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.

27. EXTREME RAINFALL IN EARLY JULY 2014 IN NORTHLAND, NEW ZEALAND—WAS THERE AN ANTHROPOGENIC INFLUENCE?

SUZANNE ROSIER, SAM DEAN, STEPHEN STUART, TREVOR CAREY-SMITH, MITCHELL T. BLACK, AND NEIL MASSEY

The risk of an extreme 5-day July rainfall event over Northland, New Zealand, such as was observed in early July 2014, has likely increased due to anthropogenic influence on climate.

Introduction. From 8 to 12 July 2014, Northland, New Zealand, suffered a deluge of rainfall that caused widespread severe flooding; the resulting damage is estimated to have cost NZD 18.8 million in insurance claims (ICNZ 2015). Low pressure to the northwest and high to the southeast resulted in strong northeasterly flows across the upper North Island. The subtropical origin of the air mass produced a conveyor belt of very moist air that fueled the extreme rainfall. High pressure over much of the rest of the country “parked” the low pressure system over Northland for about five days, allowing extremely high rainfall amounts to accumulate (Met Service NZ 2015). Kaiakohe (central Northland) received 311% of normal rainfall in July—a record July rainfall total for this location (NIWA 2014). This study investigates whether, and to what degree, there was an anthropogenic influence on July rainfall amounts in Northland such as observed in 2014.

Data and methods. Rainfall observations for the period 1972–2014 were used from the Virtual Climate Station Network (VCSN), which takes measurements from 600 sites around New Zealand and creates a 5 km × 5 km data field using a thin-plate smoothing spline interpolation (Tait et al. 2006).

Extremely large ensembles of simulations of a regional climate model came from the “climateprediction.net” project (Allen 1999) running

the “weather@home” experiment for the Australia/New Zealand (ANZ) region. This is an ANZ version of the modeling capability described by Massey et al. (2015). In this setup, the Met Office HadAM3P model (Pope et al. 2000) is run globally, providing lateral boundary conditions to the regional model HadRM3P (Jones et al. 2004), which covers a domain spanning Australia, New Zealand, and much of Indonesia at approximately 50-km resolution.

For this study, two experiments were conducted creating very large initial condition ensembles to represent many different realizations of possible weather. The first is of the year 2014 with all forcings included (ALL)—sea surface temperature (SST) from the “Operational Sea Surface Temperature and Sea Ice Analysis”, greenhouse gases, aerosol, ozone, solar, and volcanic. A second “natural forcings only” (NAT) ensemble was produced, where the anthropogenic contribution to the 2014 forcings was removed. For the SSTs, patterns of changes were estimated using 10 different Coupled Model Intercomparison Project Phase 5 (CMIP5) models and a multimodel mean. This is the same configuration as described in Schaller et al. (2014) and Black et al. (2015).

How well does the “weather@home ANZ” model simulate this event? VCSN observations in Northland (defined as New Zealand land area north of 36.6°S) were spatially averaged, and 5-day totals were summed starting on consecutive days in July. The maximum of these values for each year is shown in Fig. 27.1a. The 2014 observation of 221 mm (the 5-day total beginning on 8 July 2014) was a very clear record in the time series.

To validate the model performance, the VCSN observations and model rainfall were area-averaged over Northland, and 5-day rainfall totals were calculated. The resulting July maximum values are

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FIG. 27.1. (a) Jul maximum 5-day rainfall totals in Northland from the New Zealand VCSN observations on their 5 km × 5 km grid, plotted against time over the span of the dataset (1972–2014). (b) Quantile–quantile plot of Jul maximum 5-day rainfall total in Northland (crosses), comparing 2772 “weather@home” model ALL simulations (w@h ANZ 2014) against 43 years of VCSN observations. Each cross marks corresponding values of rainfall in the model ensemble and in the observations at the same percentile in the two (different sized) distributions. A perfect match between the model and observations would be indicated if the crosses lay on the line $x = y$ (solid). (c) Black diamonds indicate the return periods of the 43 years of VCSN observations of Jul maximum 5-day rainfall totals in Northland shown in (a). The red line is the generalized extreme value (GEV) fit through these observations, and blue is the 90% confidence interval on this GEV fit. (d) As in (c), but for the Kaikohe station (central Northland) only, for which a longer time series of 93 years is available.

