The Wind Drought During the India Summer Monsoon of 2020

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Document history

Issue	Date	Summary
A	November 12, 2020	Initial draft

Introduction

This year's summer monsoon[1] season in India generated a lot of discussions,[2] and the low wind power generation is a major concern to wind power plant owners/operators, as well as the electrical utilities and the investment community.

Total wind power generation in India for the month of July 2020 was extremely low, about 40% lower than in July 2018 or July 2019. This sharp reduction in energy production happened despite an increase in the installed wind plant capacity in India of approximately 4,900 MW (3,650 MW) compared to July 2018/2019 according to Central Electric Authority data[3]. India's wind power production has always been significantly and positively impacted by the summer monsoon, which is basically a large-scale sea breeze that brings strong winds and heavy precipitation. Figure 1.1 provides an indication that the months of May to September make up about two-thirds of the total annual energy production in India, except in 2020.

In fact, peak wind energy production is typically reached in the month of July. Therefore, people are rightly concerned when both June and July 2020 contribute to the lowest average wind speed and total wind power generation on record over the last 25 years or more (see Figure 2.3 and Figure 3.2). The weaker-than-usual monsoon circulation in 2020 can at least partly be explained by a combination of a warmer-than-normal Indian Ocean and a cooler-than-normal India subcontinent (see Appendix A).

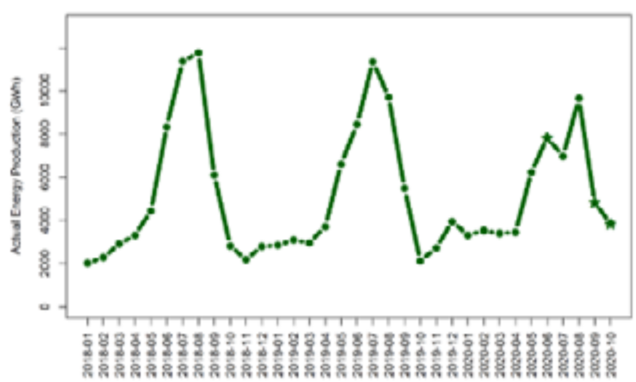


Figure 1.1: Brief history of commercial wind flow models

Despite the disappointing wind energy production in June and July of this year, the total wind energy production in India is down by approximately 4% and 6% so far compared to the same period in 2018 and 2019, respectively[4]. This is partly due to the above-average production in March, April and August 2020 as well as an increase in wind power capacity of approximately 5,275 MW between Jan. 1, 2018, and Sept. 30, 2020.

Wind speed

The wind power generation in India is mainly concentrated in seven states: Tamil Nadu, Gujarat, Maharashtra, Karnataka, Rajasthan, Andhra Pradesh and Madhya Pradesh. In order to look at the wind resource in India by region, we've been relying on the freely available ERA5[5] reanalysis (Hersbach et al., 2019), which is the latest reanalysis dataset produced by the European Center for Medium-Range Forecast (ECMWF). ERA5 provides hourly data going back to 1979 for many atmospheric, land-surface and sea-state parameters. ECMWF is producing ERA5 reanalysis data using their Integrated Forecast System (IFS) on a regular latitude-longitude grid of 0.25 degrees by 0.25 degrees resolution (~30 kilometers). The atmospheric model within the IFS is coupled to a soil model and an ocean wave model. Figure 2.1 shows the long-term average wind speeds in India as well as the location of all the wind plants (as of December 2019). We're using the last 25 years (1995-2019) as our reference climate conditions.

