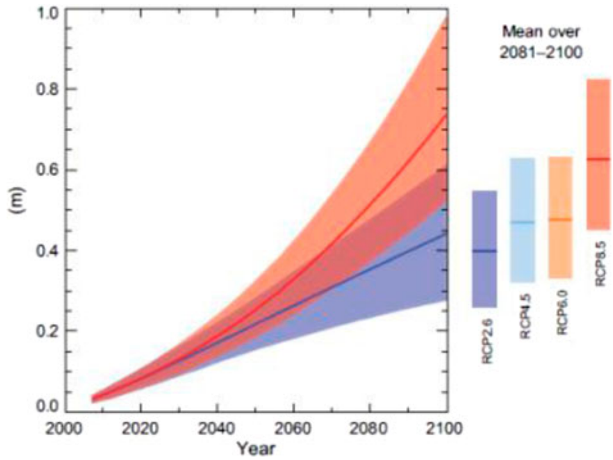

Fig 6. Forecast of global mean sea rise level.

- Studies suggest that due to higher acidification, the process of "erosion" may exceed "calcification" in the coral reef building process.[58] This may result in the extinction of some species which live and thrive on coral reefs. Other flora and fauna of the ocean will also be affected by this loss and it may lead to a decline in overall marine biodiversity.
- Figure 8[59] shows the forecast of changes in ocean surface pH for RCP 2.6 and RCP 8.5 for 2081–2100 relative to 1986–2005. It is evident that the pH changes will be widespread across oceans and will be much more severe in the RCP 8.5 scenario.

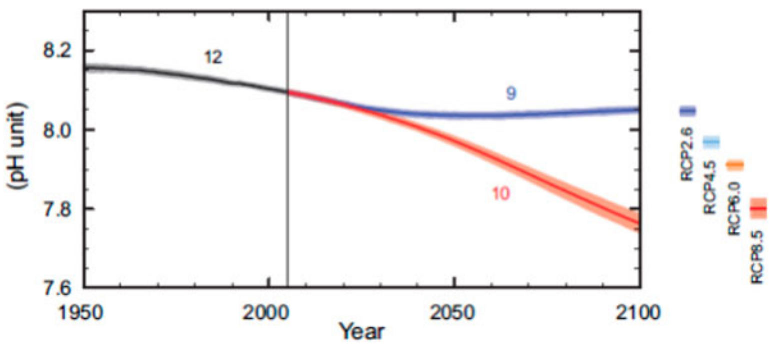

Fig 7. Projections for global mean ocean surface pH.

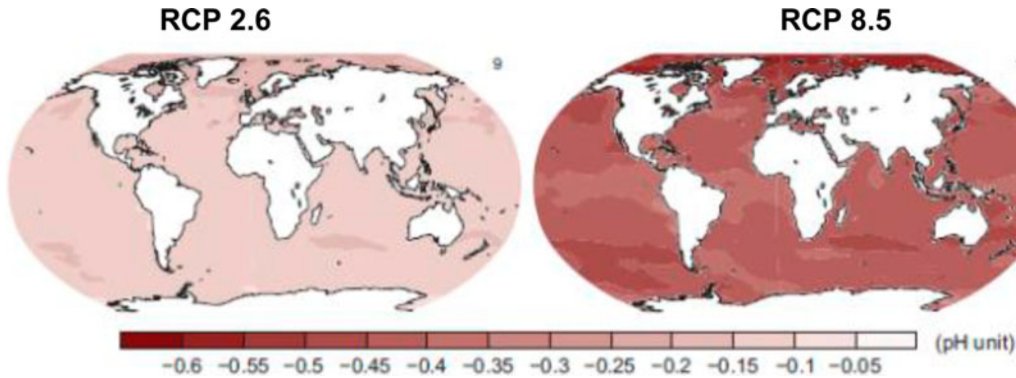

Fig 8. Forecast of changes in ocean surface pH.