compared in the quantile–quantile plot in Fig. 27.1b. The model exhibits a persistent dry bias; at each percentile, the model is approximately two-thirds as wet as the observations. Similar behavior in the same model, but over Europe, has been noted by Otto et al. (2014), Sparrow et al. (2013), and Schaller et al. (2014). The ANZ model is capable of reproducing July maxima as wet as the 2014 observed extreme but only at a greatly increased return period (Fig. 27.2a). The model dry bias is also consistent with the findings of Ackerley et al. (2012), who used the same model over a smaller domain. Running it with varying boundary conditions, they found the same systematic bias over

Northland and that this was removable by tuning a single precipitation parameter.

To assess the 2014 event against the historical record of 43 years, a generalized extreme value (GEV) distribution was fitted to the observations (Fig. 27.1c) following the methodology described in Ailliot et al. (2011). This estimates the 2014 extreme to be close to a 1-in-200-yr event, with 90% confidence of its being between about a 1-in-20-yr and 1-in-1000-yr event. This large uncertainty is narrowed when considering observations from the Kaikohe station only (Fig. 27.1d), for which a longer time series (93 years) is available. In this case, the 2014 event is still close to a 1-in-200-yr event in the GEV fit, but it is between

about a 1-in-40-yr and a 1-in-800-yr event at the 90% confidence interval (CI).

Was this event influenced by global climate change?

Figure 27.2a shows rainfall totals from the ALL and NAT model ensembles. The horizontal lines span the 5th–95th percentiles of the distribution of return periods formed by applying a standard bootstrapping technique (random resampling with replacement) to each ensemble 1000 times. Results were robust to an exploration of bootstrapping the ensembles varying numbers of times.

On this measure, the curves are separable over much of the range from approximately the 1-in-20-yr to the 1-in-400-yr event, except around the 1-in-100-yr event (gray blocks in Fig. 27.2a). Over this range of return periods, a given precipitation threshold (amount) occurs more often in the anthropogenic case than under natural forcings only. The GEV estimate for the 2014 event (1-in-200-yr) is within this range, but the long-return period end of the GEV uncertainty range is in the tail of the distribution and thus is not well characterized. A larger ensemble is necessary to address these issues more reliably as it would be expected to characterize the whole distribution better, including the tails. An identical analysis using a larger ensemble available for the year 2013 (Fig. 27.2b) reveals separability of the curves over this whole range. We also repeated the 2014 analysis using more grid points (including ocean points) in the

averaging area, and the curves showed consistently more separability over more of the range. Thus, our basic result appears robust, but it may become clearer once a larger ensemble is available for 2014.

We computed the fraction of attributable risk (FAR) proposed by Allen (2003) as $FAR = 1 - (P_n / P_a)$, where P_n and P_a are the relative frequency of the event in the NAT and ALL distributions respectively. The FAR value denotes the fraction of the risk of the event that is attributable to anthropogenic climate change.

We effectively bias corrected the model data by choosing our event threshold to be the 1-in-200-yr event in the ALL ensemble (150 mm) rather than the observed event precipitation amount (221 mm). The corresponding return period in the NAT is then approximately 1-in-350-yr. The FAR at this threshold is 0.47, indicating that 47% of the risk of such an event is attributable to anthropogenic climate change. We estimated the uncertainty in this by computing FAR at all thresholds corresponding to the range of GEV estimates (90% CI) of the “true” return period of the event. The resulting distribution of FAR values ranged from approximately 0.1 to 0.8, with a peak at around 0.27. Hence, we find almost half of the risk of an event such as that of July 2014 to be attributable to anthropogenic influence but not over the full range of uncertainty around the event threshold.

