# Column Projected response of the Indian Ocean Dipole to greenhouse warming

In recent years, enormous socioeconomic damage has been wreaked by recurrent abnormal weather events around the world. The seedbed for this abnormal weather is climate variability events on a massive spatiotemporal scale – those that cover thousands of kilometers and continue over months and years. Here we will review an article featured on the cover of the November 28, 2013 issue of Nature Geoscience on research predicting how a climate variability event in the tropical Indian Ocean, known as the Indian Ocean Dipole (IOD), will change with global warming in the future.

Title: Projected response of the Indian Ocean Dipole to greenhouse warming
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## What is the Indian Ocean Dipole event?

The Indian Ocean Dipole[*1], occurring once every few years in the tropical Indian Ocean, is a climate variability event that causes abnormal weather around the world. It was discovered in 1999 by then-Program Director, Dr. Toshio Yamagata, and a research group led at the time by Dr. Hameed Saji (Saji et al. 1999, Nature) as part of the Climate Variations Research Program of the Frontier Research Center for Global Change (FRCGC). The name comes from an east-west dipole pattern in the Indian Ocean of sea surface temperature, outgoing longwave radiation (i.e., the amount of infrared energy from ground surface and clouds, which is closely related to the amount of precipitation), and sea surface height anomalies (i.e., deviations from the mean field). A positive event is characterized by an anomalous cooling of sea surface temperature in the southeastern equatorial Indian Ocean, and an anomalous warming in the western equatorial Indian Ocean. (Figure 1, left. The event with reverse conditions defined as a negative event: Figure 1, right)

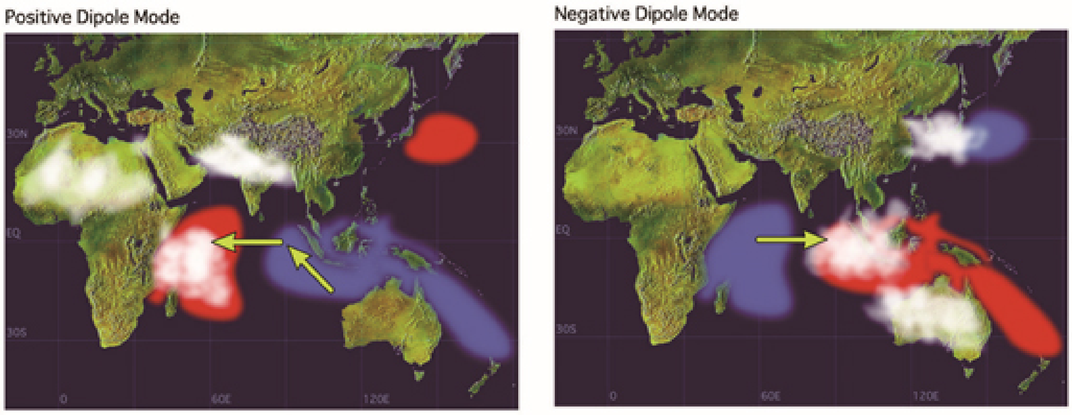


Figure 1: The red area shows anomalous warming of sea surface temperature while the blue area shows anomalous cooling. The white shaded area shows the strengthening of convection activity when the Indian Ocean Dipole mode occurs, with the arrows showing anomalous wind directions. The left side of the figure depicts the occurrence of a positive dipole event while the right side shows a negative dipole event.

*1: For a detailed explanation of the Indian Ocean Dipole event, please refer to the following URL: http://www.jamstec.go.jp/frcgc/research/d1/iod/e/iod/about_iod.html