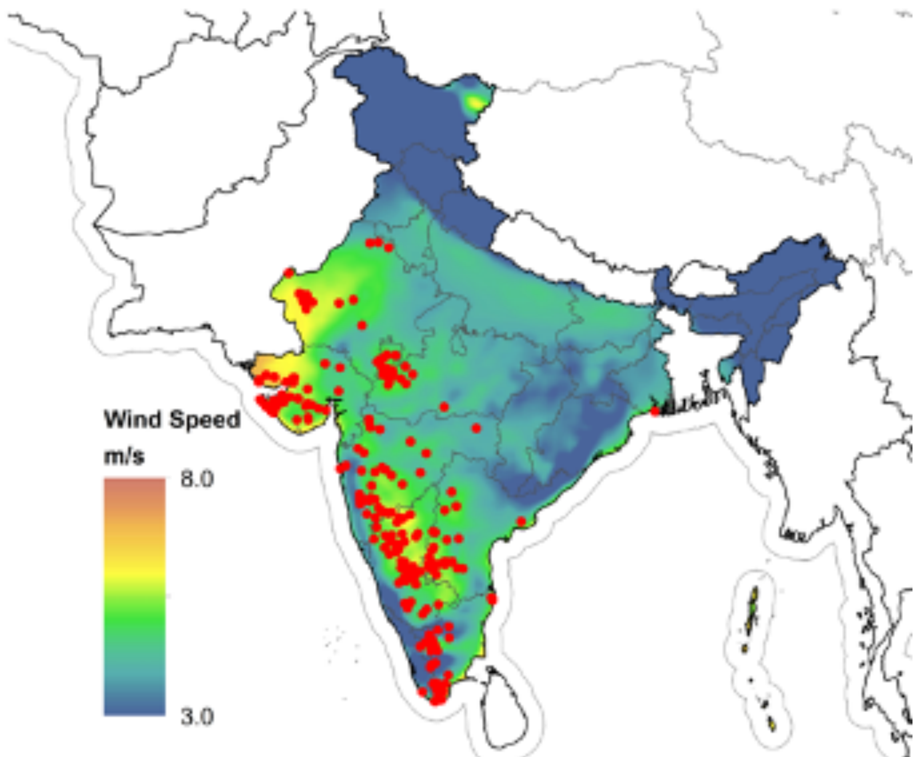


Figure 2.1: Long-term averaged wind map at 100-meter height using the ERA5 reanalysis data. The red dots correspond to the centroid of all the wind plants in India as of December 2019.

Monthly wind speed deviations

The wind speed anomaly maps at a 100-meter height clearly show the extent to which the wind resource in India has been hit hard during this summer monsoon season (see Figure 2.2). The wind speed anomaly maps indicate the relative difference in percentage between the wind speed for a specific month, e.g., July 2020, compared to the long-term average wind speed for that same calendar month, e.g., the long-term average July value. The wind speed drought during the 2020 summer monsoon season didn't hit every region in India with the same intensity. However, most of the provinces experienced a substantial decrease in winds, according to the ERA5 reanalysis dataset. The only exceptions to this wind drought are the northern provinces, e.g., Ladakh, and northeastern provinces, e.g., Assam, but those regions have no or little wind power capacity. Unfortunately, the primary states in India for wind power generation are among the ones that were heavily impacted by the low wind resource between May to July 2020. As Figure 2.2 shows, the wind speeds bounced back in August 2020 in many Indian states.

An easier way to demonstrate that the wind speeds for the month of June and July 2020 are outliers is to use a boxplot per month, as shown in Figure 2.3. According to the ERA5 reanalysis data, the wind speeds in June and July 2020 were approximately 14% and 23% below average. As shown in Figure 2.3, June and July 2020 are below the whiskers, which corresponds to a probability of less than 0.8% (p=0.992 or 2.698 σ). In other words, the wind drought in either June or July 2020 is a 1-in-129 year event at best (1/(1-p) ≅ 129). Therefore, June and July 2020 should be called extreme events/months.

