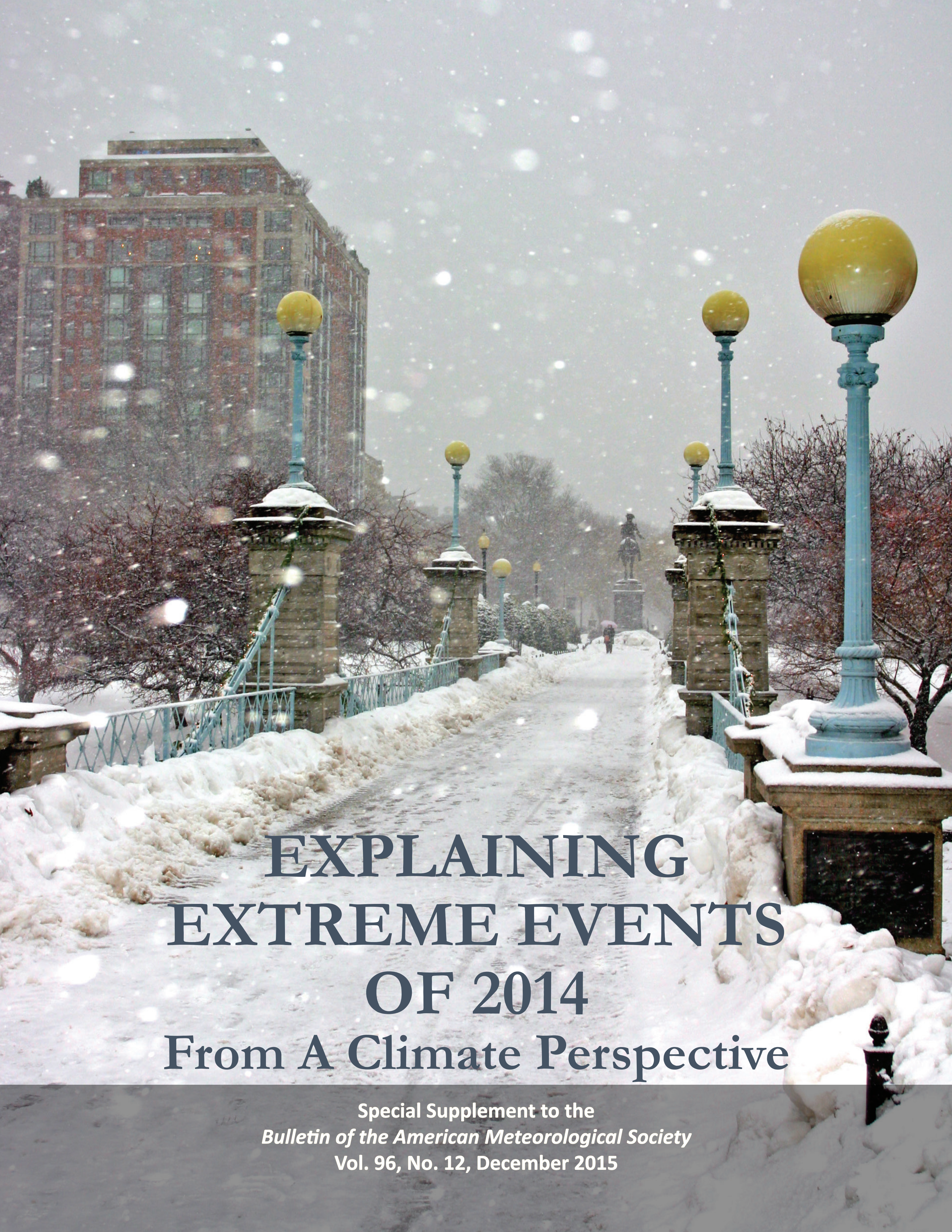

# EXPLAINING EXTREME EVENTS OF 2014

## From A Climate Perspective

Special Supplement to the
*Bulletin of the American Meteorological Society*
Vol. 96, No. 12, December 2015

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

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.

