Indian Ocean warming and its effect on southwest Monsoon

Dissertation submitted in partial fulfillment of the requirements for the degree of

Master of Sciences
in
Environmental Sciences.

by Kapoor Ritika

under the guidance of

Dr. Roxy Mathew Koll
Scientist ‘C’,
Centre for Climate Change Research
Indian Institute of Tropical Meteorology

Fergusson College, University of Pune.
Pune, Maharashtra

May 2014

CERTIFICATE

This is to certify that the dissertation entitled ***'Indian Ocean warming and its effect on southwest monsoon'*** *which is being submitted herewith for the award of the degree, Master of Science (M.Sc.) in the Department of Environmental Sciences, Fergusson College, Pune is the result of original work carried out by* ***Ritika Kapoor*** *under our supervision and guidance. To the best of our knowledge and belief the work embodied in this thesis has not formed earlier basis for the award of any degree or similar title of this or any other University or examining body.*

Place: Pune

Research Guide: 1) Dr. Roxy Mathew Koll (External Guide)

Scientist C, Centre for Climate Change and Research

Indian Institute of Tropical Meteorology, Pune

2) Mr. Amir Mulla (Internal Guide)

Department of Environmental Sciences, Fergusson College

DECLARATION

*I hereby declare that the thesis entitled '**Indian Ocean warming and its effect on southwest monsoon'** is completed and written by me and has not previously formed the basis for the award of any Degree or Diploma or other similar title of this or any other University or examining body.*

Place: Pune

Date:

Research Student: Ritika Kapoor

ACKNOWLEDGEMENTS

My dissertation would have been impossible without my guide, Dr. Roxy Mathew Koll. I would like to thank him the most, for believing that I could work on a project. With all his patience, guidance, monitoring and positive outlook, he instilled the encouragement in me to carry on with this research. I am short of words to express my gratitude towards him. The things I learnt were of great help and shall be of use in future.

Secondly, I would like to thank Prof. B.N. Goswami, Director, Indian Institute of Tropical Meteorology for allowing me to carry on my project work and providing necessary facilities.

Also, I would also like to thank my friend, roommate and companion Deepali Rautela for always being there. Without her being around, things would have been gloomy.

I am grateful to my parents and my brother Rohan for always being so loving and letting me do what I really wanted to. They have been my strength all this while in Pune and kept me always going. All my friends in Pune and Delhi have been moral-boosters whenever I felt I was not feeling right. I'm really thankful to them.

Lastly, I would also like to thank all my department teachers, especially Mr. Amir Mulla for always helping me in taking right decision.

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Chapter 1
Introduction

1.1 Oceans and Changing Climate

More than 70% of earth is covered by water, and it would be totally justifying to call it an aqua planet. We know that when we protect our environment we are protecting our future also. Ocean is the cornerstone of earth's life support system and it shapes the weather and climate. It holds most of the life on earth. 97% of earth's water is in the oceans. It is what makes life possible for us. Together with the atmosphere, the oceans help in moderating and distributing the temperature from the equator to the poles.

Industrialization and fossil fuel emissions happen to be the main reasons attributed to the increase in greenhouse gases (mainly CO_2 emission), which in turn warms up the ocean and atmosphere, leading to a change in the climate. Oceans accommodate most of the CO_2, still there is huge impact of climate change on oceans. Global Warming has led to the following changes in the oceans:

- Rise in sea-level
- Coast-line changes and erosion
- Change in ocean currents
- Increase in sea surface temperatures
- Ocean Acidification

Figure 1 shows the sea surface temperatures (SST) over the tropical oceans. These SSTs are on a rise as result of global warming (shown in Fig.2). The anomalous rise in SSTs can change the way the oceans and atmosphere interact, affect the climate variability and day to day weather events. One of the consequences of increasing temperatures is the higher frequency in extreme weather events. Studies show that the frequency of the cyclones has increased considerably over the years due to rise in SST (Webster,et al,2005). Uneven heating of oceans also leads to the change in ocean currents.

Therefore, it is important to study the cause and effect of increasing SSTs, especially that over the- Indian Ocean as it is the warmest among the global oceans (See Fig.1). Indian Ocean SSTs also plays a role on the South-West monsoon variability, as the moist air from the ocean rushes towards the Indian subcontinent (Roxy and Tanimoto, 2007). Any warming or anomaly over the Indian Ocean might affect the precipitation pattern.

1.2 South West Monsoon

In summers, the land gets more heated up than the surrounding water. This leads to the formation of low pressure area over the land. The hot land draws moisture-laden winds from the surrounding sea. As the humid air reaches the land, it rises, the moisture condenses and the precipitation takes place. This is the basic driving mechanism of South-West Monsoon.

The South-West Monsoon is really important for the Indian peninsula. It occurs from June through September. The Himalayas act like a barrier, preventing the winds from moving into Asia and forcing them to rise. The Indian peninsula divides the SW monsoon in two branches: The Bay of Bengal branch and Arabian Sea branch. India being an agricultural nation is totally dependent on south-west monsoon. It accounts for overall 70-80% rainfall in India.

As shown in the figure 3,areas of Western Ghats and north-east receive the maximum rainfall (20-25 mm/day) and regions of Thar Desert in Rajasthan and that of northern Himalayas receive less rainfall (0-3 mm/day).(Figure 3 shows mean rainfall from 1901-2011)

1.3 South-West Monsoon and Climate Change

Climate Change is not only affecting the oceans of the world, but it is also causing change in pattern of south-west monsoon. The year-to-year variability in monsoon rainfall could cause severe droughts and floods.

The recent IPCC (2013) Fifth Assessment Report states that there is a declining trend with more frequent deficit monsoons. Decrease in precipitation over central India was observed along the monsoon trough. Increasing SST over the Indo-Pacific warm pool was cited as one of the major reasons (Annamalaiet al.2007). The frequency of heavy precipitation events is increasing (Rajeevan et al., 2008; Krishnamurthy et al., 2009; Sen Roy, 2009; Pattanaik and Rajeevan, 2010), while light rain events are decreasing (Goswami et al., 2006).

Since, the monsoon is quite important for agriculture and other activities in India, there is a need to study the variability of monsoon in changing climate. ENSO plays a significant role in the success or failure of Indian monsoon development.

1.4 El Niño Southern Oscillations (ENSO):

ENSO is the largest inter-annual climate variation. The source of the phenomenon involves an interaction between the tropical Pacific Ocean and the atmosphere above it. Its impacts are felt worldwide. The heart of the ENSO lies in the tropical Pacific Ocean along the equator. Changes SST, ocean subsurface temperature, rainfall and winds contribute to produce the ENSO cycle. The variations in the Pacific basin within about 10-15 degrees latitude of the equator are the primary variables driving ENSO and are most important factors in ENSO prediction. There are large positive anomalies of precipitation in the central and eastern pacific and negative anomalies in the western pacific.