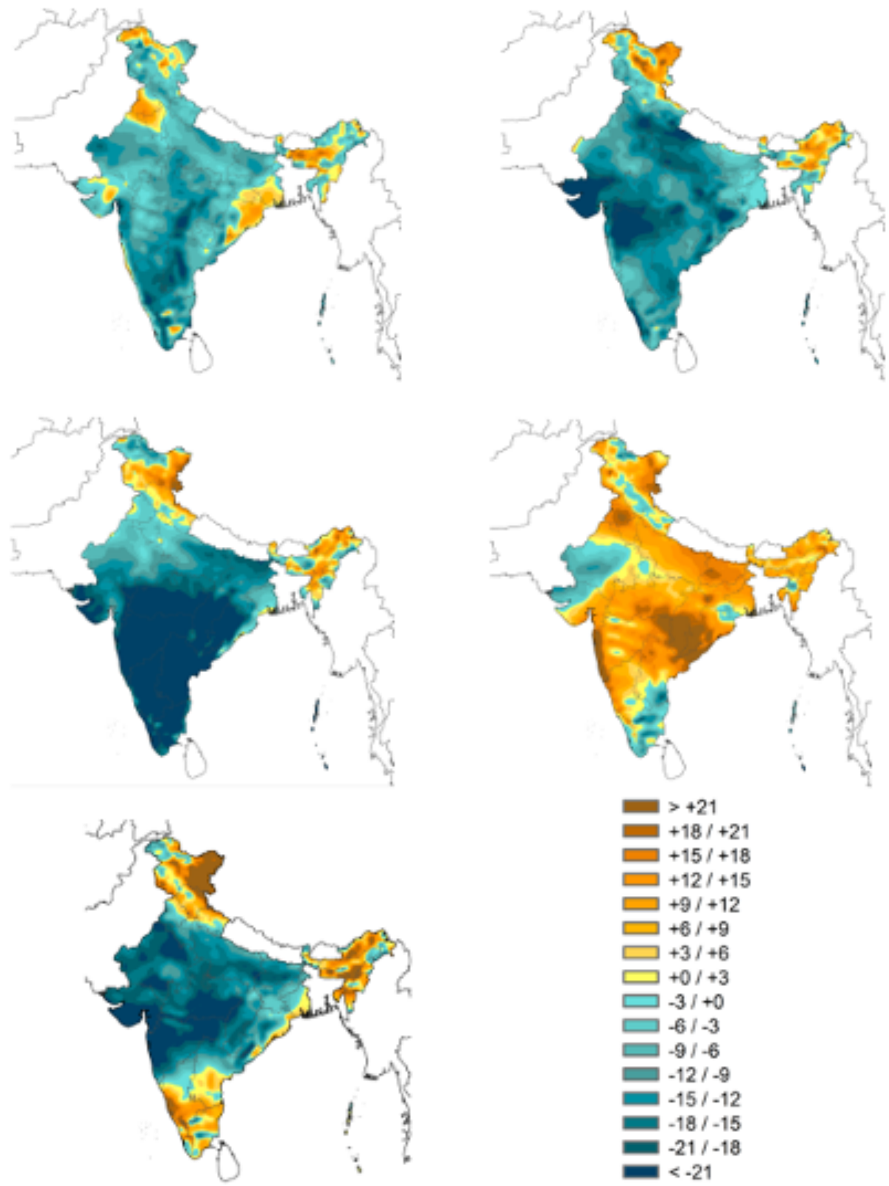


Figure 2.2: Wind speed anomaly maps from the ERA5 reanalysis data for May 2020 (top left), June 2020 (top right), July 2020 (mid-left), August 2020 (mid-right) and September 2020 (bottom left).

Annual wind speed deviations

The drastic decrease in wind speed in June and July 2020 is far more than the normal variability seen for those two summer months. However, the mean wind speeds so far in 2020 (January to September) is faring a little better with a decrease of 7% compared to the long-term average. As shown in Figure 2.4, the inter-annual variability (IAV) tends to range between 2-6% in India and much of the rest of the world as well. The only exception is the inter-tropical convergence zone along the equator, which is associated with a high degree of wind variability with IAV values approaching or exceeding 10% (not shown here, but see Brower et al. 2013 for a global IAV map). Therefore, 2020 so far can be labeled as an extreme year in terms of wind speeds.
Climate oscillations, such as the El Nino-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO) and the Indian Ocean Dipole (IOD), which have an irregular recurrence of a few years to decades, also contribute to the inter-annual variability. These climate indices have been shown to influence India's summer monsoon, but their relationship still has to be further understood (Ramu et al. 2017, Venugopal et al. 2019).

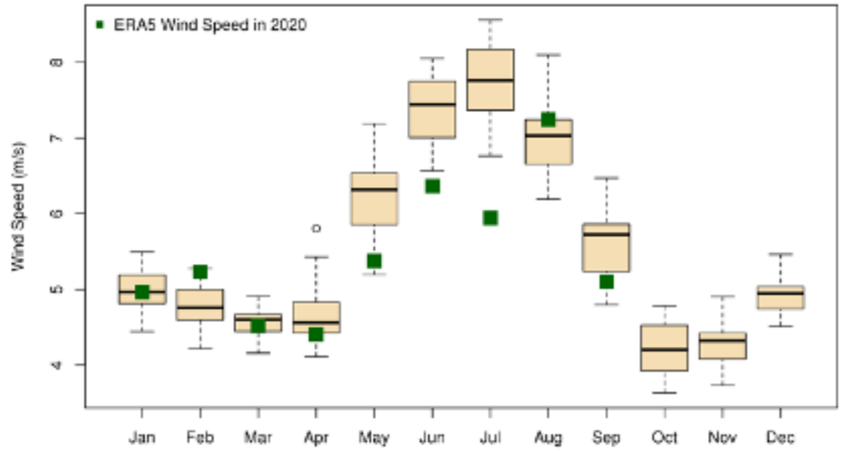


Figure 2.3: Boxplot of monthly averaged wind speeds by month based on ERA5 for the 1995-2019 period. The monthly ERA5 winds for 2020 are shown by green squares.