# 32. ATTRIBUTION OF EXCEPTIONAL MEAN SEA LEVEL PRESSURE ANOMALIES SOUTH OF AUSTRALIA IN AUGUST 2014

Michael R. Grose, Mitchell T. Black, James S. Risbey, and David J. Karoly

*It is likely that human influences on climate increased the odds of the extreme high pressure anomalies south of Australia in August 2014 that were associated with frosts, lowland snowfalls and reduced rainfall.*

*Introduction*. August 2014 saw very strong monthly positive mean sea level pressure (MSLP) anomalies and intense daily to multiday MSLP events south of Australia and in the Tasman Sea (Fig. 32.1a). To the west of Tasmania there were monthly anomalies of over 10 hPa (2.4 standard deviations from the mean), the highest on record since 1979 using ERA-Interim reanalysis (ERAint; Dee et al. 2011), or from 1850 using the Hadley Centre Sea Level Pressure analysis (HadSLP2r; Allan and Ansell 2006). Atmospheric blocking west of Tasmania on 10–15 August (Figs. 32.1b,c) featured the highest daily August MSLP anomaly in either record in that location. Blocking was seen in the south Tasman Sea later in the month, including the highest daily MSLP anomaly on record at that location. The spatial distribution of the monthly MSLP anomalies resembles a wave-3 pattern (Fig. 32.1a).

The strong MSLP anomalies were associated with severe frosts in southeast Australia throughout August, snow down to 200 m in parts of Tasmania on 10–11 August ahead of the particularly strong high, drier than average monthly rainfall in some regions of southern Australia, with <20% average rainfall in places (Bureau of Meteorology 2015), and a prolonged dry spell in the South Island of New Zealand from mid-August (NIWA 2015). A long-term increase in Southern Hemisphere midlatitude MSLP has already been partly attributed to anthropogenic influence (Gillett et al. 2013), and here we undertake the first event attribution of high monthly MSLP that we are aware of. We use the fraction of attributable risk (FAR) framework as adapted for climate work by Allen (2003), with August 2014 MSLP as a case study.

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*Methods*. We used the atmospheric model framework provided by *weather@home*; see Massey et al. (2015) and Black et al. (2015) for more details. We used this framework rather than coupled global climate models (GCMs) as previous studies have shown that coupled models underestimate the MSLP response to external forcings (Gillett et al. 2003, 2005; Gillett and Stott 2009; Barkhordarian 2012; Bhend and Whetton 2013) and underestimate atmospheric blocking (Scaife et al. 2010; Flato et al. 2013). Models with lower biases, including atmosphere-only models, have been shown to perform better (Scaife et al. 2010; Risbey et al. 2011).

We examined *weather@home* global simulations (1.25° latitude × 1.875° longitude resolution) forced by observed sea surface temperatures (SST) and atmospheric greenhouse gas, ozone, and aerosol concentrations labelled "all forcing" (2765 simulations). We compare these to simulations using 2014 observed SST with the mean estimated anthropogenic warming signal subtracted and estimated pre-industrial concentrations of greenhouse gases, ozone, and aerosols, labelled "natural". We examine eleven sets of "natural" simulations, produced using the anthropogenic signal estimated from each of ten GCMs (CanESM2, CCSM4, CNRM-CM5, GFDL-CM3, GISS-E2-H, GISS-E2-R, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, and MIROC-ESM) and the multimodel mean (MMM) of those ten. There were 490–511 simulations in each "natural" group. Ensembles were created using perturbed initial conditions of atmospheric variables and soil moisture.

Variability in August MSLP in the 2765 "all forcing" simulations, zonal wind at 200 hPa, and the longitudinal profile of the Bureau of Meteorology

