A photograph of a snowy park path, likely in Central Park, New York. The path is covered in a thick layer of snow, with footprints visible. On either side of the path are ornate blue and gold lampposts. In the background, a large brick building is visible. The sky is overcast and it appears to be snowing.

EXPLAINING EXTREME EVENTS OF 2014

From A Climate Perspective

Special Supplement to the
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EXPLAINING EXTREME EVENTS OF 2014 FROM A CLIMATE PERSPECTIVE

Editors

Stephanie C. Herring, Martin P. Hoerling, James P. Kossin, Thomas C. Peterson, and Peter A. Stott

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FRONT: ©iStockphotos.com/coleong—Winter snow, Boston, Massachusetts, United States.

BACK: ©iStockphotos.com/nathanphoto—Legget, California, United States – August 13, 2014: CAL FIRE helicopter surveys a part of the Lodge Fire, Mendocino County.

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Understanding how long-term global change affects the intensity and likelihood of extreme weather events is a frontier science challenge. This fourth edition of explaining extreme events of the previous year (2014) from a climate perspective is the most extensive yet with 33 different research groups exploring the causes of 29 different events that occurred in 2014. A number of this year's studies indicate that human-caused climate change greatly increased the likelihood and intensity for extreme heat waves in 2014 over various regions. For other types of extreme events, such as droughts, heavy rains, and winter storms, a climate change influence was found in some instances and not in others. This year's report also included many different types of extreme events. The tropical cyclones that impacted Hawaii were made more likely due to human-caused climate change. Climate change also decreased the Antarctic sea ice extent in 2014 and increased the strength and likelihood of high sea surface temperatures in both the Atlantic and Pacific Oceans. For western U.S. wildfires, no link to the individual events in 2014 could be detected, but the overall probability of western U.S. wildfires has increased due to human impacts on the climate.

Challenges that attribution assessments face include the often limited observational record and inability of models to reproduce some extreme events well. In general, when attribution assessments fail to find anthropogenic signals this alone does not prove anthropogenic climate change did not influence the event. The failure to find a human fingerprint could be due to insufficient data or poor models and not the absence of anthropogenic effects.

This year researchers also considered other human-caused drivers of extreme events beyond the usual radiative drivers. For example, flooding in the Canadian prairies was found to be more likely because of human land-use changes that affect drainage mechanisms. Similarly, the Jakarta floods may have been compounded by land-use change via urban development and associated land subsidence. These types of mechanical factors re-emphasize the various pathways beyond climate change by which human activity can increase regional risk of extreme events.

24. ANOMALOUS TROPICAL CYCLONE ACTIVITY IN THE WESTERN NORTH PACIFIC IN AUGUST 2014

LEI YANG, XIN WANG, KE HUANG, DONGXIAO WANG

The absence of western North Pacific tropical cyclone activity during August 2014 was apparently related to strong easterly wind anomalies induced by combined negative intraseasonal and Pacific decadal oscillation phases.

Introduction. During the boreal summer of 2014, the western North Pacific (WNP; 0° – 25° N, 105° E– 180°) experienced highly anomalous tropical cyclone (TC) activity: no TC formed from early August through early September, when maximum TC genesis occurs climatologically (Figs. 24.1a,b). Of the five TCs that developed during July, three became super typhoons, making 2014 the year with the highest percentage of super typhoons since 1949 (Supplemental Fig. S24.1). Tropical cyclones are significant sources of summer rainfall in the WNP and its surrounding regions. Such low TC activity in August has directly contributed to the anomalous low precipitation in south Asia and the entire WNP (Lin et al. 2015; Supplemental Fig. S24.2). The three super typhoons in July together caused at least 210 deaths, and severe damage to housing and electrical and agricultural infrastructure, amounting to a total of 7.3 billion U.S. dollars (International Disaster Database, www.emdat.be/database).