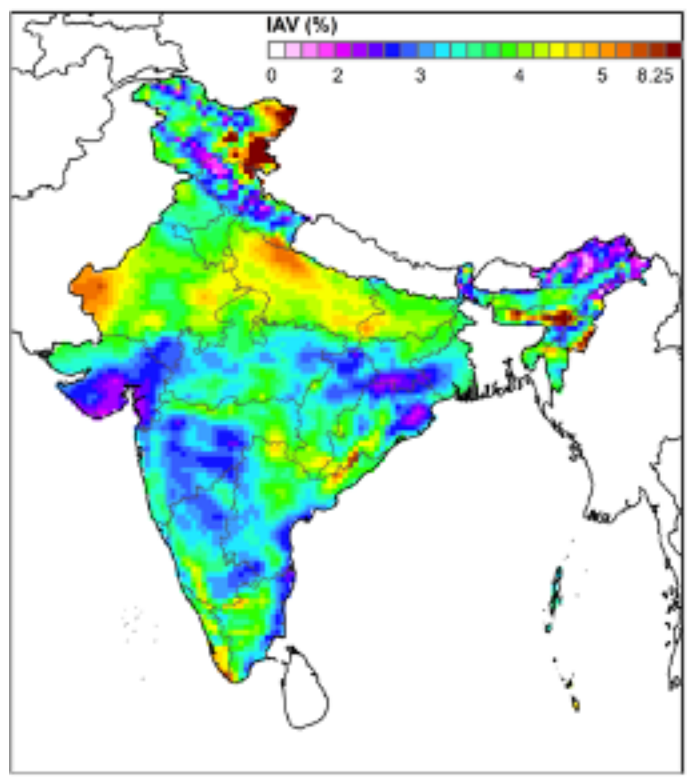


Figure 2.4: Inter-annual variability map based on the ERA5 data from the 1995-2019 period at 100 m a.g.l. Values are given as a fraction of wind speed.

Wind power generation

Our next step is to put the 2020 wind drought into historical context to better understand what happened to the wind speeds in India and, most importantly, to the wind power generation in India. We turn again to the ERA5 reanalysis dataset to provide the historical meteorological conditions and to the Central Electric Authority (CEA) for the actual power generation in India. It is possible to create a synthetic wind energy production time series going back to 1995 with these two datasets. The key is to find a strong relationship between the ERA5 winds and the CEA power generation data. Fortunately, we find a good fit between the monthly averaged ERA5 wind speed at all the wind plants and the monthly wind power generation using a linear regression[3.5]. In the wind industry, this long-term adjustment process is called Measure-Correlate-Predict, or MCP (Rogers et al. 2005). The synthetic wind energy production that was generated using linear regression is shown in Figure 3.1. This synthetic wind energy production time series corresponds to the amount of wind power that would have been generated based on the same installed wind capacity in India as in December 2019 (see Figure 2.1 for the plant location). The goal in creating synthetic wind energy production time series is to show the variations in power generation over a long period of time, e.g., 25 years, due solely to the meteorological conditions assuming everything else remains constant (same number of plants, plant capacities, plant layouts, turbine technology, etc.).

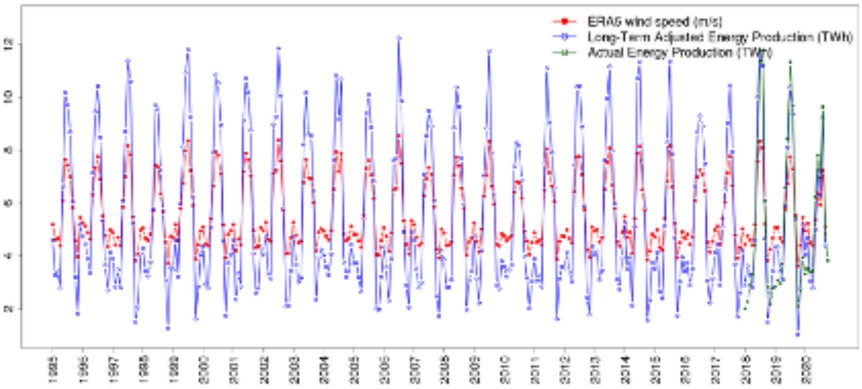


Figure 3.1: Monthly ERA5 wind speeds (red), and actual (green) and synthetic (blue) monthly wind energy production.