- *De-oxygenation*: Ocean models predict declines of 1 to 7% in the global ocean oxygen content over the next century, with declines continuing for a thousand years or more into the future.[60] This decrease will be felt acutely in hypoxic and suboxic[61] areas. It is estimated that a 1°C warming throughout the upper ocean will result in the increase of hypoxic areas by 10% and a tripling of the volume of suboxic waters.[62]
- *Other effects:* It is also forecasted that heat penetrating from the surface to the deep ocean will affect ocean circulation. Further, small changes in temperature, salinity and ice cover may trigger large and sudden changes in regional climate.

Rapidly changing oceanic properties implies that many organisms will face unsuitable environments and if they are unable to adapt, it will have cascading consequences for marine biology and the associated food chain. The forecasted changes pose "substantial risks to marine ecosystems, especially polar ecosystems and coral reefs, and will affect the population dynamics of individual species from phytoplankton to animals (*medium* to *high confidence*)".[63] Further, "there is an increased risk of loss of marine and coastal ecosystems, biodiversity, and the ecosystem goods, functions, and services they provide for coastal livelihoods, especially for fishing communities in the tropics and the Arctic".[64] It is projected that "by the mid 21st century and beyond, global marine-species redistribution and marine-biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity and other ecosystem services (*high confidence*)".[65]

Figure 9 compares the maximum catch potential of approximately 1000 exploited fish and invertebrate species between the 10-year averages for 2001–2010 and those projected[66] for 2051–2060. As is evident, there could be a significant global redistribution of marine life leading to an increased risk for livelihoods dependent on fisheries. It is also predicted that "open ocean net primary production is projected to redistribute and by 2100 fall globally under all RCP scenarios".[67,68]

AR 5 concludes that "a large fraction of anthropogenic climate change is irreversible on a multi-century to millennial time scale".[69] This, "represents a substantial multi-century climate change commitment created by past, present and future emissions of CO_2".[70]

Concerns for India

Climate change is a global phenomenon but it impacts different regions differently. Apart from the increase in global risks, which impacts the entire world, AR5 offers the following key messages for South Asia:[71]

(a) South Asia's climate is already changing and the impacts are already being felt in the form of more temperature extremes and increased heat wave frequency.

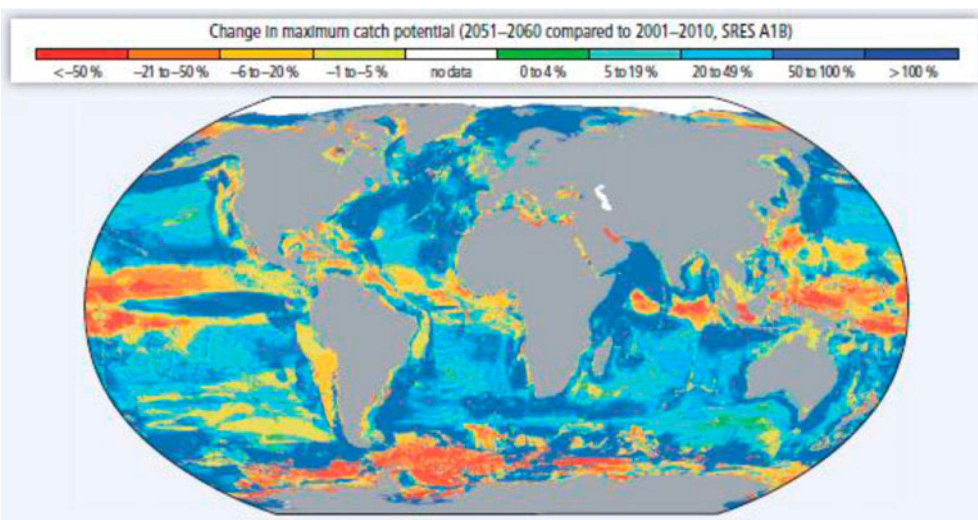

Fig 9. Projections for maximum catch potential for 2051–2060.

