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Widespread calming of the wind sapped U.S. wind energy power output in 2015, driven by the same weather patterns responsible for California's severe drought.

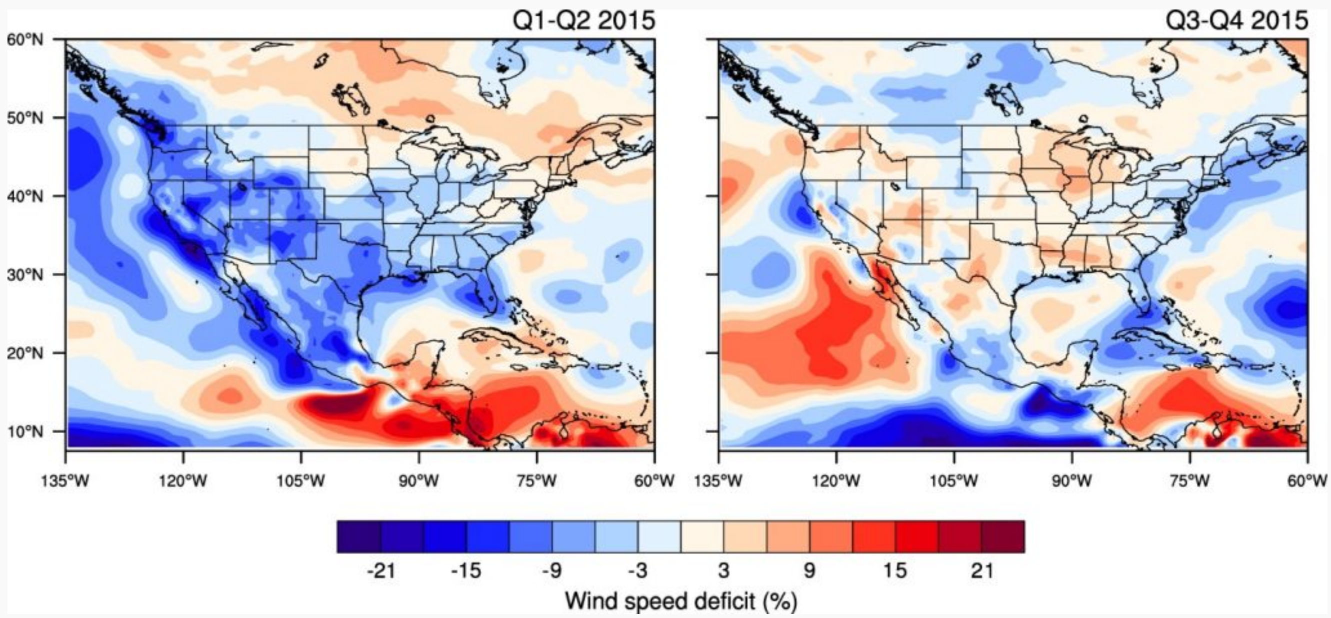


Figure 1. Windiness levels for the first and second quarters and the third and fourth quarters of 2015 compared to the 1979-2014 average. During the first and second quarters, many locations in California, Florida, Oregon, Washington, and Texas reported their lowest wind speeds in more than 30 years. Image Credit: DNV GL, 2016

Vast swaths of the United States witnessed an unprecedented drop in windiness during the first half of 2015. This "wind drought" eclipses any previous event since 1979, in terms of both geographic extent and longevity, and affected states from Washington to Florida. Reanalysis data indicate that California, Oregon, Texas, and Washington reported their lowest recorded wind speeds in more than 30 years. Wind power generation plummeted as result, and since wind power now accounts for approximately 9.5 percent of electricity generation in the western United States (AWEA 2015), the impacts were far-reaching.