Although it may be hard to determine from visual inspection of Figure 3.1, June and July 2020 are the lowest average wind speed and total wind power generation on record for any given month of June or July over the last 25 years. The wind energy production was 18% and 32% below average for June and July 2020. As shown in Figure 3.2, the months of June and July 2020 are below the whiskers, which corresponds to a probability of less than 0.8% (p=0.992 or 2.698 -). Again, the wind drought in either June or July 2020 is a 1-in-129 year event at best (1/(1-p) - 129).

In addition, the not-so-good news is that the annual wind speeds and wind energy production are trending downward during the past two decades (see Figure 3.3). In fact, the annual wind speeds and wind energy production have been below average 11 of the last 15 years.

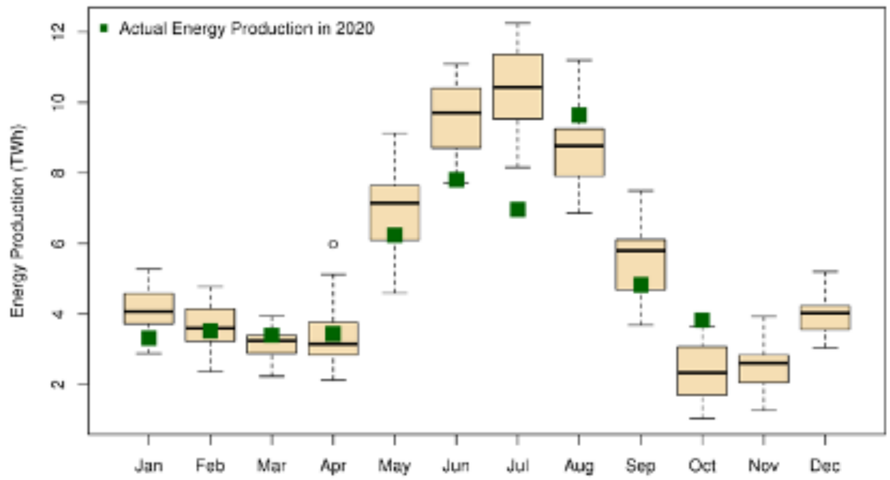
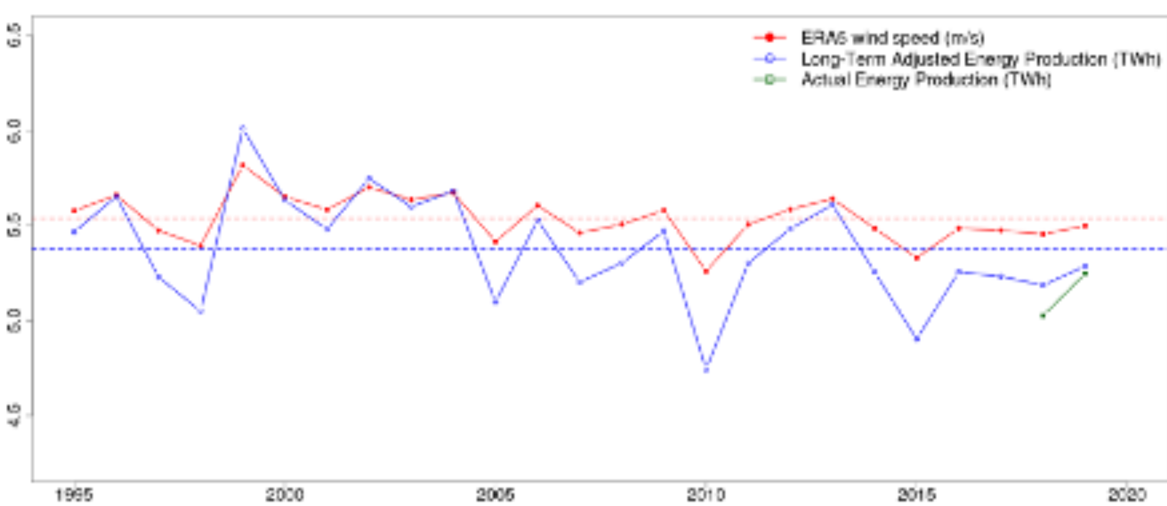


Figure 3.2: Same as Figure 5 but for synthetic monthly wind energy production

Figure 3.3: Annual ERA5 wind speeds (red), and actual (green) and synthetic (blue) monthly wind energy production. The dashed lines correspond to the long-term average ERA5 wind speed (red) and synthetic energy production (blue).