El Niño is the positive phase of ENSO, with anomalously warm waters over the east Pacific, resulting in large weather changes over the globe. During an El Niño, the zonal circulation connecting the tropical Indo-Pacific oceans, known as the walker circulation reverses, since the trade winds weaken. As a result of it, there is less coastal upwelling and the thermocline declines. This in turn contributes to warming of eastern Pacific region.(Figure 5).**La-Nina** is a pattern of ENSO circulation and is considered opposite to El-Nino circulation. The sea surface temperature (SST) during a La Nina event drops by 3–5 °C in the Pacific Ocean. The increased upwelling in Eastern Pacific due to La-Nina reinforces the anomalously cold SST.

Since the late 1990s, the maximum SST warming during El Niño has been frequently observed in the central Pacific (Ashok et al., 2007; Kao and Yu, 2009; Kug et al., 2009), with global impacts that are distinct from 'standard' El Niño events where the maximum warming is over the eastern Pacific (Ashok et al., 2007; Kao and Yu, 2009). During the past century, an increasing trend in ENSO amplitude was also observed (Li et al., 2011c), possibly caused by a warming climate (Zhang et al., 2008) although other reconstructions in this data-sparse region dispute this trend (Giese and Ray, 2011)

1.5Effect of ENSO over Indian Monsoon

Events of El Niño and La-Nina occur every 3-7 years and its anomalies are mainly concentrated over the equatorial region. But, its effects are felt all over the world due to the reversing of circulations and changes in Sea Surface Temperature (SST).

There has been quite a lot of research on the effects of El Niñoover the Indian monsoon. A relationship has been identified between the evolution of the monsoon low and the phase of the El Niño Southern Oscillation (ENSO).Years with warm SST anomalies in the equatorial central and east Pacific Ocean (El Niño) lead to a weaker monsoon circulation and a delayed onset of monsoon. An opposite behavior is noted for those La-Nina years with cold Pacific SST anomalies (K.Kumar et al.,2006).

Meanwhile, other studies suggest that 'El Niño events with the warmest sea surface temperature (SST) anomalies in the central equatorial Pacific are more effective in focusing drought-producing subsidence over India than events with the warmest SSTs in the eastern equatorial Pacific.(K.Krishna et.al,2006).Due to the different conclusions and researches, there is an increasing need to study the effect of ENSO over Indian Monsoon. Climate Models can be utilized to see the uncertainties regarding the ENSO and precipitation.

1.6 Climate Models

Climate Models are quantitative methods which simulate interactions of the atmosphere, oceans, land and surface of ice. The main aim to use the climate modeling is to study the climate system dynamics and hence understand and simulate the past and future climate. Recently, most of the climate models have been used to forecast the increase in temperature, due to the increase in greenhouse gases.

A coupled model is the one in which the ocean and atmosphere interact (couple) with each other as in nature. Changes in the ocean part of the model can cause changes in the atmosphere part, and vice versa. Fluxes such as heat, temperature, cloud cover, humidity, sea surface temperature are exchanged between the ocean and atmosphere.

These climate models work on given set of equations representing the ocean and atmospheric physics that form the basis for the complex computer programs. They are used for simulating the atmosphere, ocean, land and sea-ice processes on the earth. Figure 4 shows the flowchart of climate model.

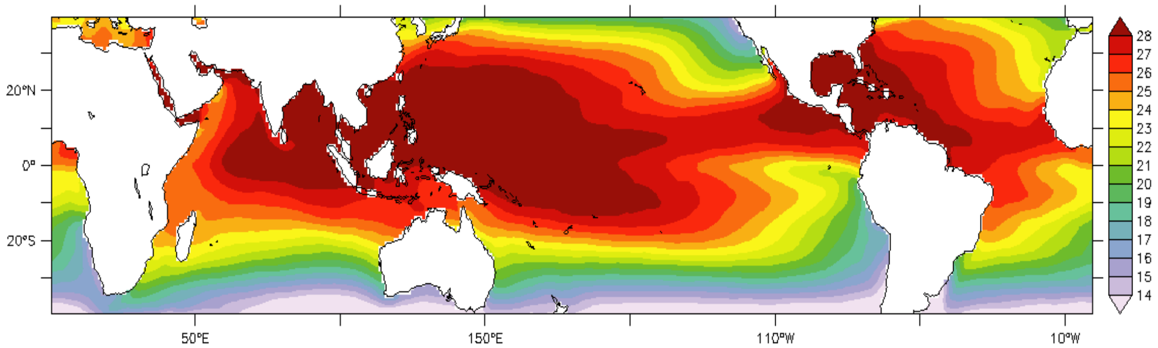

Figure 1: This figure shows the spatial distribution of SST over the tropical oceans. The warm pool region of Indo-Pacific oceans has SSTs above 28°C. Cool SSTs occur over the western Indian Ocean and off the coast of Peru.

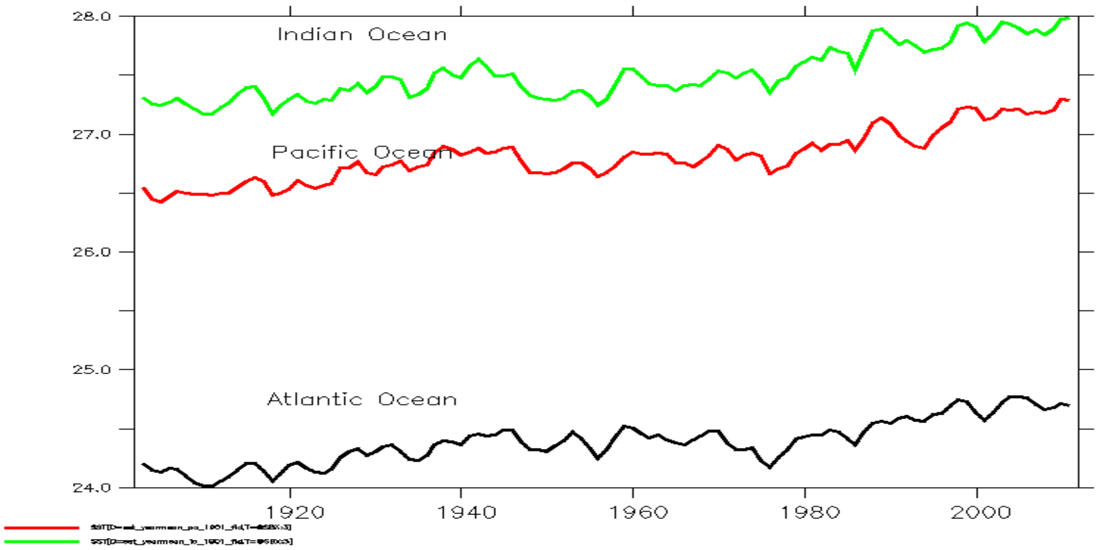

Figure 2: This figure shows the time series of SST over the major tropical oceans. Green, red and black lines are Indian, Pacific and Atlantic Ocean respectively. Indian Ocean being the warmest shows an increase of 0.7°C.