We provide an overview of the event within the context of California's prolonged drought, and the record global warmth in 2015. The unparalleled low windiness is strongly linked to an abnormal high pressure ridge that was anchored over western North America from about June 2013 to April 2015 (Hartman 2015; Swain et al. 2014). This ridge was remarkable for its longevity and robustness, and appears to have drawn its prodigious strength from an unusual ocean warming event in the northeast Pacific (Seager et al. 2015; Wang et al. 2014, Hartmann 2015). The ocean warming was a record event (NCDC 2015; Marinaro et al. 2015), and helped to set the stage for the severe drought in California. El Niño was neutral (dormant) from May 2013 to about January 2015, and therefore unlikely to have played a role in this ocean warming event. Interestingly, the analyses of Wang et al. (2014) and Hartmann (2015) suggest that the northeast Pacific Ocean warming pattern is a precursor to El Niño, typically maximizing one year prior to the formation of the El Niño.

It remains an open question whether these extreme events can be linked to human activities or are within the envelope of natural variability. A companion paper further explores the record Northern Hemisphere warmth of 2015 (Cohan et al. 2016).

Meteorology of 2015

The prolonged period of low winds across much of the United States during the first half of 2015 was extreme. Like other aspects of the global climate system, winds exhibit natural variability, but rarely do such variations result in lulls this dramatic and so long-lived. To aid understanding of the windiness patterns across the U.S. during the first half 2015, we first present departures from the long-term mean in Fig. 1. These are generated using Modern Era Retrospective-analysis for Research and Applications (MERRA) hourly 50-m-AGL wind speeds from 1979-2015 inclusive. Departures, termed “anomalies,” are calculated by differencing quarterly means for 2015 with the same quarterly means over the 1979-2014 period. This differencing indicates that wind speeds over much of the U.S. ranged from 6 percent below the long-term mean to a deficit as high as 20 percent. Over California, Oregon, Washington, Nevada, Arizona, southeast Texas, and Florida, these are the lowest observed average wind speeds within the entire 1979-2015 record. However, other regions were not nearly as affected, including the Great Plains, which also have a large installed capacity of operating wind farms. By mid-year, the winds returned to a more normal range.

It is important to note that wind power potential is proportional to the cube of wind speed, and even small changes in wind speed have a dramatic impact on wind power production. This further illustrates why the low wind speeds during first half of 2015 resulted in plummeting wind power.

Origins of Record Low Windiness

As a result of the persistent low winds, wind energy production plummeted during the first and second quarter.

What is the cause of these unprecedented low winds, and can we expect similarly long-lived and widespread calming in the future?