What about the future?

What does this mean for next year or the next 10, 25 or 50 years? We do not know for sure. We do know that this past monsoon season, i.e., June to September 2020, was far outside the expected variations in terms of wind speed and wind energy production. In addition, the wind speeds have been on a downward trend for the past 15 years or so. Statistically speaking, the wind speeds in India should regress to the long-term averages, i.e., the average speeds calculated from 20 or 30 years, and trend back to their climate norms.

However, the impact of climate change could be such that future monsoons will not follow historical climate norms. Climate forecasts out to several months can provide some insights into the future. Several long-range climate forecasts are available, such as ECMWF's SEAS5[7] seasonal forecast and the National Centers for Environmental Prediction (NCEP's) CFSv2[8] seasonal climate forecast. However, it should be kept in mind that long-range forecasts have large uncertainties. One approach often used in forecasting to improve accuracy and quantify the uncertainties is to rely on an ensemble of multiple, and ideally independent, forecasting models. Much research is devoted to better understanding and predicting the Indian summer monsoon — although for mostly rainfalls rather than wind speeds — and the skills of the state-of-the-art models are improving, e.g., Pradhan et al. 2017, Ramu et al. 2017 and Venugopal et al. 2018. UL can offer seasonal wind anomaly forecasts based on the methods described in this technical note. UL has previously provided seasonal forecasts to a number of customers across the globe to help guide their expectations of wind production for the upcoming months. It is important to understand, though, that while these seasonal wind forecasts can give helpful insights that are better than relying on historical climatology statistics alone, they are of relatively higher uncertainty than the long-term energy predictions of performance relied upon by investors for project financing of renewable assets.

The long-term future of India's summer monsoons and their associated winds will depend on whether the land or the ocean warms faster. In general, land warms faster than the ocean, which in turn increases the thermal gradient, forcing the summer monsoon. However, the Indian Ocean is warming at a faster rate than any other region of the tropical oceans (Roxy et al. 2014), potentially weakening the monsoonal wind speeds over the Indian subcontinent (Gao et al. 2018). As Dr. Murtugudde put it, "Until we have many more years of data and reanalysis, a complete separation of the global warming impact from natural climate variability, such as due to El Niño, may not be possible[9]."

Appendix A

The monsoon circulation in 2020 was hindered by a reduced land-ocean temperature gradient, which is the main driver for the large-scale sea breeze. The Indian subcontinent was cooler than normal during the pre-monsoon and monsoon season in 2020, and the Indian Ocean was warmer than normal. This pattern can easily be seen by looking at land and ocean temperature deviation maps from the National Oceanic and Atmospheric Administration's (NOAA) Global Climate Reports[10].