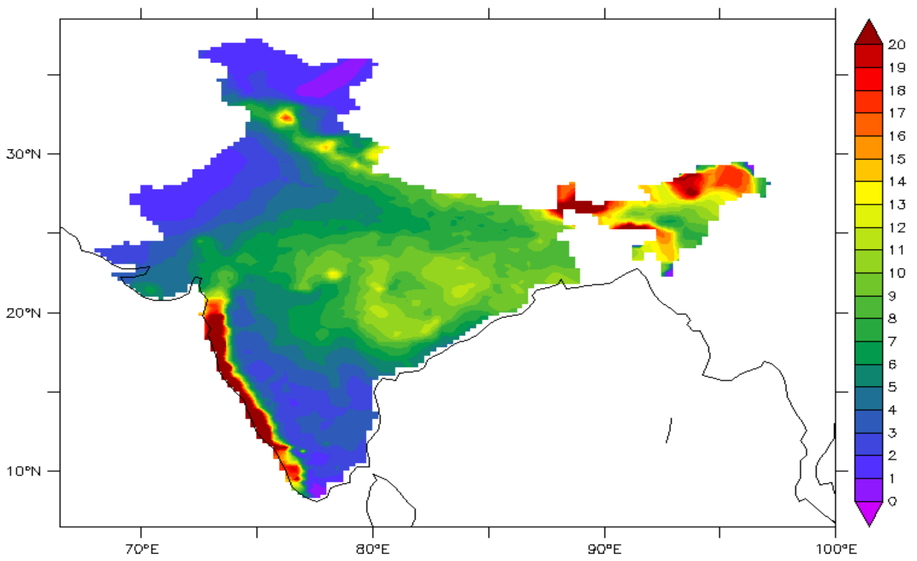

Figure 3: This shows the mean rainfall during JJAS (SW monsoon) during the past 111 years (1901-2011).

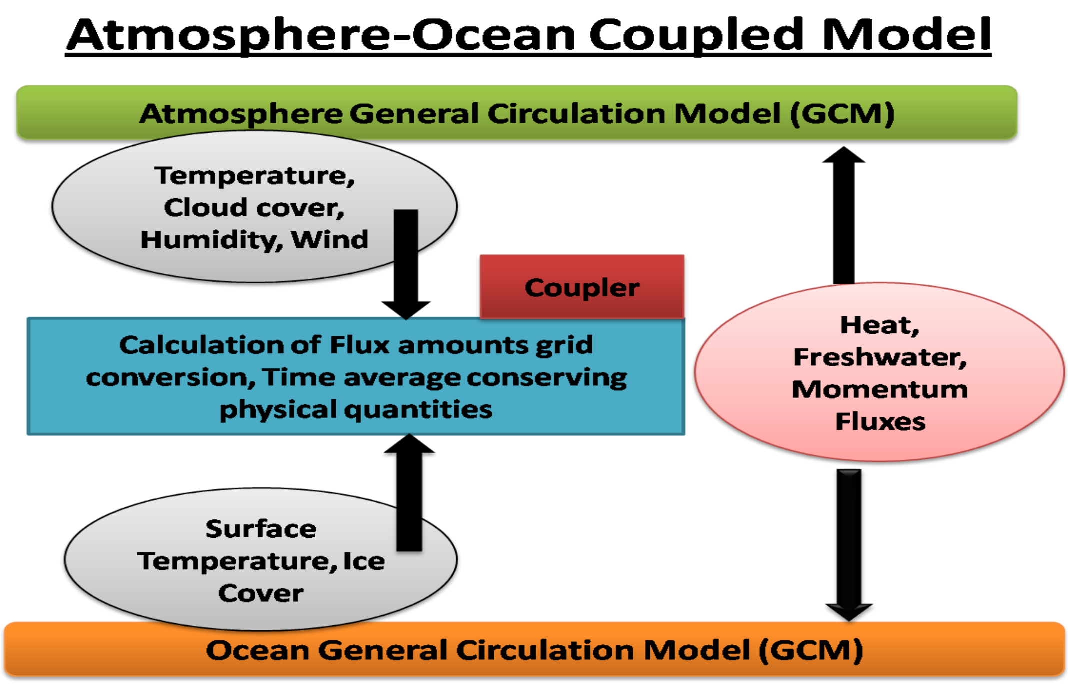

Figure 4: Schematic of an ocean-atmosphere coupled model

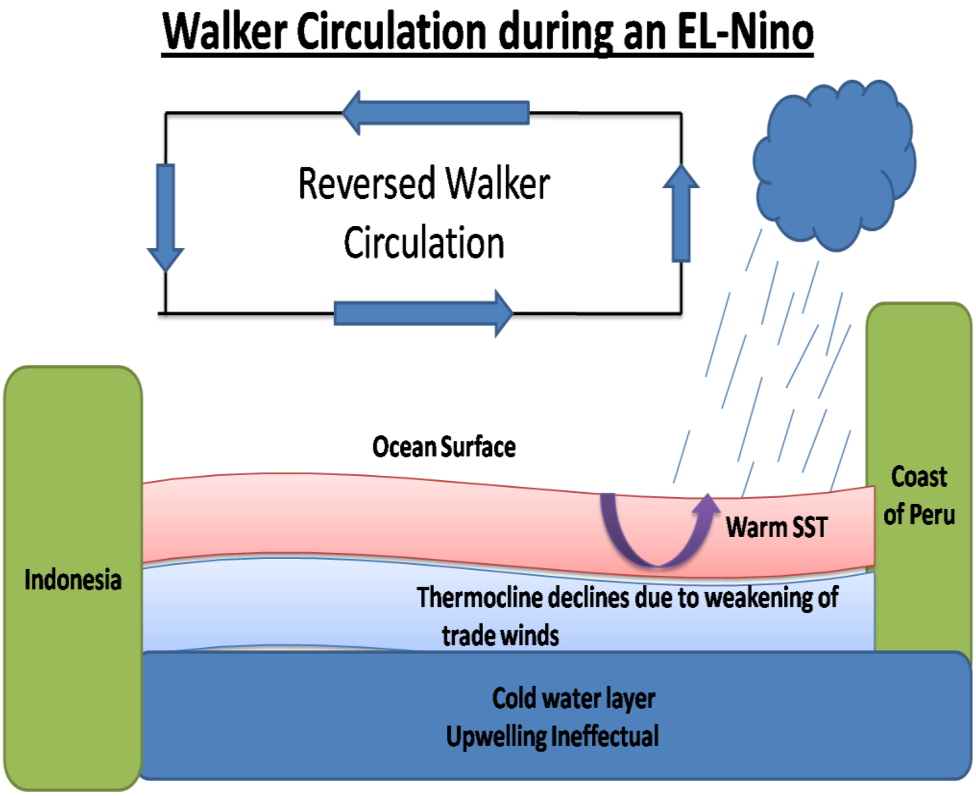

Figure 5: Schematic of the ocean-atmospheric conditions and the walker circulation during an El Niño, over the Pacific Ocean.