The TC data used here are from the best-track dataset produced by the Joint Typhoon Warning Center (JTWC), which has TC records from 1949 through 2014. In this study, a TC is defined as a storm with enclosed cyclonic circulation and sustained winds of 25 knots (kt; $1 \text{ kt} = 0.51 \text{ m s}^{-1}$) or above. A TC with maximum wind greater than 135 kt is considered a super typhoon. The variation of TC genesis is closely related to the intraseasonal oscillation (ISO) over the WNP (e.g., Gray 1979; Camargo et al. 2009; Li et al. 2012; Li and Zhou 2013). Around 70% of the TCs in the WNP form during the active ISO period of June to December (Huang et al. 2011). Also of interest for our study are the East Asian summer monsoon (EASM)

circulation which has been weakening since the end of 1970s (Zhou et al. 2009), and the Pacific decadal oscillation (PDO) which became positive in 2014 and has remained significantly positive through July 2015 (Supplemental Fig. S24.3). We examine the relevant mechanisms, and role of climate change, in the long period with no TC occurrence after the temporal clustering of super typhoons in the WNP in 2014, especially in the context of a possible PDO phase transition from negative to positive and multidecadal weakening of the EASM.

Historical context. Using the U.S. National Centers for Environmental Prediction (NCEP) reanalysis dataset (Kalnay et al. 1996), we analyze the atmospheric circulation anomaly in August 2014, including 850-hPa wind, midlevel humidity (600 hPa), low-level relative vorticity (850 hPa), vertical wind shear of horizontal wind (200–850 hPa), moisture flux (850 hPa), and velocity potential (250 hPa). Convection associated with the ISO is based on the interpolated outgoing longwave radiation (OLR) from National Oceanic and Atmospheric Administration (NOAA), which comprise daily data on a $2.5^{\circ} \times 2.5^{\circ}$ grid from 1979 to 2014 (Liebmann and Smith 1996). All anomalies used in the study are relevant to the base period of 1970–2010.

In August 2014, anomalous low-level northeasterly flow dominated the northeast sector of the WNP (area “B” indicated in Fig. 24.1c), and turned to easterly around 140° E until 40° E (area “A” indicated in Fig. 24.1c). The strong easterlies mainly prevailed over the tropical WNP and northern tropical Indian Ocean (TIO). Along with these prevailing easterlies, there were the midlevel dry conditions and negative low-level vorticity (Figs. 24.1d,e). The moisture flux field showed that the anomalous midlevel dry conditions were mainly due to the sustained easterly anomaly (Fig. 24.1f). The anomalous wind pattern played an important role in leading to the unfavorable condi-

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FIG. 24.1. (a) Annual cycle of tropical cyclones in the WNP for climatology and 2014; bars in dark gray (black) represent all TCs (super typhoons). (b) Time series of the tropical cyclone numbers in Aug in the WNP during 1949–2014. (c) 850-hPa wind anomaly (m s^{-1}) for Aug 2014. (d) 600-hPa specific humidity anomaly (g kg^{-1}) for Aug 2014. (e) Low-level relative vorticity anomaly (10^{-5} s^{-1}) for Aug 2014. (f) Moisture flux anomaly ($\text{g kg}^{-1} \text{ m s}^{-1}$) for Aug 2014. (g) Velocity potential anomaly at 250hPa ($10^{-6} \text{ m}^2 \text{ s}^{-1}$) for Aug 2014. (h) Time series of 850-hPa wind anomaly (m s^{-1}) in Aug during 1948–2014 for U-component over area “A” [indicated in (c)] and V-component over area “B” [indicated in (c)]. (i) 20–100-day filtered OLR (W m^{-2}). (j) As in (h), but for filtered 850-hPa wind anomaly (m s^{-1}). Note that the positive trend lines in (h) and (j) mean further negative values since 2000 and represent increasing easterlies during 2000–14.

tions for TC genesis by continuously transporting dry air from midlatitudes into the WNP and through the western TIO. Correspondingly, a positive velocity potential anomaly at 250 hPa dominated the WNP with a maximum around 160°E, indicating strong divergence and enhanced subsidence in the region (Fig. 24.1g). The vertical wind shear anomaly was not significant and likely had a lesser influence on the anomalous TC genesis (Supplemental Fig. S24.4).