(b) As on date, climate related risks threaten lives, food security, health and well-being in many parts of South Asia.
(c) The Asian region as a whole experienced the most weather and climate-related disasters in the world between 2000 and 2008, and suffered almost 30% of total climate-related global economic loss.
(d) Climate change poses key risks and challenges to growth and development for vulnerable communities, given their limited ability to cope.

A study[72] by Indian Network for Climate Change Assessment (INCCA) was undertaken to review the impacts of climate variability in the four major climate sensitive regions in India, namely the Himalayan region, the North-Eastern region, the Western Ghats and the Coastal region. The report presents an assessment of the impacts of climate change in the 2030s on four key sectors of the economy that are climate dependent, namely Agriculture, Water, Natural Ecosystems and Biodiversity, and Human Health. Key results of the 4×4 assessment indicate significant impacts of increasing temperature, variation in precipitation, variability of monsoons, higher intensity of extreme temperatures, increase in extreme precipitation, glacial loss, snow cover reduction, increased river flow, increased frequency and intensity of droughts and floods, increase in cyclonic intensity, increase in storm surges, and increase in sea level rise[73] along the Indian coast. Likely physical and biophysical impacts of projected climate change in India include decrease in total crop production and per-capita calorie availability, increased vulnerability of crop yields to a host of climate-related factors in the region, and increased threat to deltaic regions and coastal cities, which are particularly exposed to compounding climate risks.

Table 3 shows the evidence-backed observed changes related to climate change and the projected impacts for India according to a study[74] commissioned by the World Bank and undertaken by the Potsdam Institute for Climate Impact Research and Climate Analytics.

Adaptation and Mitigation

The above threats are significant and hence pose challenges to the growth and development in India especially for vulnerable communities, given their limited ability to cope with such changes. Therefore, India needs to take action for adaptation as well as for mitigation.

Table 3. Observed changes and projected impacts of climate change in India.

Event/threat	Evidence-backed observed changes	Projected impacts
Extreme heat	India is experiencing a warming trend	• Extreme temperatures, increase in duration of spells of hot weather and its frequency
Changing rainfall patterns	A decline in monsoon rainfall since the 1950s and increase in frequency of heavy rainfall events	• Increasing unpredictability of summer monsoon • Changing monsoon patterns leading to frequent droughts and greater flooding in large areas • Increase in severity of monsoon and rainfall in coastal areas
Droughts	Parts of South Asia have become drier and there has been an increase in the number of droughts since the 1970s	• Droughts are expected to be more frequent in north-western India, Jharkhand, Orissa and Chhattisgarh • Crop yields are expected to fall significantly because of extreme heat by the 2040s
Groundwater	Overexploitation of groundwater resources	• Water tables are expected to reduce further
Glacier melt	Most Himalayan glaciers have been retreating over the past century. However, glaciers in the north western Himalayas and in the Karakoram range – have remained stable or even advanced	• Indus and the Brahmaputra, which are primarily glacier-fed rivers, are expected to have variability in flow, across seasons • Alterations in the flows of the Indus, Ganges, and Brahmaputra rivers could significantly impact irrigation
Sea level rise	Increases in sea water intrusion	• Higher rises in sea levels leading to coastal flooding, as compared to countries in higher latitudes

Table 3 (*Continued*)

Event/threat	Evidence-backed observed changes	Projected impacts
		• Kolkata and Mumbai, are particularly vulnerable to the impacts of sea-level rise and riverine flooding • Sea-level rise coupled with storm surges would lead to saltwater intrusion in the coastal areas, impacting agriculture and degrading groundwater quality
Agriculture and food security	Rising temperatures with lower rainfall at the end of the growing season have caused a significant loss in India's rice production High temperatures (above 34°C) in northern India have had a substantial negative effect on wheat yields	• Substantial yield reductions in both rice and wheat can be expected in the near- and medium-term threatening food security • It is estimated that by the 2050s, India may need to import more than twice the amount of food-grain as compared to a scenario in which there was no impact of climate change
Energy security	Climate-related impacts on water resources has impacted hydropower and thermal power generation[a]	• The increasing variability and long-term decreases in river flows can pose a major challenge to hydropower plants and increase the risk of physical damage from landslides, flash floods, glacial lake outbursts, and other climate-related natural disasters
Water security	Many parts of India are experiencing water stress[b]	• The threat to water security is very high over central India,