Chapter-2
Data, Model and Methods

As described earlier, the ocean-atmosphere interactions play a crucial role in modulating the south-west monsoon. Since India is an agricultural nation and a developing economy, the country depends significantly on the amount of precipitation. But, in the climate change scenario and due to frequent ENSO events, the precipitation differs every year. Rise in SST was studied in detail as it is one of the serious consequences of climate change.

In this study of Indian Ocean warming and change in patterns of South-West monsoon, the parameters like SST and precipitation (rainfall) are observed in detail. The SST from January 1901 to December 2011 (111 years) has been used for the analysis.

For the study of Indian Ocean, SST values from Hadley Centre Sea Surface Temperature (HadISST) were retrieved. Our domain of study is tropical Indian Ocean, extending from 40°E to 100°E latitude and 30°Sto 30°N longitude. For the winds, data from the National Centers for Environmental Prediction (NCEP) was used. For precipitation analysis data from the Climate Research Data (CRU) from January 1901 to December 2011 (111 years) were used. The correlation analysis and other procedures were carried out using the software Climate Data Operator (CDO)fromMax-Planck institute of Meteorology. The results were plotted using the softwareFerret, provided by NOAA. Since, the focus is on South-West monsoon, the months from June-September (JJAS) were considered for all the analysis.

For carrying out further analysis, a dynamic, coupled model, the Climate Forecast System version 2 (CFSv2) was used. It is an ocean-atmosphere coupled model (Fig. 3). CFSv2 was developed by NCEP. It was developed from four independently designed pieces of technology, namely the- NCEP- Department of Energy (DOE) Global Reanalysis 2 (R2; Kanamitsu et al.,2002) that provided atmospheric and land surface initial conditions, a global ocean data assimilation system (GODAS) operational at NCEP in 2003 (Behringer 2007) that provided the ocean initial states, NCEP's global forecast system (GFS) operational in 2003 that was the atmospheric model run at a lower resolution and the Modular Ocean Model, version 3 (MOM3) from Geophysical Fluid Dynamics Laboratory (GFDL). CFSv2 also has few novelties: an upgraded four-level soil model, an interactive three-layer sea ice model and historically prescribed (i.e.,rising) CO_2 concentrations. Overall, CFSv2 was designed to improve the consistency between model state and the initial states produced by the data assimilation systems.

In our model experiments, two model simulation runs were done, a Sensitivity Run and a Control Run. In the Control Run the mean conditions are kept similar, in accordance with the present weather conditions. Whereas, the conditions of sensitivity run are changed. In our model run, the sea surface temperature over western Indian Ocean was increased concentrically and its effect was studied over the Indian subcontinent.The climate model run was carried out on High Performance computer (HPC), Prithvi at Indian Institute of Tropical Meteorology(IITM), Pune (Fig. 6).

One of the most simple and frequently used methods for studying the relationship between two sets of variables is the correlation analysis. It measures the relationship between two data sets that are scaled to be independent of the unit of measurement. The correlation coefficient, r, is a way of determining how well two (or more) variables co-vary in time or space. In this study we first extracted the trend of SST over Indian Ocean and then correlated it with the ENSO events, to examine the relationship between them. Further, to investigate the role of Indian Ocean warming on the monsoon, the time series of the Indian

Ocean SST anomalies were correlated with the time series of precipitation over the Indian sub-continent.

Figure 6: HPC Prithvi

Chapter 3
Results and Discussions

3.1 Warming over Western Indian Ocean:

As shown in Figure 2, the Sea Surface Temperature (SST) of all the oceans has increased considerably with time. However, the warming trend over Indian Ocean surpasses that of other tropical oceans and has the potential to modify the south-west circulation and associated rainfall. There is an increase of about 0.8°C in SST of Indian Ocean from 1901 to 2011(111 years). Interestingly, we observed consistent warming over western Indian Ocean from 1901-2011(Figure 7).

Figure 6 shows the trend of Sea Surface Temperature over 111 years i.e. from 1901 to 2011 for the JJAS (June, July, August, September) months. The western Indian Ocean region (50°-65°E,10°N-5°S) shows an increase of 1.2°C over all these yen bars. The SST over western Indian Ocean increased from 26.5°C to 27.8°C. It can be observed in Figure 8 .

Generally, the western Indian Ocean is relatively cooler than the rest of the Indian Ocean. However, our analysis shows that the rest of the Indian ocean (70°-100°E, 20°N-20°S) experienced weaker trends in comparison to the western Indian Ocean. Rest of the Indian Ocean showed warming of about 0.7°C over 110 years, which is 0.5°C less than our region of interest. Figure 8 explains it. This is significant with respect to Indian Ocean SSTs and in turn the monsoon dynamics.

An SST increase from 26.5°C to 28.0°C can drastically change the convective response, from shallow to deep convection over the western Indian Ocean (Gadgil et al.,1984, Roxy,2013) It can also lead to weakening of winds and in turn change the dynamics of monsoon. (Izumo, T.et.al, 2008)

In figure 8, initially it can be seen that warming over western Indian Ocean is lesser in comparison to rest of Indian Ocean. But, after 1950 it starts on increasing and by the year 2011, it warms up to an SST of same value as rest of the Indian Ocean.

3.2 Correlation of ENSO Events and Warming Over Western Indian Ocean

El Niño Southern Oscillations are one of the most important sources of climate variability on year-to year timescales. The warm waters in the pacific are the major driving forces of climate variability in the tropics (Wang, B. et al., 2013, Krishna Kumar K et al.,1999). There have been some studies that have suggested a connection between warming up of waters in Pacific and Indian Ocean (Cadet,D.L.,1985, Tourre et al.,1995, Nicholson, S.E.,1997, Yu, L.&Rienecker, M.M.,1997, Murtugudde,R.,2000, Xie S.-P et al, 2002, Tokinaga, H. &Tanimoto, Y.,2004) during individual years, but no relationship has so far been explored in relation to the long term warming trends over the Indian Ocean.

Since the persistent warming over western Indian Ocean has been unexplored and never brought to light, its association with ENSO is analyzed.

In figure 9, we can see the correlation between the SST in pacific and WIO. Significant positive correlation is observed over the western Indian Ocean, around the same region with the maximum warming trend. However, the SSTs over the rest of the Indian Ocean (region other than WIO) does not show any significant correlation. This means that ENSO, manifested in the highs (El Niño) and lows (La Niña) of the east Pacific SST anomalies, dominates the western tropical Indian Ocean variability.

It is also striking to note that the events of El Niño have increased after the year 1950, (1951-2000, 12 events), in comparison with the former half (1901-1950, 7 events).

During years 1950-2000 not only the El Niñoevents increased, but the warming over WIO also increased. However, it was observed that La-Nina events had no effect on the WIO. La-Nina events lower the SST of east pacific. There was no correlation between the cooling of warmed up region of WIO during its occurrence. (Figure 10)

A few studies have indicated that global warming has resulted in a higher frequency of El Niño events in the recent decades (Cai, W. et al.,2014) . El Niñoevents are warming up the WIO. Hence, higher the frequency of the El Niños, the warmer the Indian Ocean will be.