Discussion. Our result is broadly consistent with observed trends (Alexander et al. 2006), theory (Hart-

FIG. 27.2. (a) Jul maximum 5-day rainfall totals (mm) in Northland, New Zealand, from the “weather@home ANZ” model, plotted against corresponding return periods (log scale). Black diamonds show the 2772 ALL forcings simulations, and red diamonds the 5601 NAT (natural only) forcings simulations, both for 2014. The horizontal lines span the 5th–95th percentiles of the distribution of return periods computed after applying a standard bootstrapping technique (random resampling with replacement) to each distribution 1000 times. The gray blocks show approximately the range of return periods over which the curves separate on the 5th–95th percentile measure. (b) As in (a), but from runs of a very similar model setup for 2013 (instead of 2014), and having a much larger ALL ensemble (6197 simulations).

mann et al. 2013), other modeling studies (Carey-Smith et al. 2010), future projections (Sillman et al. 2013), and the attribution of extreme precipitation to anthropogenic influence for Northern Hemisphere land areas (Zhang et al. 2013). However, other studies analyzing different regions using a very similar model configuration do not find an anthropogenic influence on extreme precipitation changes, for example, Sparrow et al. (2013) and Schaller et al. (2014). This raises the question of why a stronger signal should be apparent here.

New Zealand's situation as a maritime landmass in the midlatitude westerlies means its precipitation is usually delivered via the eastward progression of low pressure systems and their interaction with orography (Sturman and Tapper 2006). There is some evidence that the most extreme events arise because of "atmospheric rivers" (Zhu and Newell 1998) of exceptionally moist air forced to make landfall in New Zealand. Dean et al. (2013) found that all the most extreme rainfall events in Golden Bay, New Zealand, were associated with very moist air of subtropical origin. Harrington et al. (2015, manuscript submitted to *Geophys. Res. Lett.*) have found that the most extreme precipitation events in Northland coincide almost exclusively with anomalously high moisture fluxes of subtropical origin, and much more so than midlatitude continental regions such as Europe. This suggests New Zealand's maritime position, with unimpeded access to the West Pacific warm pool, may make an anthropogenic signal in extreme rainfall more easily detectable. Further analysis of these ideas with the weather@home model is ongoing and requires the model to be capable of adequately reproducing observed features of the event (see online supplemental material).

Conclusions. Results from very large ensembles of regional model simulations show evidence of increased July maximum 5-day precipitation in Northland, New Zealand, in the anthropogenic world for events with return periods longer than about 1-in-20-yr. An event as extreme as that of July 2014 is estimated to change from approximately 1-in-350-yr in the "natural" world to 1-in-200-yr with anthropogenic influences, with a corresponding FAR of 47%. The results do not, however, exhibit a statistically significant change consistently over the entire range of the estimated uncertainty (90% CI) in the return period of the extreme event; thus, we suggest medium confidence in the exact degree to which anthropogenic factors increased the risk of events such as this one.

Results from a larger ensemble (but for 2013) show a significant anthropogenic influence consistently across the full range of event return period uncertainty, suggesting that additional ensemble members might strengthen these conclusions.

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REFERENCES

- Ackerley, D., S. Dean, A. Sood, and A. B. Mullan, 2012: Regional climate modelling in New Zealand: Comparison to gridded and satellite observations. *Wea. Climate*, **32** (1), 3–22.
- Ailliot, P., C. Thompson, and P. Thomson, 2011: Mixed methods for fitting the GEV distribution. *Water Resour. Res.*, **47**, W05551, doi:10.1029/2010WR009417.
- Alexander, L. V., and Coauthors, 2006: Global observed changes in daily climate extremes of temperature and precipitation. *J. Geophys. Res.*, **111**, D05109, doi:10.1029/2005JD006290.
- Allen, M. R., 1999: Do-it-yourself climate prediction. *Nature*, **401**, 642.
- , 2003: Liability for climate change. *Nature*, **421**, 891–892.
- Black, M. T., D. J. Karoly, and A. D. King, 2015: The contribution of anthropogenic forcing to the Adelaide and Melbourne, Australia, heatwaves of January 2014 [in "Explaining Extreme Events of 2014 From a Climate Perspective"]. *Bull. Amer. Meteor. Soc.*, **96** (12), S145–S148, doi:10.1011/BAMS-D-15.00098.1.
- Carey-Smith, T., S. Dean, J. Vial, and C. Thompson, 2010: Changes in precipitation extremes for New Zealand: Climate model predictions. *Wea. Climate*, **30**, 23–48.
- Dean, S. M., S. M. Rosier, T. Carey-Smith, and P. A. Stott, 2013: The role of climate change in the two-day extreme rainfall in Golden Bay, New Zealand, December 2011 [in "Explaining Extreme Events of 2012 from a Climate Perspective"]. *Bull. Amer. Meteor. Soc.*, **94** (9), S61–S63.

