# EXPLAINING EXTREME EVENTS OF 2014

## From A Climate Perspective

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# EXPLAINING EXTREME EVENTS OF 2014 FROM A CLIMATE PERSPECTIVE

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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 reemphasize the various pathways beyond climate change by which human activity can increase regional risk of extreme events.

# 14. THE CONTRIBUTION OF HUMAN-INDUCED CLIMATE CHANGE TO THE DROUGHT OF 2014 IN THE SOUTHERN LEVANT REGION

K. Bergaoui, D. Mitchell, R. Zaaboul, R. McDonnell, F. Otto, and M. Allen

*A combined modeling and observational study suggests that the persistent rainfall deficit during the 2014 rainy season in southern Levant was made more likely due to anthropogenic climate change.*

*Introduction.* While the extent to which the 2007/08 drought in the Levant region destabilized the Syrian government continues to be debated, there is no questioning the enormous toll this extreme event took on the region's population. The movement of refugees from both the drought and war affected regions into Jordan and Lebanon ensured that the anomalously low precipitation in the winter of 2013/14 amplified impacts on already complex water and food provisions.

It is hypothesized that droughts over the Levant region can be linked to three types of synoptic regimes (Saaroni et al. 2014). The regimes include 1) an expansion of the subtropical high over the majority of the Mediterranean Basin, 2) a pronounced stagnant ridge/block, and 3) an intrusion of lower-level continental polar air. The 2014 drought, affecting parts of Jordan, Lebanon, Palestine, and Israel, was characterized by extremes in low rainfall, the extent of the long dry periods, and three exceptional rainfall events that interspersed these. The drought itself was thought to be due to a large-scale winter blocking event that prevented weather systems from reaching the region (Udasin 2014).

The motivation for this study is twofold: 1) due to the instability in the Levant region, stresses such as meteorological extremes can often lead to enhanced public and political tensions. 2) There is a clear bias in the literature for looking at extreme events over industrialized countries (e.g., Herring et al. 2014)—this study provides an example in an alternative geographic region.

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*Data and Methods.* In studying the 2014 drought, one of the challenges to overcome is accessing data in this extremely politically charged region. As such, we only concentrate on precipitation changes here and discuss their relevance for wider impacts.

A spatially and temporally coherent set of station precipitation data is available from the Israeli Meteorological Service (http://data.gov.il/ims), and it follows the World Meteorological Organization quality control guidelines. The data span the period 1980–2014. Additional data for the Levant region was obtained from the Jordanian Ministry of Water and Irrigation and the Palestinian Water Authority. All station locations are plotted on Fig. 14.1a, and these stations provide the longest reliable record available for this region. In addition, we use the gridded E-OBS dataset (Haylock et al. 2008) to put the analysis in the context of longer-term climate variability.

Often direct observational inferences of extreme events are highly uncertain due to small sample sizes (e.g., Sipple et al. 2015). This is especially true in the Levant region. One well-established technique to circumvent this issue is using climate models to run many thousands of simulations of "possible" climate, thereby sampling internal climate variability. Here, we make use of the weather@home project (Massey et al. 2015), which allows us to run many thousands of simulations for 2014 over the region of interest. We use the atmosphere-only model, HadAM3P, to drive a regional model (HadRM3P) that simulates climate for mid-northern Africa and the southern Levant