A correlation analysis between eastern pacific water and WIO is explored for further evidence on the El Niño– Indian Ocean connection mentioned above. We took the region of eastern pacific (240°E-280°E,5°N-5°S) and the region of WIO (50°E-65°E,10°N-5°S). A correlation of 0.6 can be seen.(Figure 11). Therefore, we can say that there is a positive correlation between the warming over eastern Pacific and WIO. It is also found that El Niño events have a stronger impact on the warming, than the La Niña events in cooling the Indian Ocean. (Figure 10 and 11).

For examining the physical mechanism interlinking the east Pacific and the westerntropical Indian Ocean, the atmospheric circulation features over the tropics during El Niño andLa Niña years were compared against the climatological walker circulation. (Figure 12 a). During the climatological conditions, there is cool SST over east Pacific and warm SST over west Pacific. This results in ascending air over west Pacific and a descending cell over WIO. The walker circulation thus plays along the monsoon westerlies over the lower atmospheric column in the Indian Ocean.

The El Niñocomposites however show an anomalous shift in the circulation over the tropics, with the ascending cell over the east Pacific and subsidence over maritime continent, resulting in low level easterly anomalies over WIO. This weakens the monsoon westerlies. (Figure 12 b) El Niñoevents therefore contribute to the warming over WIO. In the La-Nina composites the ascending cell is located over the maritime continent and subsidence over west Pacific. However, this does not show any significant change in low level winds over Indian Ocean. (Fig 12 c) This might be a reason why the warming events over the western Indian Ocean are notdotted with any significant cooling events. In figure 13, correlation of warming over WIO can be seen with ENSO events.

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3.3 Climate model analysis: Influence of the long-term Indian Ocean warming on the Indian monsoon

The WIO warming has the potential to alter the monsoon dynamics and affect the rainfall characteristics and distribution. We carried out numerical model experiments to analyze the effect of it over Indian region and SW monsoon. An ocean-atmosphere coupled model- the CFSv2 detailed in chapter 2 was utilized for this. The sea surface temperature over WIO was increased concentrically in the model (called the sensitivity run), and compared to a reference (called the control run) without the SST increase. In the sensitivity run, the SST was increased by 2°C over the WIO (with the anomalies gradually tapering off on the periphery) (Figure 14a). For the control run the conditions were kept, without any changes, and according to model climatological conditions. The results obtained from the difference of control and sensitivity runs indicate the role of WIO warming on the climate.

The artificially induced increase of SST (with respect to observed trends) can be seen in Figure 14b. The consequent effect on Indian subcontinent and SW monsoon can be seen in Figure 15b. The decrease in precipitation is considerable over Central Indian region along with an associated weakening of South-Westerly winds due to increase in SST over WIO.

From the model analysis, we find that there is decrease in rainfall over central Indian region with respect to Indian Ocean warming. The wind vectors show the flow of easterly anomalies towards the Indian Ocean during the JJAS months. The mean winds are South-Westerly. Thus, these easterly anomalies will weaken the south-west monsoon and hence result in decreased precipitation.

3.4 Observational evidence of the influence of Indian Ocean warming on the Indian monsoon

In order to validate the results for the model analysis on considerable decrease in precipitation over central India, we analyzed the observed precipitation data of CRU. The annual summer (June-September) mean of 111 years of precipitation was done and was correlated with the WIO region (50-65°E,10°N-5°S). The decrease in precipitation was also observed in the trend analysis for 111 years. Based on the analysis of observed trends in SST and rainfall, we can say that, there is weakening of monsoon over India due to WIO warming, especially over the central Indian region. This validates the results and conclusions based on the climate model analysis.

A correlation analysis of the WIO SST anomalies with the precipitation anomalies showed that the precipitation trends are related to warming of WIO. It also showed decrease in precipitation over central Indian region.

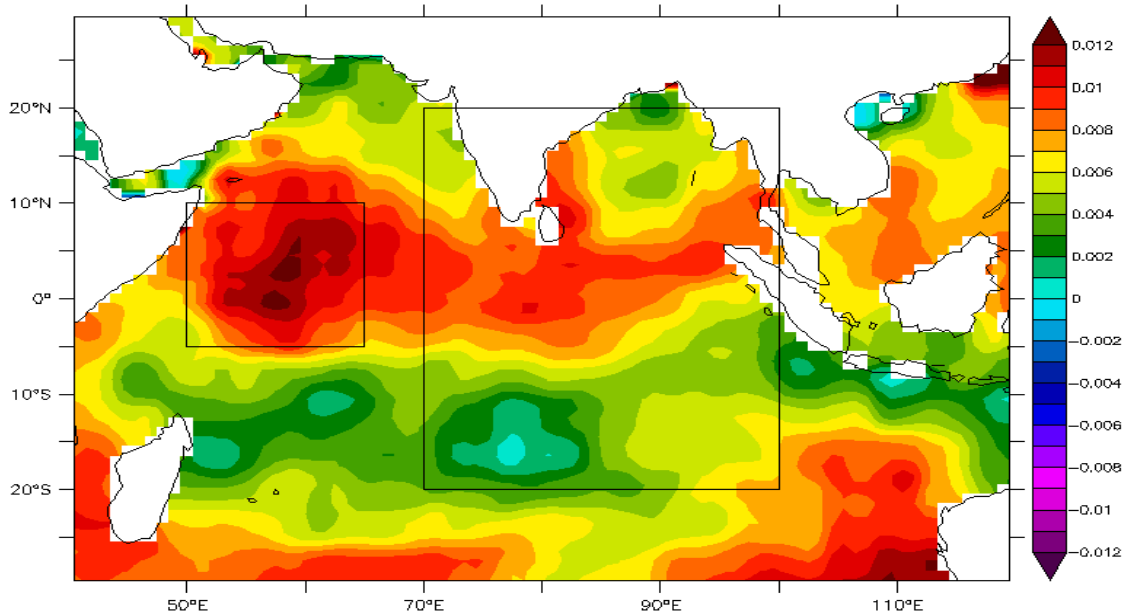


Figure 7: This trend shows warming over WIO. Two boxes are considered- WIO and RIO.

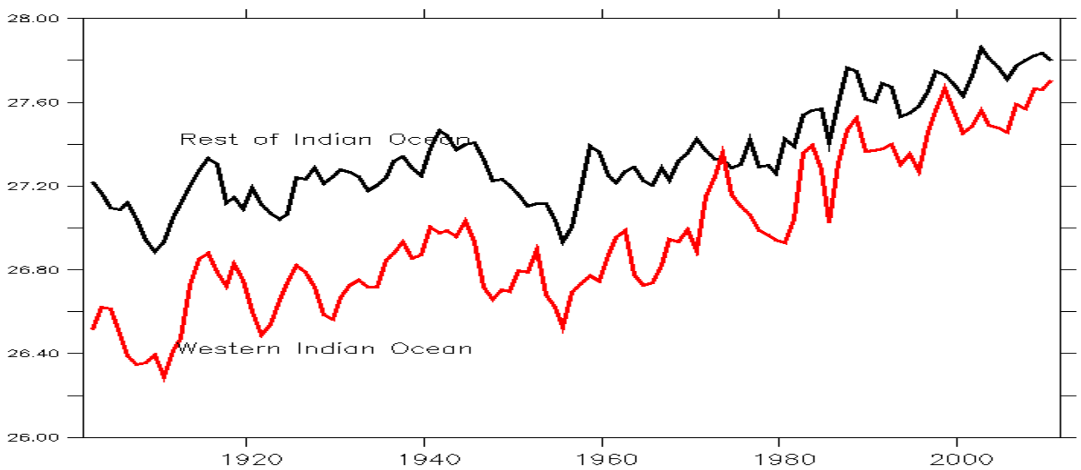


Figure 8: This is a plot in which SST of WIO and RIO is compared. The SST of WIO reaches RIO in some years.