The sustained easterly anomalies over the WNP in August 2014 were unusual. By examining the easterly anomalies in August during 1948–2014, it is found that such strong anomalous easterly flow over the area “A” occurred in only three years: 1988, 1998, and 2014 (Fig. 24.1h and Supplemental Fig. S24.5). Different from those of August 2014, the easterly flows in 1988 and 1998 prevailed from the central Pacific, but weakened and diverged at the eastern TIO (Supplemental Fig. S24.6). It is well known that 1988 and 1998 were strong La Niña years, during which the easterly winds were mostly related to the strong sea surface temperature gradient (SSTG) due to strong cooling in the eastern Pacific (Wang et al. 2000). However, 2014 was a neutral year, according to the Niño 3.4 index (NOAA Climate Prediction Center), and the SSTG was less likely to contribute to the strong easterly anomalies in August 2014. Meanwhile, the average northeasterly flow over the area “B” in August 2014 was anomalously strong, which transported dry air into the WNP and also led to a strong divergence anomaly centered at 160°E, acting together with the strong westerly flow over the eastern North Pacific (ENP). Both the northeasterly and easterly anomalies exhibit strong interannual variability with a positive trend in the recent decade (Fig. 24.1h). The sea level pressure anomaly was slightly positive over the WNP in August 2014, which is different from that in 1998, when the TIO warming after the strong El Niño (1997) induced strong Kelvin wave propagation into WNP, leading to anomalous high pressure over the WNP (Du et al. 2011; Tao et al. 2012; Supplemental Fig. S24.6).

The modulation of the ISO. In contrast to the anomalous atmospheric circulation in the WNP in August 2014, the central North Pacific (CNP) and ENP experienced an almost exactly opposite situation, with strong westerlies, moist midlevels, and increased vorticity and convergence (Figs. 24.1c–g). Correspondingly, more TC activities were recorded in the CNP/ENP during the period. The differences in the atmospheric circulation anomalies and TC activity

between WNP and ENP suggest a possible connection to the ISO phase.

In early July of 2014, strong positive convection dominated the WNP and western TIO, while negative convection was located in the CNP and ENP. The positive convection center in the western TIO gradually moved northward into the WNP and combined with the positive center in the WNP. At the end of July, the positive center started to move out of the WNP and split into two branches, one moving northward and one eastward (Supplemental Fig. S24.7) and marking a phase change from positive to negative (negative to positive) in the WNP (ENP). With the continuing northward propagation of the ISO signals, a strong negative convection anomaly center dominated the WNP and lingered until the end of August, leading to unfavorable conditions for TC genesis (Fig. 24.1i).

Did anthropogenic climate change influence the extreme TC activity in August 2014? The variations of TC genesis frequency and intensity in the WNP, from intraseasonal to interdecadal time scales, are related to ISO phases (e.g., Gray 1979; Huang et al. 2011; Li and Zhou 2013; Yang et al. 2015), monsoon trough variability (e.g., Ritchie and Holland 1995; Chen et al. 2004; Wu et al. 2012), the El Niño–Southern Oscillation (e.g., Chan 2005; Du et al. 2011; Kim et al. 2011), and the PDO (e.g., Yang et al. 2012; Liu and Chan 2013). WNP TC genesis frequency depends on the ISO phase (Huang et al. 2011) and might also vary with different climate backgrounds of the EASM (Zhou et al. 2009; Wang et al. 2012) and PDO phase (Liu and Chan 2013). Previous studies suggested that the modulation of TCs by the ISO during July–August of 1979–2008 or 1979–2004 was relatively weak compared to other seasons (Huang et al. 2011; Kim et al. 2008). Here, a strong positive correlation between the ISO and TC frequency in the WNP is found during August 2000–14 (Supplemental Fig. S24.8). Averaged 20–100-day filtered 850-hPa wind anomaly over the WNP in August showed an increasing trend during 2000–14 (under PDO negative phase and possible transition to positive phase), which corresponded well with the decreasing trend in TC frequencies (Fig. 24.1j). During this period, the correlation between filtered easterlies in area “A”, northeasterlies in area “B”, and OLR anomalies over the WNP (5°–20°N) is 0.75, 0.73, and -0.74, respectively (Fig. 24.2a–c). During the other two PDO phases, negative phase of 1950–76 and positive phase of 1977–99, the correlation was much lower,