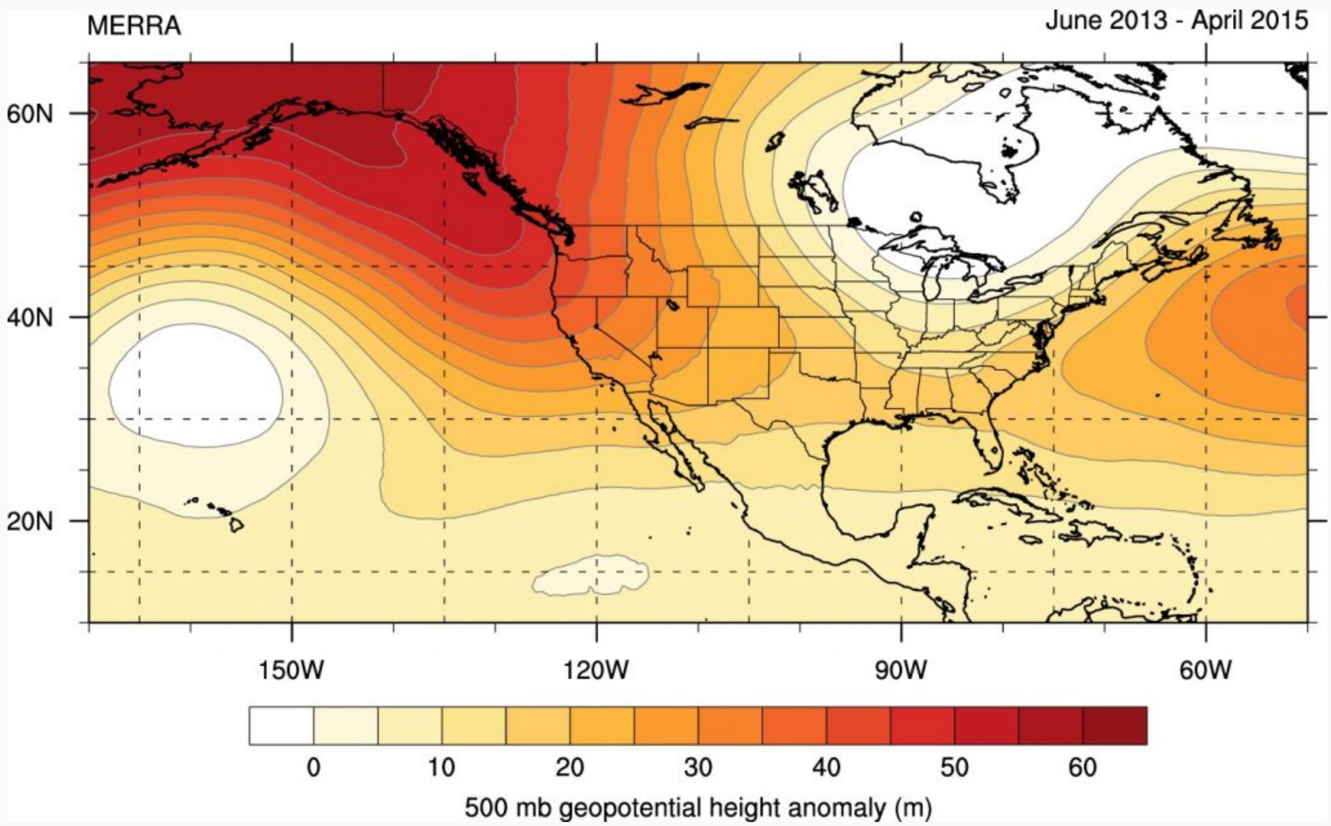


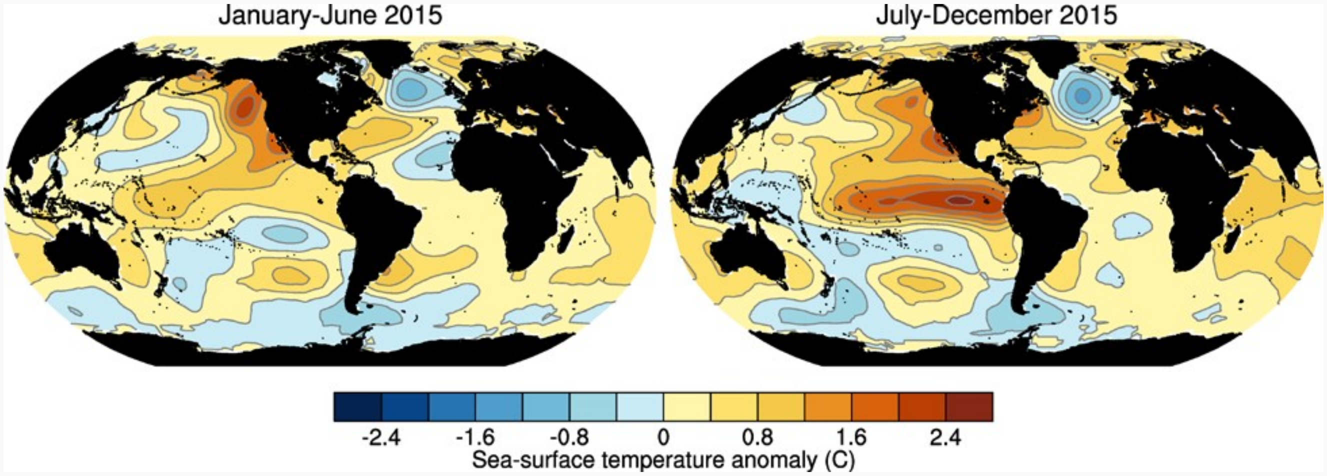
Figure 2. Atmospheric height anomalies in the mid troposphere (500-mb geopotential height) for June 2013-April 2015 compared to the 1981-2010 average. Positive values are indicative of high pressure. Image Credit: Data Source: NASA MERRA project. Analysis performed by: Daran Rife