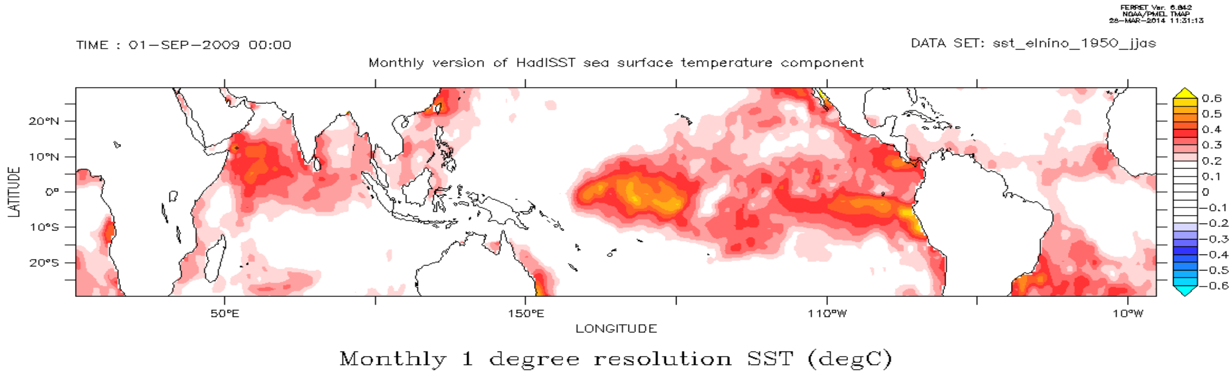


Figure 9: Warm water over eastern Pacific(El-Nino), show a correlation with WIO. Warming over WIO can be seen**.**

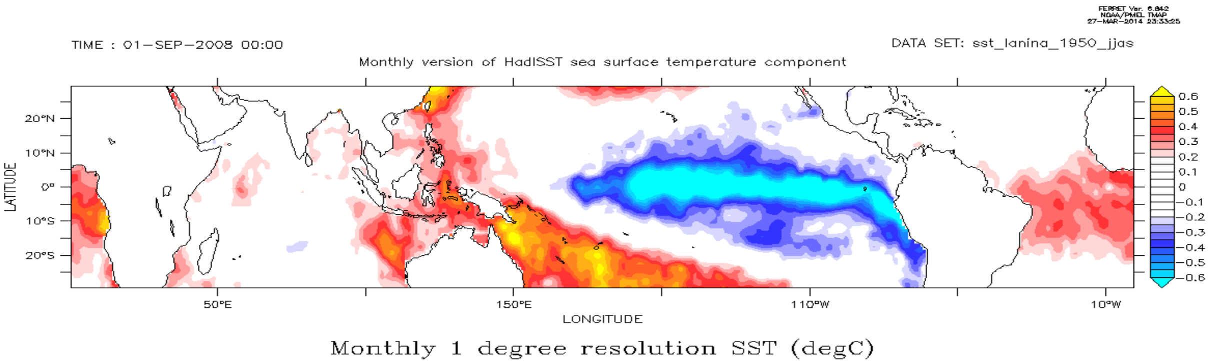


Figure 10: Cool water over eastern Pacific(LaNina),shows no correlation with WIO. No warming or cooling can be seen