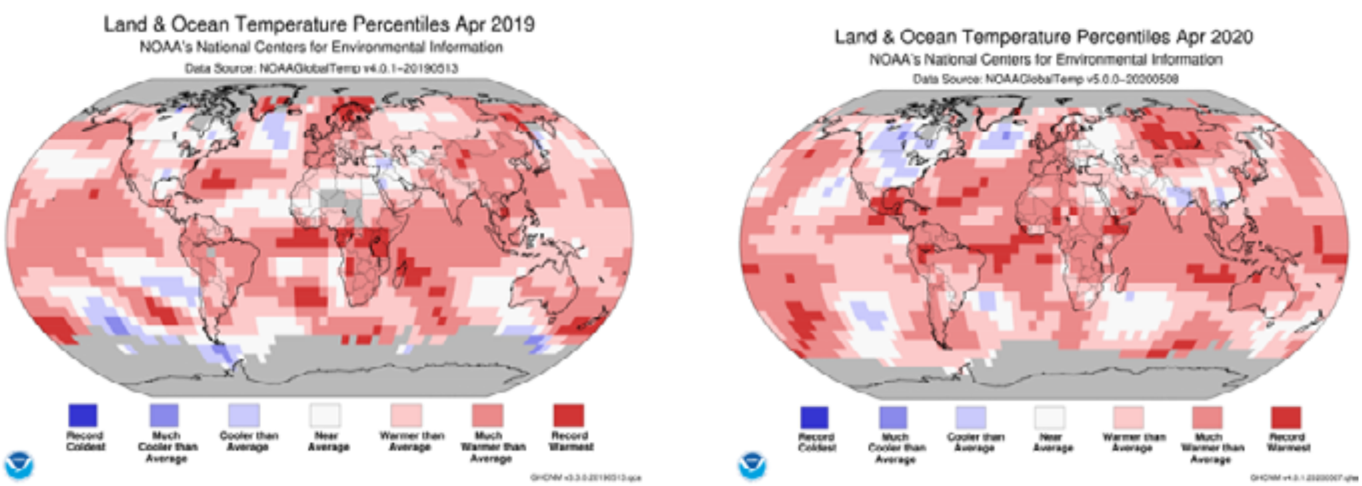


Figure 5.1: Land and ocean temperature deviations for April 2019 (top) and 2020 (bottom).

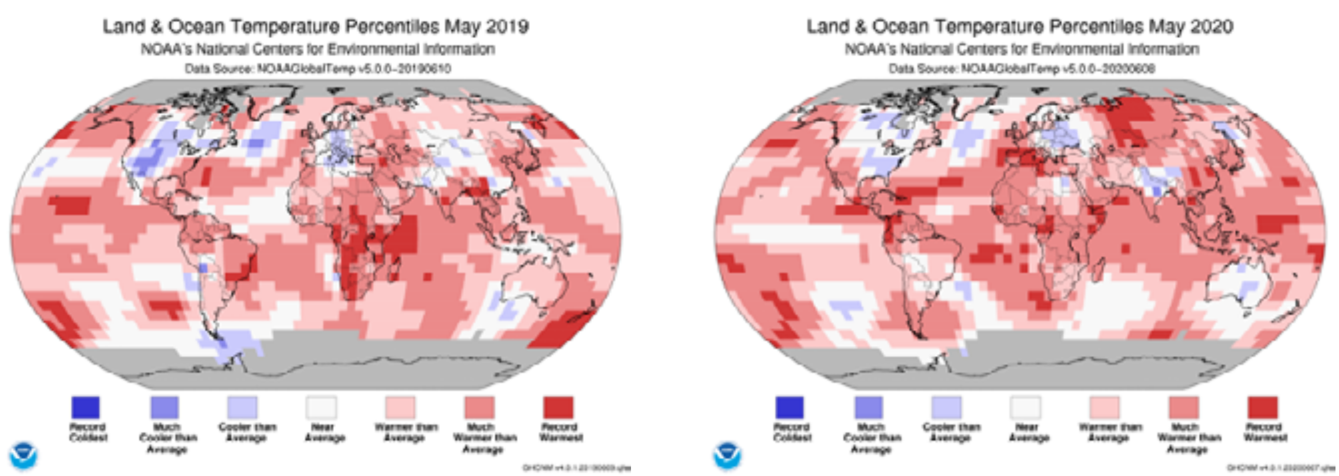


Figure 5.2: Land and ocean temperature deviations for May 2019 (top) and 2020 (bottom).

Figure 5.1 to Figure 5.4 compares the temperature deviations in 2019 and 2020 from the climate normal. It is considered that 2019 was more of a typical monsoon season and 2020 was an anomalous monsoon season.