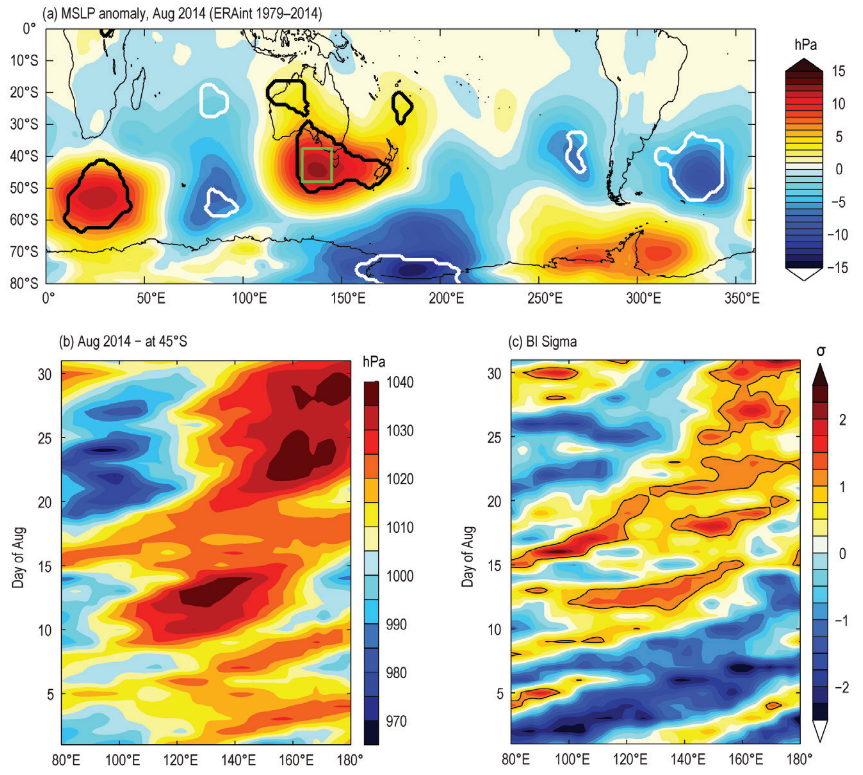

**Fig. 32.1. Mean sea level pressure during Aug 2014: (a) MSLP monthly anomaly in ERAint showing where 2014 was highest in the record (black) and lowest in the record (white) and the analysis box (green); (b) Hovmöller plot of daily MSLP in at 45°S (hPa); (c) Hovmöller plot of the daily Bureau of Meteorology blocking index (BI) plotted as standard deviations (σ) with >1 σ outlined by a black line**

blocking index (Pook and Gibson 1999) from 90° to 200°E in the "all forcing" simulations was compared to ERAint. This was not a formal evaluation, as it compared multiple simulations of 2014 to a climatology of multiple years, but was done to gauge the general model performance in terms of variability and circulation.

To avoid uncertainty in the extreme tail of distributions, event attribution studies typically use the second highest extreme rather than the actual extreme value as the threshold for FAR (e.g., Lewis and Karoly 2013). Here we used the second highest monthly MSLP in the analysis box from 1914 in HadSLP2r, 1021.0 hPa (2014 was 1025.5 hPa). We calculate FAR = 1 − Natural/All forcing and Likelihood Ratio = All forcing/Natural using pressure at this magnitude.

*Results*. The standard deviation of monthly mean August MSLP in "all forcing" simulations is broadly similar to ERAint over southern Australia (Figs. 32.2a,b). The standard deviation of MSLP in the analysis box in "all forcing" simulations it is 3.8 hPa, which lies between 4.7 hPa in ERAint in 1979–2014, and 2.4 in HadSLP2r in 1850–2014. The model also shows a similar depiction of jets and the wintertime split jet over the Tasman Sea to ERAint (Figs. 32.2c,d) and the longitudinal profile of the Bureau of Meteorology blocking index is also similar to ERAint (not shown). The model produces internal variability of August mean MSLP comparable with observed interannual variability and contains the basic components of southern hemisphere circulation similar to reanalyses.