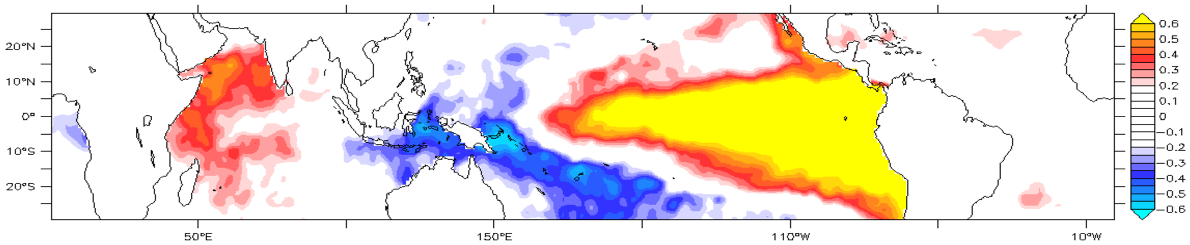


Figure 11: Correlation between the El-Nino and warming over WIO

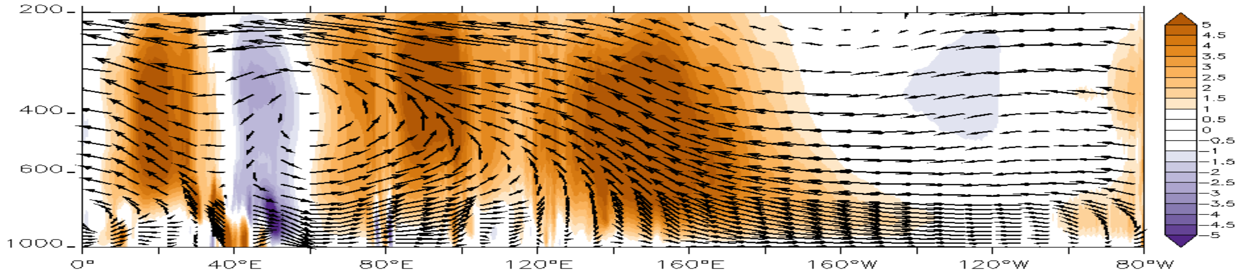


Figure 12 a: Mean climatological Walker Circulation

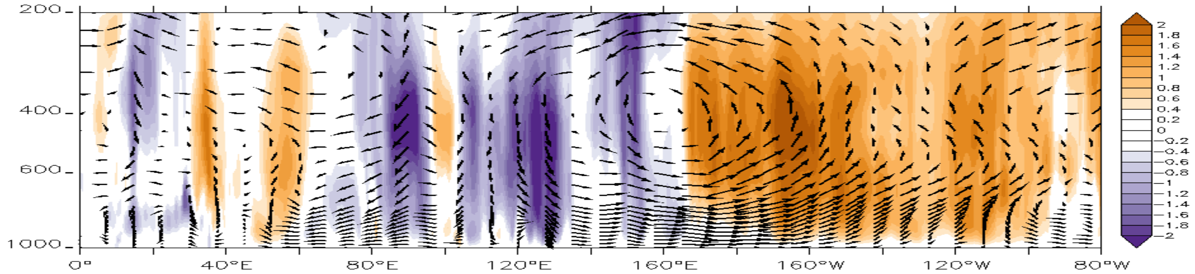


Figure 12 b: El-Nino composite of Walker Circulation

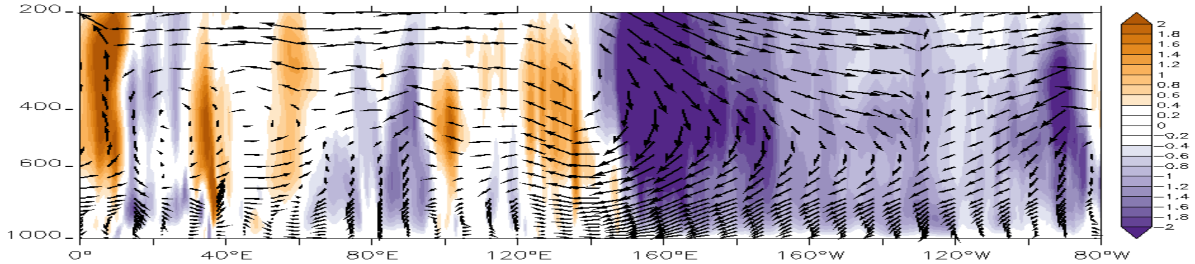


Figure 12 c: La-Nina composite of Walker Circulation

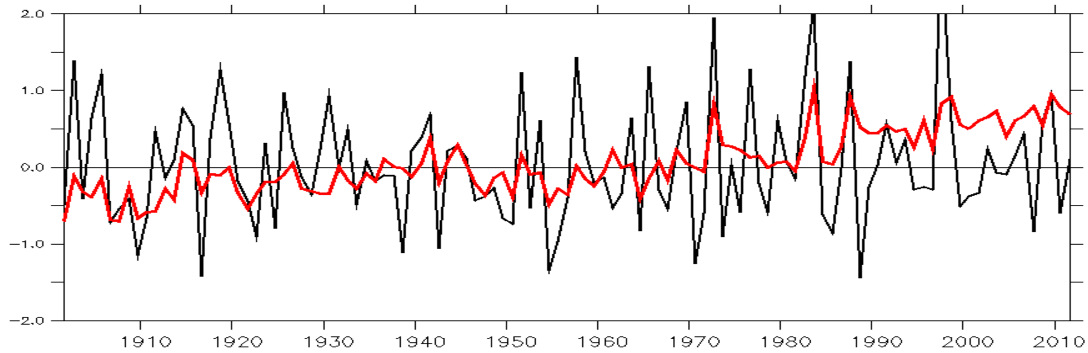
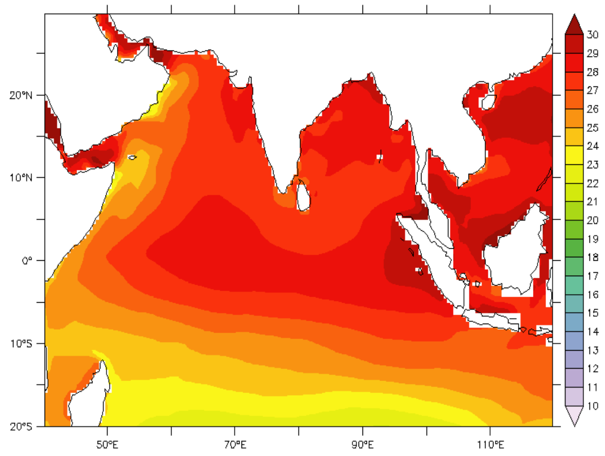


Figure 13: This shows the correlation between the ENSO events and warming over WIO. There is increase in SST during El-Nino but there is no increase/decrease during the La-Nina event.



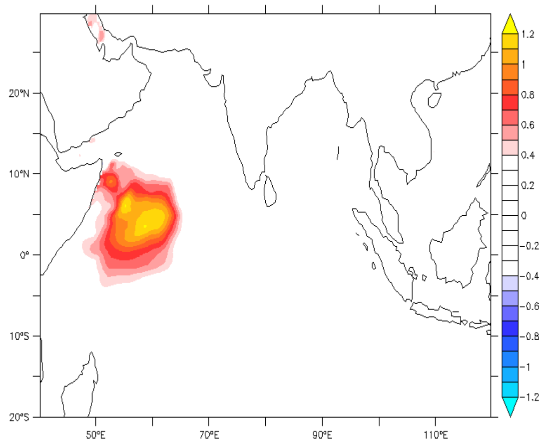


Figure 14a: The spatial plot on left shows the SST of Indian Ocean during the normal conditions.

Figure 14b: The spatial plot on right shows SST is increased over WIO by modeling.

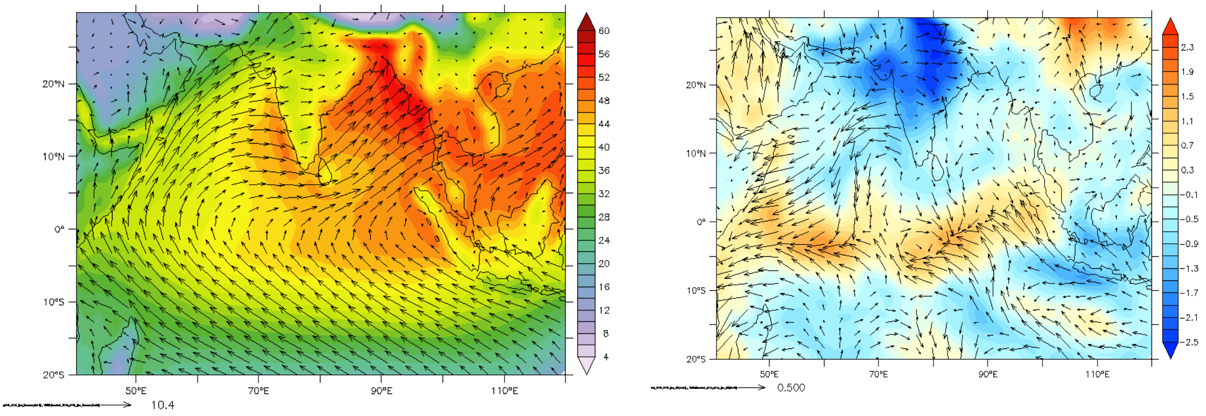


Figure15a: This plot shows the flow of south-westerly during JJAS.
Figure 15b: This is the model analysis, which shows flow of easterly. The flow of easterlies has weakened the SW monsoon in Central India