FIG. 24.2. Scatter plot between TC numbers and (a) filtered 850-hPa wind anomaly over area “A”. (b) Filtered 850-hPa wind anomaly over area “B”. (c) OLR anomaly over WNP during 2000–14. Scatter plot of 850-hPa wind anomaly (U-component; m s^{-1}) between 20 CMIP5 historical runs and NCEP reanalysis for (d) 1950–76, (e) 1977–99, and (f) 2000–14. (g) Time series of 850-hPa wind (U-component) anomaly (m s^{-1}) simulated by CMIP5 historical runs (gray lines) and derived from NCEP reanalysis (blue line). **Notes:** 1) All figures are for Aug; 2) the positive trend in (c) and (g) represents a further negative value and means increasing convection inhibition and easterlies, respectively, during 2000–14.

with increasing tendency from 1950–76 to 1977–99 (Supplemental Fig. S24.8).

Was the increased correlation with different PDO phases related to the weakening of EASM or climate change induced by anthropogenic forcing? The averaged 850-hPa wind anomaly over the WNP and ENP derived from the historical simulation of 20 Coupled Model Intercomparison Project Phase 5 (CMIP5) models are analyzed. A model is chosen based on its performance in reproducing the averaged 850-hPa wind during 1948–2005. Those with an obvious pattern difference

are not selected. Only one model has historical data in 2014 which simulate an opposite pattern of 850-hPa easterly anomaly compared to the reanalysis data: westerly anomaly in the WNP and easterly anomaly in the ENP (Supplemental Fig. S24.9). Scatter plots of 850-hPa wind anomaly between reanalysis and 20 model runs for the three PDO phases since 1948 show a poor correlation (Figs. 24.2d–f). None of the twenty models can simulate a reasonable result for all three periods (Fig. 24.2g). Comparisons during the third PDO phase period are less meaningful due to small samples because there were only two model runs after

2005. The inability of CMIP5 models to replicate the easterly anomaly pattern might be partly due to the inconsistency of PDO phase transition (Zhou et al. 2013) and the variation of EASM with observations. Therefore, the study cannot conclude the role of climate change in the low TC activity in the WNP.

Concluding remarks. The year 2014 was the first since 1949 that no TC formed in the WNP during August, which is climatologically a peak TC month. It is found that ISO played an important role in inhibiting TC genesis in August 2014 by inducing anomalous easterlies, which led to decreased moisture and vorticity, and increased divergence. The strength of the modulation of TC frequency by the ISO over the WNP during August has been increasing since 1948 under three PDO phases with the strongest during the recent negative PDO phase. However, the anomaly pattern as well as the interannual variations of 850-hPa wind anomaly cannot be captured by the CMIP5 models, and therefore, we currently cannot determine whether the significant easterly trend as well as the observed TC activity is part of natural climate variability or climate change induced by anthropogenic forcing. In the future, application of downscaling techniques in atmospheric general circulation models may be needed to diminish the biases in the tropical areas.