- Hartmann, D. L., and Coauthors, 2013: Observations: Atmosphere and surface, Supplementary material. *Climate Change 2013: The Physical Science Basis*, T. F. Stocker et al., Eds., Cambridge University Press, 30 pp. [Available online at www.climatechange2013.org/images/report/WG1AR5_Ch02SM_FINAL.pdf.]
- ICNZ, 2015: Cost of disaster events in New Zealand. Insurance Council of New Zealand. [Available online at www.icnz.org.nz/statistics-data/cost-of-disaster-events-in-new-zealand/.]
- Jones, R. G., M. Noguer, D. C. Hassell, D. Hudson, S. Wilson, G. J. Jenkins, and J. F. B. Mitchell, 2004: Generating high resolution climate change scenarios using PRECIS. Met Office Hadley Centre, 40 pp. [Available online at http://precis.metoffice.com/docs/PRECIS_Handbook.pdf.]
- Massey, N., and Coauthors, 2015: weather@home—development and validation of a very large ensemble modelling system for probabilistic event attribution. *Quart. J. Roy. Meteor. Soc.*, **141**, 1528–1545, doi:10.1002/qj.2455.
- Met Service NZ, 2015: The Northland floods of July 2014. Meteorological Service of New Zealand Ltd. [Available online at <http://blog.metservice.com/2014/07/the-northland-floods-of-july-2014/>.]
- NIWA, 2014: Monthly climate summary: July 2014. NIWA National Climate Centre. [Available online at www.niwa.co.nz/climate-summary-for-july-2014.]
- Otto, F. E. L., S. M. Rosier, M. R. Allen, N. R. Massey, C. J. Rye, and J. Imbers Quintana, 2014: Attribution analysis of high precipitation events in summer in England and Wales over the last decade. *Climatic Change*, doi:10.1007/s10584-014-1095-2, Open access.
- Pope, V., M. Gallani, P. Rowntree, and R. Stratton, 2000: The impact of new physical parameterizations in the Hadley Centre climate model: HadAM3. *Climate Dyn.*, **16**, 123–146.
- Schaller, N., F. E. L. Otto, G. J. van Oldenborgh, N. R. Massey, S. Sparrow, and M. R. Allen, 2014: The heavy precipitation event of May–June 2013 in the Upper Danube and Elbe basins [in “Explaining Extreme Events of 2013 from a Climate Perspective”]. *Bull. Amer. Meteor. Soc.*, **95** (9), S69–S72.
- Sillman, J., V. V. Kharin, F. W. Zwiers, X. Zhang, and D. Bronaugh, 2013: Climate extremes indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections. *J. Geophys. Res. Atmos.*, **118**, 2473–2493, doi:10.1002/jgrd.50188.
- Sparrow, S., C. Huntingford, N. Massey, and M. R. Allen, 2013: The use of a very large atmospheric model ensemble to assess potential anthropogenic influence on the U.K. summer 2012 high rainfall totals [in “Explaining Extreme Events of 2012 from a Climate Perspective”]. *Bull. Amer. Meteor. Soc.*, **94** (9), S36–S38.
- Sturman, A., and N. J. Tapper, 2006: *The Weather and Climate of Australia and New Zealand*. Oxford University Press, 541 pp.
- Tait, A., R. Henderson, R. Turner, and X. G. Zheng, 2006: Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall scheme. *Int. J. Climatol.*, **26**, 2097–2115, doi:10.1002/joc.1350.
- Zhang, X., H. Wan, F. W. Zwiers, G. C. Hegerl, and S.-K. Min, 2013: Attributing intensification of precipitation extremes to human influence. *Geophys. Res. Lett.*, **40**, 5252–5257, doi:10.1002/grl.51010.
- Zhu, Y., and R. E. Newell, 1998: A proposed algorithm for moisture fluxes from atmospheric rivers. *Mon. Wea. Rev.*, **126**, 725–735, doi:10.1175/1520-0493.

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.