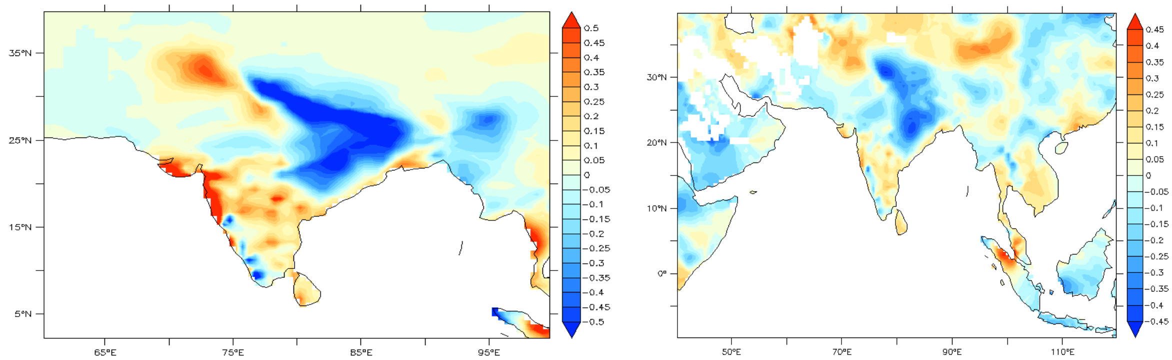


Figure 16a: CRU trend of precipitation from January 1901 to December 2011 also shows decrease in rainfall over Central India.
Figure 16b: Correlation of CRU and WIO. Decreased precipitation over central India can be seen.

Chapter 4
Summary and Conclusions

We have studied the cause of the warming over the Indian Ocean and its effect on the rainfall variability over the Indian subcontinent. The results can be summarized as follows-

1) Climate Change as a result of anthropogenic activities have contributed to an increase in the frequency of El Niño events. The frequency of occurrence of El Niñoshave increased from 7 during 1900-1950 to 12 during 1950-2000.

2) The increase in the number of El Niñoevents is found to have a long-term warming trend over Western Indian Ocean(WIO, 50°-65°E,10°N-5°S). The SST over WIO has increased by 1.2°C in last 110 years, with a significant correlation of 0.6 to the east Pacific SST anomalies (ENSO events).

3) Though El Niñoevents induce significant warming over the WIO, La Nina events do not lead to any significant cooling over the region.

4) A model analysis was done, which shows considerable decrease in precipitation over central India when the SST over WIO is increased over time. The WIO SST anomalies induced easterly anomalies over the Indian Ocean, which in turn would weaken the climatological mean south-westerlies.

5) Our model results indicate that, as the WIO has experienced warming over a long period (more than a century), it has weakened the south-westerly winds, which drive the monsoon. This weakening of winds has led to decreased precipitation over Indian subcontinent. The most significant decrease was observed over Central India. We validated our model analysis with observed SST and rainfall data (the trend in past). The rainfall has been decreasing over central India with respect to WIO warming.

6) Analysis of the model simulations and the observed data indicates that, if the warming keeps on increasing over WIO, the central Indian rainfall might decrease further in magnitude.

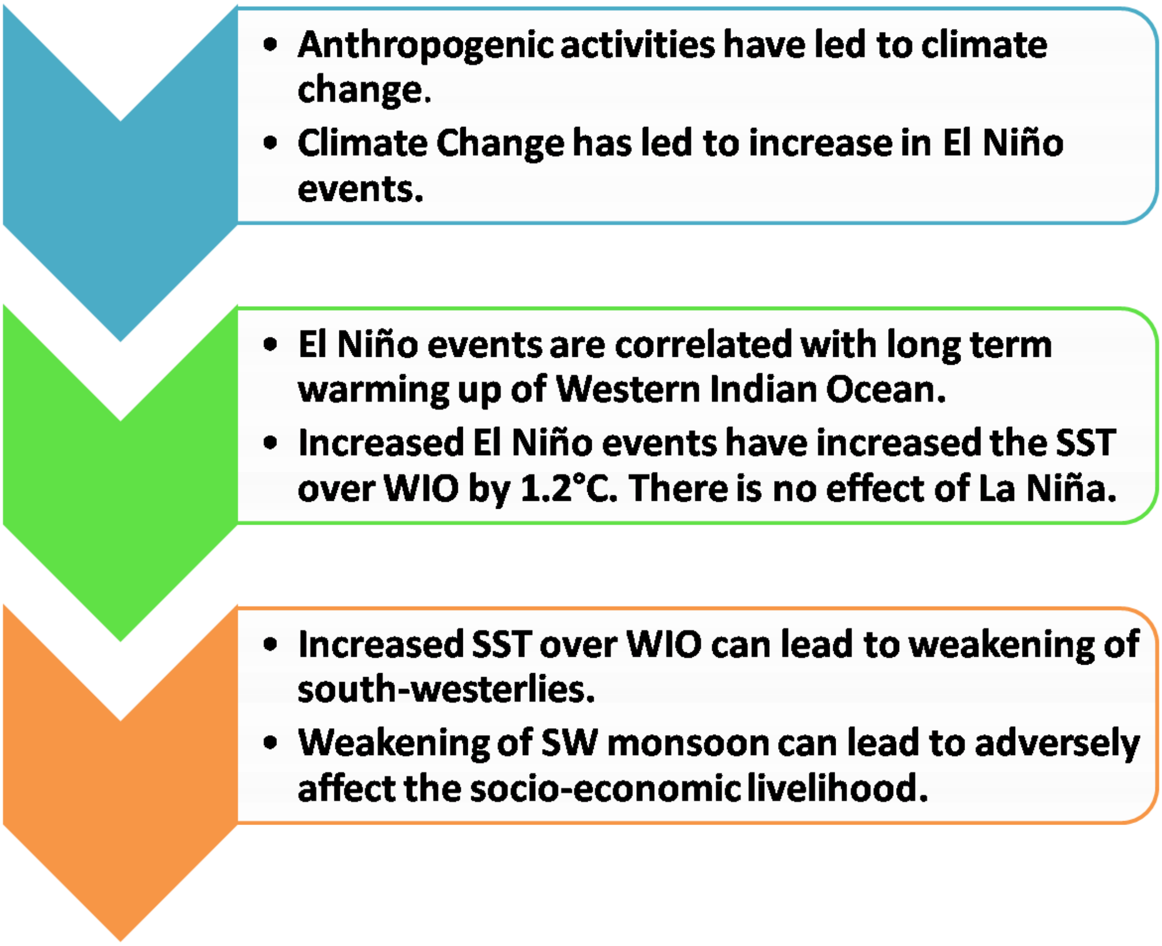


Figure 17: Summary flowchart

Suggestions: Since India is a nation dependent on agriculture, decrease in rainfall would adversely affect the livelihoods. Most of India's population lives in rural area and are farmers by profession. Most of the crops are dependent on monsoon as the water resources are limited and being a developing nation, the irrigation facilities are not yet optimized or available. If the precipitation keeps on decreasing, then it will be major setback to the farmers as well as the economy of the country. Accurate El Niño predictions along with a watch-out of the Indian Ocean SST trends should be made so that long-term plans for water resources can be made on time. As far as climate change and its consequences are concerned, cleaner sources of energy, green technology and less use of fossil fuels are suggested.

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