## The Indian Ocean Dipole event causes abnormal weather around the globe!

The Indian Ocean Dipole (IOD) event is a cause of abnormal weather around the world, with enormous socioeconomic impacts[*2]. When a positive event occurs, typically, active convection in the eastern Indian Ocean will shift westward, which causes heavy rainfall in Eastern Africa, and severe drought and forest fires in Indonesia (Figure 1, left). A positive IOD event is believed to have caused the damage of the 1994 intense heat wave in Japan, and the 2006 extreme flooding in Kenya, drought in eastern Australia, and wildfires in Borneo. Also, a positive event is accompanied by increased precipitation in eastern Africa, and an outbreak of malaria-carrying mosquitos, which is thought to have caused the large-scale resurgence of malaria in eastern Africa in the 1990s (Hashizume et al., 2012, Sci. Rep.). Moreover, in 2006, 2007, and 2008, three years of consecutive positive events brought about uncharacteristic drought in southeastern Australia, and the worst wildfires in Australian history in 2009, which led to numerous deaths. This calamity is now called Black Saturday[*3]. Elsewhere, a connection to the occurrence of typhoons has been suggested. For example, one of the causes of the violent typhoon that assailed the Philippines in 2013, Haiyan (the thirtieth named storm of that season), might be an occurrence of active convection together with high ocean temperatures in the western equatorial Pacific Ocean, including the sea to the east of the Philippines (see the column “Typhoon Haiyan”). In 2013 from summer to fall in the northern hemisphere, there was a weak La Niña event in the Pacific Ocean, and in the Indian Ocean there was a weak negative IOD event; the combined effect of the two could have been an above-average intensification of the convection activity of the Philippine and Indonesian maritime continent.

*2: Japan Agency for Marine-Earth Science and Technology developed the SINTEX-F1 seasonal forecast system, which predicts the occurrence of Indian Ocean Dipole events, and provides this information publicly since 2006.
http://www.jamstec.go.jp/frcgc/research/d1/iod/e/seasonal/outlook.html

*3: Dry grasslands and drought caused wildfires to break out on February 7, 2009 in the forests and grasslands of the state of Victoria, causing 173 deaths and the destruction of numerous homes by fire, with over 2,000 victims.

## What changes will global warming bring to mean fields in the Indian Ocean?

With global warming, during northern hemisphere fall (the season when the IOD event reaches its peak), there is a greater possibility that the sea surface temperature of the western Indian Ocean will rise above that of the eastern part. Analyses of observed data since the 1900s and the results of global warming simulations using leading climate models have made it possible to verify a rising trend in the Indian Ocean Dipole Mode Index (DMI)[*4]. That is to say, mean fields in the Indian Ocean in September-November will more closely resemble the conditions in which a positive IOD event is always occurring. In recent years, the impression that positive dipole events are occurring frequently could be due to a change in the mean fields themselves due to global warming.

*4: An index (°C) showing the intensity of the Indian Ocean Dipole event. It is defined as the difference between the sea surface temperature anomaly in the western Indian Ocean tropics (50E–70E, 10S–10N) and the eastern Indian Ocean tropics (90E–110E, 10S–0N). Anomaly means deviation from the annual average. Related data can be downloaded from the following URL: http://www.jamstec.go.jp/frcgc/research/d1/iod/HTML/Dipole%20Mode%20Index.html

## With global warming, how will the Indian Ocean Dipole event itself change?

With global warming, mean fields in the Indian Ocean will more closely resemble the conditions in which a positive dipole event is always occurring. Then, if the IOD is defined as a deviation from the mean field, how will the IOD event itself change? Upon analysis of global warming projection experiments using several leading climate models, the following trends can be affirmed in most of the models.

1. When the IOD is viewed as a deviation from the mean fields, there is no significant change in frequency or amplitude of the IOD events.
2. The asymmetry that a positive IOD event is apt to be stronger relative to a negative event, is reduced.

In a more detailed analysis, significant changes were also observed in a few of the physical processes important for the IOD event. As the mean thermocline depth becomes shallow in the tropical Indian Ocean, there is a trend toward more active heat transport between the sea surface temperature and the thermocline (increase in SST-thermocline feedback). Also, because global warming is accompanied by an increase in atmospheric stability, the relationship between the zonal sea surface temperature gradients and zonal winds tends to be weakened (decrease in zonal wind and zonal SST gradient feedback).

It is necessary to be careful to interpret the results because they are on a basis of numerical experiments with climate models and their linear decompositions to the mean field changes and the IOD changes. The results can also be interpreted to mean a readily occurring positive dipole mode on a perennial basis. In the field of paleoclimatology, it has been suggested that a perennial occurrence of El Niño was possible millions of years ago in a warmer climate. The IOD event develops or decays through the combined influences of some air-sea feedback processes and strong remote influences by the Pacific Ocean, which make the IOD an extremely complex climate variability event. Even with state-of-the-art modeling, there is uncertainty in the relative strength of each physical process and the reproducibility of the mutual balance among them. In the future, we must clarify long-term variations of the Indian Ocean Dipole event based on understanding the mechanism, improving climate models and reducing the uncertainty of future predictions.

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