Table 3 (*Continued*)

Event/threat	Evidence-backed observed changes	Projected impacts
		along the mountain ranges of the Western Ghats, and in India's north eastern states
Health	Increased health impacts	• Increasing malnutrition and related health disorders • Increased incidence of malaria and other vector-borne diseases, along with and diarrheal infections leading to higher child mortality • Rise in mortality from heat waves and injuries from extreme weather events
Migration and conflict	South Asia is a hotspot for the migration of people from degraded areas to other national and international regions	• Climate change impacts on livelihoods can increase the number of climate refugees

[a]Fresh water is required for cooling thermal plants.
[b]Even without the impact of climate change, water security is a major concern.

Adaptation is fundamentally about risk management and it can bring immediate benefits. No single approach is appropriate for reducing risks across all settings and therefore adaptation needs to be place and context specific.[75] Reducing vulnerability and exposure to climate induced risks through overall human development, strengthening disaster management capabilities, ecosystem management, and better planning will lead to reduced impacts of climate change. Incremental and context specific adaptation through structural and physical changes such as building sea walls and coastal protection structures, use of water saving technologies in agriculture, ecological restoration, improved water storage, co-management of fisheries, provision of enhanced emergency medical services etc. will also strengthen resilience.[76] Transformational adaptation such as building institutional capability, strengthening social systems and behavioural changes will also be beneficial in the long run. Local and sub-national governments can play an important role in adaptation planning and implementation. National governments can coordinate these efforts, which can be enhanced through complimentary actions. It is also suggested that action on climate change adaptation can bolster development and some low-carbon development options may be less costly in the long run. India can therefore play a major role by simultaneously pursuing these overlapping approaches to adaptation effectively to manage the risks from climate change.

While adaptation strategies can lead to climate resilient pathways, mitigation is equally important and should commence at the earliest. As climate change is a problem of global commons, international cooperation is essential for effective mitigation. Further, it is only cumulative global emissions reductions that will eventually change the Business as Usual (BAU) scenario of emissions. However, issues of equity and fairness must be kept in perspective and outcomes that are seen as equitable can lead to more effective cooperation amongst member countries. Mitigation strategies can also create co-benefits and can lead to achieving other societal goals.[77] Some of these co-benefits include improvement in local environment quality, sustainable development and provisioning of public goods. Including co-benefits into policy goals can therefore strengthen the basis for formulation of climate mitigation strategies. India therefore needs to integrate climate adaptation and mitigation along with its sustainable development agenda in order to emerge as a developed country by the end of this century.

India's Stand in Climate Negotiations

India is now the third largest emitter of CO_2 and contributes to about 5% of the total annual global emissions. However in the cumulative sense India's contribution would be much less if historical emissions are taken into account. Further, with a per capita emission of 1.6 tonnes of CO_2 per year (as in 2012), it is amongst the world's low emitters. India is an active party to the United Nations Framework Convention on Climate Change (UNFCCC), and in accordance with its obligations, India submitted the first National Communication (NATCOM) to the UNFCCC in 2004. The second NATCOM was submitted in 2012, which included a national inventory of anthropogenic emissions and other relevant information.