MSLP is more than 1 hPa higher in the mean of "all forcing" compared to "natural (MMM)" simulations over the subtropical jet region in both the mean and more than 2 hPa lower over parts of the Antarctic coast (Fig. 32.2e). In the analysis box the mean difference is 1.2 hPa (range of 0.01–2.4 hPa using different "natural" simulations). There is a similar pattern in the difference of 90th percentiles of MMM, and there is a slightly different spatial pattern in each of the sets of "natural" simulations (Supplemental Figs. S32.1, S32.2). Also, geopotential height at the 500-hPa level is more positive over the positive MSLP region, zonal wind at the 500-hPa level simulations is more negative and rainfall is lower to the north of the region with negative zonal wind and positive rainfall anomalies to the south (not shown). The mean difference between "natural" and "all forcing" simulations is more zonally symmetric than the observed 2014 anomalies (Fig. 32.1a), indicating that there was a component of forced response but also a component of natural internal variability leading to the wave-3 pattern observed.

The "natural" and "all forcing" monthly data for the box (MMM shown in Fig. 32.2f) are statistically different (Kolmogorov–Smirnov test with 0.05 significance) in all cases except for the simulations using the GISS-E2-H signal. Using a generalised extreme value (GEV) distribution for the MMM simulations, FAR for the 1021.0-hPa threshold is 0.63 and the Likelihood Ratio is 2.7 (170% more likely). The FAR estimate is quite insensitive to the choice of distribution (e.g., Beta gives 0.70, Pearson gives 0.51), or to the threshold of MSLP (e.g., 1020 hPa gives 0.65, 1022 hPa gives 0.70). In the different "natural" simulations, FAR is 0.42–0.86 (mean 0.67) and Likelihood Ratio is 1.7–6.3 (mean 3.9), excluding the non-significant GISS-E2-H results (where FAR = 0.3 and Likelihood = 1.4).