The record low windiness across the western and southern U.S. appears to be linked to an unusually strong upper level ridge that was anchored over western North America for nearly two years, from about June 2013 to April 2015 (Fig. 2). Wang et al. (2104) examined historical weather analysis records, and found that the ridging pattern appears to recur approximately every five years; however, the present event is by far the strongest within records dating back to 1960. The link between this pressure pattern and the low winds is supported by correlation analysis, which reveals a strong and statistically significant linear relationship between the ridge pattern and windiness in the western U.S. (DNV GL, 2016). It is well-known that winds are typically weak within a well-established high-pressure ridge (Met Office 2016), and thus it seems reasonable to conclude that the low windiness during the first half of 2015 is directly linked to the persistent ridge.

The Source of the High Pressure Ridge's Strength: Unusual Ocean Warming

This ridge appears to have drawn its prodigious strength from an unusual ocean warming event in the northeast Pacific. Hartmann (2015) calls this warm pattern the Northern Pacific Mode (NPM), noting that it recurs on a decadal time scale and is typified by anomalously warm sea surface temperatures in the northeast Pacific Ocean. The NPM became strongly positive in May 2013, and our analysis indicates that it remained positive through late spring 2015 (DNV GL, 2016). This ocean-warming episode is one of the strongest on record (Marinaro et al. 2015), and the northeast Pacific is one of many regions across the globe that recorded the highest surface temperatures in history during 2015 (NCDC 2015). Fig. 3 shows observed sea surface temperature anomalies for the January-June 2015 period, as well as the July-December 2015 period. The anomalously warm waters in the eastern Pacific are clearly evident.

Hartmann (2015) demonstrates that the NPM is associated with an atmospheric high pressure anomaly pattern over western North America that closely resembles the long-lived pattern first observed during the winter 2013-2014, and which remained through the winter of 2014-2015 (Fig. 2). Marinaro et al. (2015) and Yu and Zhang (2015) also show a strong link between the NPM and the blocking ridge over western North America during this period. This same blocking ridge was responsible for the prolonged severe hydrological and agricultural drought in California (Seager et al. 2015; Swain et al. 2014; Wang et al. 2014). Thus, it appears that the NPM is the most likely cause of the abnormal high-amplitude upper level ridge that was anchored over western North America. The ridge broke down entirely by June 2015.



SST anomalies for the first and second quarters (left) and the third and fourth quarters (right) of 2015, compared to the 1981-2010 average. Derived from Extended Reconstructed SST Version 4 data. Image Credit: Data Source: Huang et al.,2014; Liu et al., 2014. Analysis performed by: Daran Rife

There has been much speculation about the connection between El Niño and the record low windiness in 2015. El Niño was in its nascent phase during the first half of 2015—the same time as the record low winds—and the latest analyses from the various climate monitoring centers indicate that this year's event is only now (early 2016) approaching its peak (e.g., Climate.gov 2016). Indeed, the top panel of Fig. 3 shows little visual manifestation of El Niño during January-June 2015. Moreover, it is important to note that the atmospheric and oceanic response to El Niño exhibits a characteristic lag, and for some atmospheric variables (e.g., rainfall) the lag extends to several months. The reason for this lag is the due to the "atmospheric bridge"—the coupling between the tropical Pacific Ocean, the atmosphere, and the remote extra-tropical and North Pacific, both of which most directly influence weather in the U.S. (e.g., Alexander et al. 2002). The atmosphere takes approximately two weeks to respond to the SST anomalies in the tropical Pacific via surface heat fluxes (the primary driver of the bridge), and the ocean integrates the forcing associated with the bridge over the next few months (e.g., Bjerknes 1966; 1969, Lau 1996, Hoerling and Kumar 2002, and Alexander et al. 2002). Given that El Niño was only beginning to develop in early 2015, any claims of its connection to U.S. windiness during the first and second quarter of 2015 are tenuous at best.