India's actions towards mitigating climate change are in accordance with the principle of Common But Differentiated Responsibilities (CBDR), respective capabilities, specific regional and national development priorities, objectives and circumstances.[78] In response to the challenge of climate change, India has drawn up the National Action Plan on Climate Change (NAPCC), which identifies eight core "national missions"[79], and outlines the existing and future policies and programs addressing climate mitigation and adaptation. As on date, all national missions are at different stages of implementation. Further, under advice of the Central Government, State Governments have also prepared State Action Plans on Climate Change (SAPCC) that are aimed at creating institutional capacities and are implementing sectoral activities to address Climate Change.[80]

At the 15th Conference of the Parties (COP) to the UNFCCC, India voluntarily announced its intention to reduce the emissions intensity of its gross domestic product (GDP) by 20–25% from 2005 levels by 2020.[81] However, India emphasized that its domestic mitigation actions are not legally binding. Further, India has committed that its per capita emissions will not rise above the OECD level. This was followed by setting up of an expert group[82] to develop strategies for low-carbon inclusive growth to meet the intensity reduction targets in the 12th 5-year plan (2012–17).

Although India has voluntarily announced its targets, it has reiterated in the joint statement released in the 18th BASIC (Brazil, South Africa, India and China) ministerial meeting held in August 2014 at New Delhi, that they will not agree to any binding cuts in emissions. Further, it has reemphasized that economic and social development and poverty eradication are the first and overriding priorities of the developing countries. They reiterated that the Intended Nationally Determined Contributions (INDCs) of developing countries will be in the context of their social and development needs and will also be premised on the extent of financial, technological and capacity-building support provided by developed countries.[83]

Although India is on a strong footing and its position is legitimate in accordance with the principles enshrined in the UNFCCC, it is facing the tag of an "obstructionist" in climate negotiations due to its hardline stand. On the other hand, Indian government can help to promote ambitious global action on climate change mitigation by agreeing to be a part of an international, legally binding climate deal. India therefore faces a significant challenge and it needs a clearly defined strategy and a well articulated stand before the next landmark climate negotiations, to be held in December 2015 at Paris. It is also opined that India needs to adopt a more flexible approach while championing the cause of an equitable and fair climate deal. Whatever stand India takes remains to be seen, but one can only hope that the world can conclude a climate deal, as the window of opportunity for avoiding catastrophic changes in the climate is rapidly closing.

Conclusion

Climate and the oceans function as an integrated system, and oceans play a key role in climate regulation. The absorptive and buffering capacity of the oceans is being lowered and the natural processes that are performed by the ocean are now being altered. Observations provide a clear evidence of the rapid changes and the devastating impacts of climate change on the oceans. Forecasts predict that climate change is inevitable in the coming decades and the deterioration in the marine ecosystems may further exacerbate climate change. Although the degradation of the oceans is not as immediately apparent as terrestrial effects, the impacts are much longer lasting and cannot be predicted with certainty. The growing threat from climate change and the increasing vulnerability is a major cause of concern for India. Therefore, India needs to take action for adaptation as well as for mitigation. Although India's position in climate negotiations is legitimate, it needs to adopt a more flexible approach while championing the cause of an equitable and fair climate deal. It can therefore be concluded that there is a strong case for bringing oceans into the public debate on climate change, and strengthening India's resilience capacity is the key to face the growing threat of climate change.

Notes

1. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, H. L. Miller, eds, IPCC, 2007: Summary for Policymakers. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, H. L. Miller (Cambridge: Cambridge University Press, 2007) (abbreviated as SPM-WG1, AR4).
2. Key findings from "Millennium Ecosystem Assessment" (MA) note that an unprecedented mass extinction of life on Earth is occurring. Scientists estimate that between 150 and 200 species of life become extinct every 24 hours.