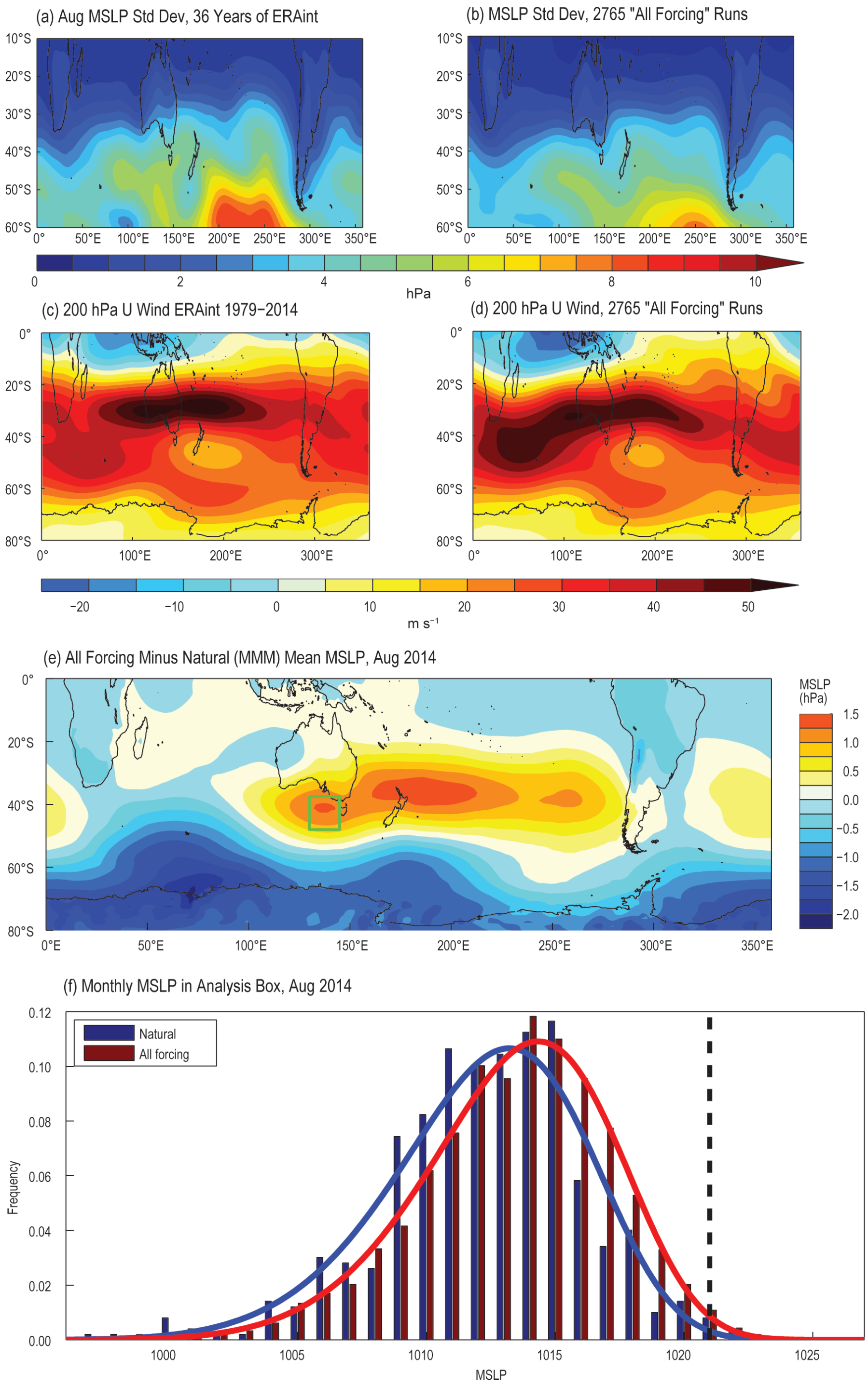

**Fig. 32.2. Aug mean sea level pressure and zonal wind: (a) MSLP standard deviation in NCEP1 1948–2014; (b) MSLP standard deviation in 2765 "all forcing" simulations; (c) zonal wind at the 200-hPa level in ERAint 1979–2014; (d) zonal wind at the 200-hPa level in the mean of "all forcing" simulations; (e) difference in MSLP between "all forcing" and "natural (MMM)" simulations (analysis box shown in green); (f) histogram and fitted GEV distribution of August MSLP in "natural" and "all forcing" simulations in the analysis box (normalized by number of simulations), dashed line marks the second highest MSLP value reached in HadSLP2r (1021 hPa) used for the FAR calculation.**

*Discussion and Conclusion.* Here we have performed the first case of event attribution of extreme monthly mean MSLP anomalies that we are aware of. The results suggest that the monthly MSLP anomaly of the intensity observed south of Australia in August 2014 was about twice as likely (at least 70%) given the climate change we have seen since pre-industrial times. Or to phrase it another way, the MSLP anomaly would have been about 1 hPa less intense without the anthropogenic influences. However, attribution was not significant using one model. For the others the attributions are modest but statistically significant, so the attribution is meaningful.

The MSLP anomalies were associated with low rainfall in southeast Australia, consistent with climate projections due to anthropogenic forcing. The MSLP anomalies were also linked to severe frosts in southeast Australia and snow down to low levels in Tasmania, so this attribution implies that human influence has contributed to an increase in the likelihood of frost, offsetting the influence of long-term warming. Also, some other notable events were possibly linked, at least in part, to the strong MSLP anomalies of August 2014 such as high temperature anomalies in parts of Western Australia and higher than average rainfall on the Australian eastern seaboard with 400% of average rainfall in places (Bureau of Meteorology 2015).

The *weather@home* modelling system provided a method for examining changes due to anthropogenic climate change while possibly avoiding many of the problems associated with coupled models such as their bias in atmospheric blocking and possible under-estimation of response to forcings. The use of a very large ensemble of atmospheric model simulations allowed us to estimate the uncertainty from initial conditions. However, the limitations of the methods used must be acknowledged. The system uses one atmospheric model and so does not sample the structural uncertainty from different models. It also assumes that removing an estimate of the climate change signal from the observations of a particular year creates a meaningful proxy for pre-industrial conditions.