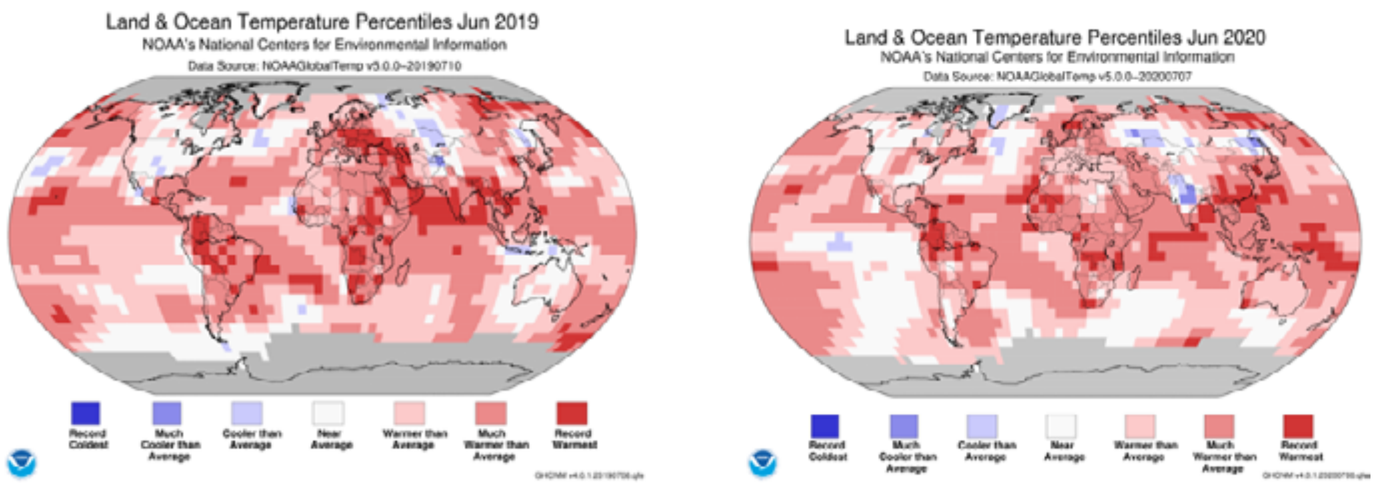


Figure 5.3: Land and ocean temperature deviations for June 2019 (top) and 2020 (bottom).

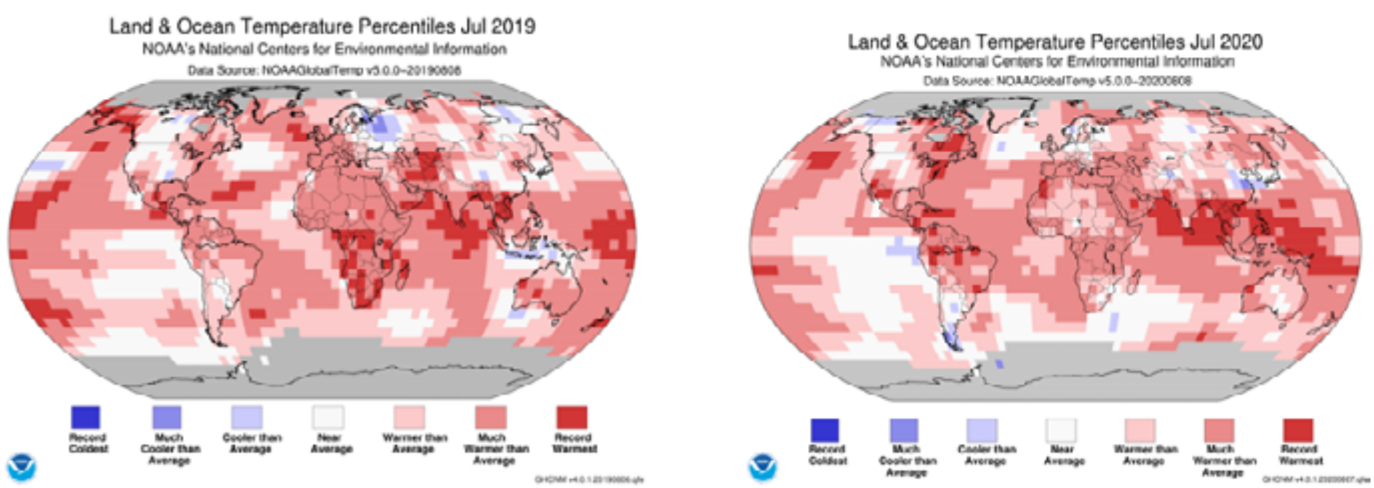


Figure 5.4: Land and ocean temperature deviations for July 2019 (top) and 2020 (bottom).

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End notes

1. Monsoons originate from large-scale temperature gradients between the land and ocean, i.e., when the temperature on land is significantly warmer or cooler than the temperature of the ocean.
2. https://weather.com/en-IN/india/monsoon/news/2020-08-14-curious-case-monsoon-2020-peek-strange-evolution-progress-this-year
3. http://cea.nic.in/reports.html
4. By contrast, based on the ERA5 reanalysis, the average wind speeds across all of India's wind farms is down by approximately 7% and 6% so far this year compared to the same period in 2018 and 2019, respectively.
5. https://climate.copernicus.eu/climate-reanalysis
6. Goodness-of-fit for the regression was RMSE = 0.89 TWh, R2 = 0.92 and F ratio = 336.9.
7. https://www.ecmwf.int/en/forecasts/documentation-and-support/long-range
8. https://www.cpc.ncep.noaa.gov/products/CFSv2/CFSv2seasonal.shtml
9. https://thewire.in/environment/india-monsoon-changes
10. https://www.ncdc.noaa.gov/sotc/global/202004

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