3. United Nations Environment Programme (UNEP), "The State of the Planet's Biodiversity", http://www.unep.org/wed/2010/english/biodiversity.asp (accessed August 11, 2014)
4. IPCC, 2013: Summary for Policymakers. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Cambridge: Cambridge University Press, 2013) (abbreviated as SPM-WG1, AR5).
5. IPCC, 2014: Summary for Policymakers. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White (Cambridge: Cambridge University Press, 2014), pp. 1–32 (abbreviated as SPM-WG2, AR5).
6. IPCC, 2014: Summary for Policymakers. In *Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlomer, C. von Stechow, T. Zwickel and J.C. Minx (Cambridge: Cambridge University Press, 2014) (abbreviated as SPM-WG3, AR5).
7. IPCC describes the likelihood of an outcome in terms of percentages: "Extremely likely", "Very likely" and "Likely" corresponds to "95% or more", "90% or more" and "66% or more" certainty respectively.
8. The process of adjustment to actual or expected climate and its effects. SPM-WG2, AR5, p. 5.
9. The capacity of social, economic, and environmental systems to cope with a hazardous event, while responding or reorganizing in ways that maintain their essential function, while also maintaining the capacity for and transformation. SPM-WG2, AR5, p. 5.
10. Mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases. SPM-WG3, AR5, p. 5.
11. Most of Earth's oxygen comes from tiny ocean plants – called phytoplankton – that live near the water's surface. Scientists are unsure about the exact amount but estimates suggest that 50–85% of the world's oxygen is contributed by the sea.
12. Earth Sky. "How much do oceans add to world's oxygen?", http://earthsky.org/earth/how-much-do-oceans-add-to-worlds-oxygen (accessed August 19, 2014).

13. Out of cumulative anthropogenic emissions of 555 [470–640] Gigaton carbon (GtC) released from 1750 to 2011, 240 [230–250] GtC have accumulated in the atmosphere, 155 [125–185] GtC have been taken up by the ocean and 160 [70–250] GtC have accumulated in natural terrestrial ecosystems.
14. SPM-WG3, AR5, p. 12.
15. SPM-WG1, AR4.
16. Arctic News. “Accelerated warming in the Arctic”, http://arctic-news.blogspot.in/2012_09_01_archive.html (accessed August 25, 2014).
17. This section is based on SPM-WG1, AR5, pp. 1–27.
18. AR 5 assigns five levels of confidence in a finding, which are: very low, low, medium, high and very high. The level of confidence derives from a synthesis of the evidence that exists and the degree of scientific agreement on what the evidence means.
19. Coloured lines indicate different data sets and uncertainties are indicated by coloured shading.
20. SPM-WG1, AR5, p. 8.
21. Relative to the mean of all datasets for 1970.
22. As estimated from a linear trend with the estimated range as $[15–19]\times10^{22}$ J.
23. Estimated range is 0.09–0.13°C per decade.
24. Estimated range is 0.17–0.21 m.
25. Coloured lines indicate different data sets and uncertainties are indicated by coloured shading.
26. SPM-WG1, AR5, p. 8.
27. Ibid, p. 9.
28. Ibid.
29. $pH=\log_{10}(1/a_{H^+})$ where a_{H^+} is the hydrogen ion activity in the solution. Pure water has a pH of 7.0 at 25°C.
30. Since pH is a logarithmic scale, a difference of one pH unit is equivalent to a tenfold difference in hydrogen ion concentration.
31. European Project on Ocean Acidification. “FAQs about ocean acidification”, http://www.epoca-project.eu/index.php/what-is-ocean-acidification/faq.html (accessed August 25, 2014)
32. V. J. Fabry, B. A. Seibel, R. A. Feely and J. C. Orr, “Impacts of Ocean Acidification on Marine Fauna and Ecosystem Processes”, *ICES Journal of Marine Science*, 65 (2008): 414–432.
33. Environmental Defence fund (EDF). “Five ways climate change is affecting our oceans”, http://www.edf.org/blog/2013/11/14/five-ways-climate-change-affecting-our-oceans (accessed August 16, 2014).