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Table 34.I. ANTHROPOGENIC INFLUENCE

ON EVENT STRENGTH †

	INCREASE	DECREASE	NOT FOUND OR UNCERTAIN
Heat	Australia (Ch. 31) Europe (Ch.13) S. Korea (Ch. 19)		Australia, Adelaide & Melbourne (Ch. 29) Australia, Brisbane (Ch.28)
Cold		Upper Midwest (Ch.3)	
Winter Storms and Snow			Eastern U.S. (Ch. 4) N. America (Ch. 6) N. Atlantic (Ch. 7)
Heavy Precipitation	Canada** (Ch. 5)		Jakarta**** (Ch. 26) United Kingdom*** (Ch. 10) New Zealand (Ch. 27)
Drought	E. Africa (Ch. 16) E. Africa* (Ch. 17) S. Levant (Ch. 14)		Middle East and S.W. Asia (Ch. 15) N.E. Asia (Ch. 21) Singapore (Ch. 25)
Tropical Cyclones			Gonzalo (Ch. 11) W. Pacific (Ch. 24)
Wildfires			California (Ch. 2)
Sea Surface Temperature	W. Tropical & N.E. Pacific (Ch. 20) N.W. Atlantic & N.E. Pacific (Ch. 13)		
Sea Level Pressure	S. Australia (Ch. 32)		
Sea Ice Extent			Antarctica (Ch. 33)

† Papers that did not investigate strength are not listed.

†† Papers that did not investigate likelihood are not listed.

* No influence on the likelihood of low rainfall, but human influences did result in higher temperatures and increased net incoming radiation at the surface over the region most affected by the drought.

** An increase in spring rainfall as well as extensive artificial pond drainage increased the risk of more frequent severe floods from the enhanced rainfall.

*** Evidence for human influence was found for greater risk of UK extreme rainfall during winter 2013/14 with time scales of 10 days

**** The study of Jakarta rainfall event of 2014 found a statistically significant increase in the probability of such rains over the last 115 years, though the study did not establish a cause.

	ON EVENT LIKELIHOOD ††			Total Number of Papers
	INCREASE	DECREASE	NOT FOUND OR UNCERTAIN	
Heat	Argentina (Ch. 9) Australia (Ch. 30, Ch. 31) Australia, Adelaide (Ch. 29) Australia, Brisbane (Ch. 28) Europe (Ch. 13) S. Korea (Ch. 19) China (Ch. 22)		Melbourne, Australia (Ch. 29)	7
Cold		Upper Midwest (Ch.3)		1
Winter Storms and Snow	Nepal (Ch. 18)		Eastern U.S. (Ch. 4) N. America (Ch. 6) N. Atlantic (Ch. 7)	4
Heavy Precipitation	Canada** (Ch. 5) New Zealand (Ch. 27)		Jakarta**** (Ch. 26) United Kingdom*** (Ch. 10) S. France (Ch. 12)	5
Drought	E. Africa (Ch. 16) S. Levant (Ch. 14)		Middle East and S.W. Asia (Ch. 15) E. Africa* (Ch. 17) N.E. Asia (Ch. 21) S. E. Brazil (Ch. 8) Singapore (Ch. 25)	7
Tropical Cyclones	Hawaii (Ch. 23)		Gonzalo (Ch. 11) W. Pacific (Ch. 24)	3
Wildfires	California (Ch. 2)			1
Sea Surface Temperature	W. Tropical & N.E. Pacific (Ch. 20) N.W. Atlantic & N.E. Pacific (Ch. 13)			2
Sea Level Pressure	S. Australia (Ch. 32)			1
Sea Ice Extent			Antarctica (Ch. 33)	1
TOTAL				32

† Papers that did not investigate strength are not listed.

†† Papers that did not investigate likelihood are not listed.

* No influence on the likelihood of low rainfall, but human influences did result in higher temperatures and increased net incoming radiation at the surface over the region most affected by the drought.

** An increase in spring rainfall as well as extensive artificial pond drainage increased the risk of more frequent severe floods from the enhanced rainfall.

*** Evidence for human influence was found for greater risk of UK extreme rainfall during winter 2013/14 with time scales of 10 days

**** The study of Jakarta rainfall event of 2014 found a statistically significant increase in the probability of such rains over the last 115 years, though the study did not establish a cause.