This event attribution in MSLP is consistent with a wider change in the mean state of atmospheric circulation expected as greenhouse gas forcing increases, including an expansion of the Hadley Cell and poleward shift in storm tracks (Collins et al. 2013). Recent decreases in MSLP at high latitudes have already been partly attributed to greenhouse and aerosol forcings (Gillett et al. 2003, 2005; Hegerl et al. 2007) and some studies also attribute MSLP increases over the Mediterranean in winter (Gillett et al. 2003; Gillett and Stott 2009; Barkhordarian 2012). External forcing from greenhouse gasses, aerosol, and stratospheric ozone depletion each have a distinct seasonal and geographic signature on MSLP, all contributing to MSLP increase over southern Australia in winter but greenhouse gases contributing the most (Gillett et al. 2013). The results can be contrasted with Dole et al. (2011) who finds no greenhouse attribution for blocking in the Russian heatwave of 2010. The consistency in different atmospheric variables and shift in the mean climate adds physical understanding and therefore confidence to the results.

**ACKNOWLEDGEMENTS**. We thank Weather@Home at Oxford University, the Australian Detection and Attribution workshop (Will Hobbs and Nathan Bindoff), Andrew Marshall, Terry O'Kane, Peter McIntosh and Mike Pook. Michael Grose was supported by ACCSP and the Weather and Climate Extremes project, James Risbey was supported by ACCSP and GRDC. The Weather@Home ANZ simulations, and Mitchell Black and David Karoly were supported by the ARC Centre of Excellence for Climate System Science (Grant CE110001028).

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## Table 34.1. ANTHROPOGENIC INFLUENCE

### ON EVENT STRENGTH †

| | INCREASE | DECREASE | NOT FOUND OR UNCERTAIN |
|---|---|---|---|
| **Heat** | **Australia** (Ch. 31)<br>**Europe** (Ch.13)<br>**S. Korea** (Ch. 19) | | **Australia, Adelaide & Melbourne** (Ch. 29)<br>**Australia, Brisbane** (Ch.28) |
| **Cold** | | **Upper Midwest** (Ch.3) | |
| **Winter Storms and Snow** | | | **Eastern U.S.** (Ch. 4)<br>**N. America** (Ch. 6)<br>**N. Atlantic** (Ch. 7) |
| **Heavy Precipitation** | **Canada**** (Ch. 5) | | **Jakarta****** (Ch. 26)<br>**United Kingdom***** (Ch. 10)<br>**New Zealand** (Ch. 27) |
| **Drought** | **E. Africa** (Ch. 16)<br>**E. Africa*** (Ch. 17)<br>**S. Levant** (Ch. 14) | | **Middle East and S.W. Asia** (Ch. 15)<br>**N.E. Asia** (Ch. 21)<br>**Singapore** (Ch. 25) |
| **Tropical Cyclones** | | | **Gonzalo** (Ch. 11)<br>**W. Pacific** (Ch. 24) |
| **Wildfires** | | | **California** (Ch. 2) |
| **Sea Surface Temperature** | **W. Tropical & N.E. Pacific** (Ch. 20)<br>**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)<br>**Australia** (Ch. 30, Ch. 31)<br>**Australia, Adelaide** (Ch. 29)<br>**Australia, Brisbane** (Ch. 28)<br>**Europe** (Ch. 13)<br>**S. Korea** (Ch. 19)<br>**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)<br>**N. America** (Ch. 6)<br>**N. Atlantic** (Ch. 7) | 4 |
| **Heavy Precipitation** | **Canada**** (Ch. 5)<br>**New Zealand** (Ch. 27) | | **Jakarta****** (Ch. 26)<br>**United Kingdom***** (Ch. 10)<br>**S. France** (Ch. 12) | 5 |
| **Drought** | **E. Africa** (Ch. 16)<br>**S. Levant** (Ch. 14) | | **Middle East and S.W. Asia** (Ch. 15)<br>**E. Africa*** (Ch. 17)<br>**N.E. Asia** (Ch. 21)<br>**S. E. Brazil** (Ch. 8)<br>**Singapore** (Ch. 25) | 7 |
| **Tropical Cyclones** | **Hawaii** (Ch. 23) | | **Gonzalo** (Ch. 11)<br>**W. Pacific** (Ch. 24) | 3 |
| **Wildfires** | **California** (Ch. 2) | | | 1 |
| **Sea Surface Temperature** | **W. Tropical & N.E. Pacific** (Ch. 20)<br>**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.

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