34. M. Rhein, S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G. C. Johnson, S. A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L. D. Talley and F. Wang, Observations: Ocean. In: SPM-WG1, AR5, p. 44.
35. OMZ are naturally occurring regions present at 100–1000-m depths of the ocean.
36. Oceans Scientists for Informed Policy, "Ocean Deoxygenation", http://oceanscientists.org/index.php/topics/ocean-deoxygenation (accessed July 29, 2014).
37. M. Rhein, S. R. Rintoul, S. Aoki, E. Campos, D. Chambers, R. A. Feely, S. Gulev, G. C. Johnson, S. A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L. D. Talley and F. Wang, Observations: Ocean. In: SPM-WG1, AR5, pp. 256–316.
38. It is *very likely* that regions of high salinity have become more saline, while regions of low salinity have become fresher since the 1950s.
39. The ocean redistributes large amounts of heat around the planet via global ocean currents, called thermohaline circulation and through regional scale upwelling and downwelling. Upwelling, is a process where cold, nutrient-rich waters are brought to the surface, while downwelling takes the oxygen-rich waters from the surface to lower layers.
40. El Niño-Southern Oscillation (ENSO) is a global coupled ocean-atmosphere phenomenon that has important consequences for weather around the globe.
41. State Climate office of North Carolina. "Global Patterns- El Niño-Southern Oscillation (ENSO)", http://www.nc-climate.ncsu.edu/climate/patterns/ENSO.html (accessed August 19, 2014).
42. P. C. Reid, A. Fischer, E. Lewis-Brown, M. P. Meredith, M. Sparrow, A. J. Andersson, A. Antia, U. Bathmann, G. Beaugrand, H. Brix, S. Dye, M. Edwards, T. Furevik, R. Gangstø, H. Hátún, R. R. Hopcroft, M. Kendall, S. Kasten, R. Keeling, C. Le Quéré, F. T. Mackenzie, G. Malin, C. Mauritzen, J. Ólafsson, C. Paull, E. Rignot, K. Shimada, M. Vogt, C. Wallace, Z. Wang and R. Washington, "Impacts of the Oceans on Climate Change", *Advances in Marine Biology*, 56 (2009): 1–150.
43. This accompanied with continued overfishing has depleted marine ecosystems and is undermining the resilience of ocean systems. It is estimated that about 9000–10,000 tonnes of fish is caught from the Ocean every hour. In 2012, the UN FAO determined that 70% of world fish populations are unsustainably exploited, of which 30% have biomass collapsed to less than 10% of unfished levels.
44. International Programme on the State of the Ocean. "Big Threats – The main factors destroying Ocean health", http://www.stateoftheocean.org/threats.cfm (accessed August 21, 2014).
45. SPM-WG3, AR5, p. 4.

46. "Hypoxic" areas are defined as regions where oxygen limitation is detrimental to most organisms.
47. Although not immediately fatal, coral bleaching affects the ability of a coral to grow and reproduce, and may increase susceptibility to disease.
48. Center for Ocean Solutions. "Coral Bleaching", http://centerforoceansolutions.org/climate/impacts/ocean-warming/coral-bleaching/ (accessed August 22, 2014).
49. Mark Eakin, Joan Kleypas and Hoegh Guldberg, International Coral Reef Initiative. "Global Climate change and coral reefs", http://icriforum.org/sites/default/files/CLIM%20Acid%20and%20temps%20FINAL%20CH1%20-%20Dec08_0.pdf (accessed August 22, 2014).
50. The severity of damage depends not only on the magnitude of the change but also on the potential for irreversibility. Climate change that takes place due to increases in carbon dioxide concentration is largely irreversible for 1000 years after emissions stop.
51. Susan Solomon, Gian-Kasper Plattner, Reto Knutti and Pierre Friedlingstein, "Irreversible climate change due to carbon dioxide emissions", *Proceedings of the National Academy of Sciences*, 106 (2009): 1704–1709.
52. Forecasts are derived from SPM-WG1, AR5.
53. Four set of scenarios, called the Representative Concentration Pathways (RCPs), were used for the simulations. RCP 2.6 corresponds to a low emissions scenario while RCP 8.5 corresponds to a high emissions scenario. Two intermediate scenarios of RCP 4.5 and RCP 6.0, which assumed some stabilization in emissions, were also used.
54. SPM-WG1, AR5, p. 20.
55. Ibid, p. 24.
56. Coloured vertical bars show the assessed *likely* ranges for the mean while the median value is represented by a horizontal line. SPM-WG1, AR5, p. 24.
57. Colored vertical bars show the mean and associated uncertainties averaged over 2081–2100 for all RCP scenarios. The numbers of models used to calculate the multi-model mean is indicated inside the inset. Ibid, p. 19.
58. Endangered Species International. "Coral Reefs", http://www.endangeredspeciesinternational.org/coralreefs7.html (accessed August 18, 2014).
59. SPM-WG1, AR5, p. 20.
60. R. F. Keeling, A. Kortzinger and N. Gruber, "Ocean deoxygenation in a warming world", *Annual Review of Marine Science*, 2 (2010): 199–229, Palo Alto: Annual Reviews, available at http://scrippsscholars.ucsd.edu/rkeeling/content/ocean-deoxygenation-warming-world.