Nevertheless, it is instructive to examine the linear relationship between El Niño and wind speed anomalies. We compute the correlation between the most widely used El Niño index, the Southern Oscillation Index (SOI) data are obtained from the NCAR Climate Analysis Section, and the observationally-based MERRA reanalysis for 1979-present. Our analysis indicates that the relationship is strongest for a lag of three months (e.g., the winds for January are most correlated with one of the El Niño indices for the preceding October). Fig. 4 shows the time series of the two variables at four characteristic sites across the western and central U.S. with nearby wind energy projects: Columbia River Gorge, Oregon; Tehachapi, California; eastern Nebraska, and southeast Texas. The three-month lagged correlation is reported in the upper-right hand corner of each panel. It is evident that there is an overall lack of relationship between the SOI and trends in wind speed. Note that we repeated this analysis with the cube of wind speed and found results analogous to those shown in Fig. 4.

Summary and Conclusions

2015 was a year of records:

- It was the warmest year on record globally.
- A highly anomalous ocean warming event in the northeast Pacific (NPM) strongly controlled the weather and climate over North America.
- A high amplitude ridge of unparalleled strength and longevity over western North America dominated until April 2015.
- Record low windiness was recorded across a huge expanse of the U.S. during the first and second quarter, significantly diminishing wind power generation.
- California continued to experience one of the most severe and prolonged droughts in its history, with some relief in the 2015-2016 rainy season.
- Thirty major tropical cyclones occurred in the Northern Hemisphere, shattering the previous record of 23 (set in 2004), and 25 of those storms reached the Saffir-Simpson Hurricane Wind Scale of 4 or 5

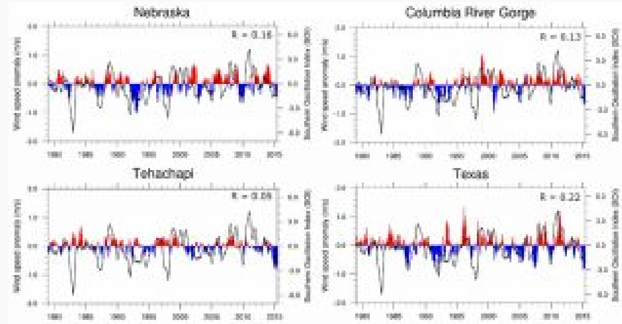


Figure 4. Time series of MERRA monthly 50-m-AGL wind speed anomalies (colors) and the SOI (black lines) at four characteristic sites across the U.S. Positive wind speed anomalies are red, and negative wind speed anomalies are blue. The time series are smoothed using a five-month moving average to clarify the signal. Three-month lagged Pearson correlations are shown in the upper right-hand corner of each panel. Note that negative SOI indicates El Niño, and positive SOI indicates La Niña. Image Credit: DNV GL, 2016

(NASA Earth Observatory 2016).

Many of these events appear to be connected to one another, and illustrate the complex and sometimes far-reaching impacts of climate variability and climate change. It is not yet known if human activities may have played a role, or whether these extreme events lie within the envelope of natural variability.

The NPM gradually trended downward to neutral during the first half of 2015. This change coincided with a dissipation of the ocean warming in the northeastern Pacific, and with a breakdown of the blocking ridge over that same region. Thereafter, regional winds returned to their more normal patterns of variability. Given that there appears to be little relationship between antecedent El Niño conditions and U.S. wind speed anomalies, and because the 2015 El Niño was in its infancy during the first and second quarter, it is highly unlikely that it contributed to the record low winds or bolstered the high amplitude ridge.

Given the increasing importance of energy from weather-sensitive renewable sources such as wind, solar, and hydro to our economy, weather forecasting is increasingly important for managing energy supply and demand (e.g., Lang 2005, Hering and Genton 2010). Such features as the northeast Pacific warming of 2013-2015, and its association with a widespread calming of the wind, suggest that some weather-related variability could be forecast even several months in advance. This is one potential application of monthly to seasonal forecasts now being developed by weather forecast providers (Kirtman et al., 2014; Krakauer et al, 2013).

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