61. Suboxic zones have oxygen concentrations 98% lower than the mean surface concentrations. Most life cannot be sustained in suboxic zones and significant biogeochemical changes occur due to altered water chemistry.
62. C. Deutsch, H. Brix, T. Ito, H. Frenzel and L. A. Thompson, "Climate-Forced Variability of Ocean Hypoxia", *Science*, 333, 336 (2011). Available at http://web.atmos.ucla.edu/~cdeutsch/papers/Deutsch_sci_11.pdf (accessed August 17, 2014).
63. SPM-WG2, AR5, p. 17.
64. Ibid, p. 13.
65. Ibid, p. 17.
66. Projections do not include analysis of potential impacts of overfishing.
67. SPM-WG2, AR5, p. 17.
68. Ibid, p. 16.
69. SPM-WG1, AR5, p. 26.
70. Ibid, p. 25.
71. Elizabeth Carabine, Alberto Lemma, Mairi Dupar, Lindsey Jones, Yacob Mulugetta, Nicola Ranger and Maarten van Aalst. "The IPCC's Fifth Assessment Report-What's in it for South Asia?" Executive Summary (Overseas Development Institute and Climate and Development Knowledge Network (CKDN), 2014).
72. Indian Network For Climate Change Assessment (INCCA). "Climate Change and India: A 4×4 Assessment – A Sectoral and Regional Analysis for 2030s" (Ministry of Environment & Forests, Government of India, 2010).
73. Data indicates that the sea level along the Indian coast has been rising at the rate of about 1.3 mm/year on an average.
74. The World Bank, "Turn Down the heat – Climate Extremes, Regional Impacts, and the Case for Resilience" (Washington DC: International Bank for Reconstruction and Development, 2013).
75. SPM-WG2, AR5, p. 25.
76. Ibid, p. 27.
77. SPM-WG3, AR5, p. 5.
78. Lok Sabha Secretariat, Parliament Library And Reference, Research, Documentation And Information Service (LARRDIS), Members' Reference Service, Reference Note, No. 25/Rn/Ref./August/2013, "Climate Change – India's Perspective", p. 8.
79. These are National Solar Mission, National Mission for Enhanced Energy Efficiency, National Mission on Sustainable Habitat, National Water Mission, National Mission for Sustaining the Himalayan Ecosystem, National Mission for a Green India, National Mission

for Sustainable Agriculture and National Mission on Strategic Knowledge for Climate Change.

80. Lok Sabha Secretariat, p. 10.
81. N. Pahuja, N. Pandey, K. Mandal and C. Bandyopadhyay, "GHG Mitigation in India: An Overview of the Current Policy Landscape", Working Paper (Washington, DC: World Resources Institute, 2014), http://www.wri.org/publication/ghg-mitigation-ind-policy.
82. The Final Report of the Expert Group on Low Carbon Strategies for Inclusive Growth was submitted on April 1, 2014.
83. Joint Statement, 18th BASIC Ministerial Meeting on Climate Change, August 8, 2014, New Delhi, http://pib.nic.in/newsite/PrintRelease.aspx?relid=108305 (accessed September 5, 2014).