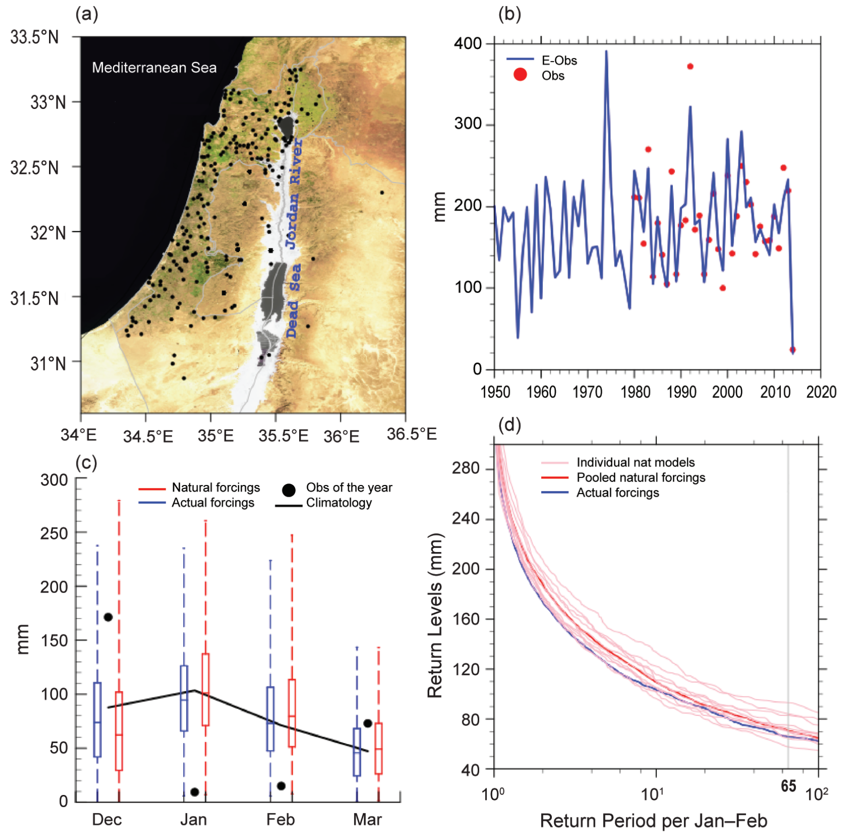


**Fig. 14.1. (a) A map of the southern Levant region, showing the topography, political boundaries, and station locations. The region is bounded by 46°N–14°S and 25°W–63°E. (b) The cumulative rainy season (JF) precipitation totals for each year of the observational record averaged over the whole domain. The dots show stations, and the blue line shows E-OBS. The correlation coefficient between these datasets is ~0.94. (c) The monthly observed climatology (black line) of domain-averaged precipitation from 1980 to 2014. The 2013/14 values are plotted as black circles. Box-and-whisker plots show the median, interquartile range, and range for the biased corrected model data for actual conditions (blue) and natural conditions (red). (d) Return level plots of cumulative precipitation for Jan and Feb during the rainy season for natural conditions (red) and actual conditions (blue). Gray line shows the 65-year return level. Individual natural SST patterns are shown with thin pink lines, and the pooled SST pattern is shown with a thick orange line.**

at 50-km resolution. The details are the same as the European model described in Massey et al. 2015.

To perform the 2014 event attribution, we simulate two possible climates under 2014 conditions: 1) an experiment with all known natural and anthropogenic climate forcings ("actual conditions") and 2) an experiment with only natural climate forcings ("natural conditions"). All anthropogenic and natural conditions follow the recommendations outlined by the Intergovernmental Panel on Climate Change (IPCC; Solomon et al. 2007). For the actual conditions experiment, the sea surface temperatures (SSTs) are taken from Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) observations (Stark et al. 2007). For the natural conditions experiment, the anthropogenic signal is taken out of the OSTIA SST patterns to leave only the naturalized SST pattern. The anthropogenic fingerprint is calculated by differencing the Coupled Model Intercomparison Project Phase 5 (CMIP5) "historical" and "historicalNat" simulations from 11 GCMs that performed these experiments and then subtracting this change in SST pattern from the OSTIA SSTs (see Schaller et al. 2014 for details). The use of 11 different models gives us 1 potential naturalized SST pattern.

*The observed perspective.* Figure 14.1b shows the extreme persistence of this two-month precipitation deficit event is unprecedented in the observational record. The cumulative JF precipitation for 2014 is clearly an outlier over the 1950–present period. Figure 14.1c shows the monthly climatology of observed precipitation along with the specific 2013/14 observed values. In December, the precipitation was in the upper quartile of the observed range, and most of that was due to a 10-day extreme downpour midway into the month (not shown). Following that wet extreme event, both January and February had the lowest rainfall since observations began. While the wet and dry events balance out in the seasonal average, the extreme persistence of this two-month precipitation deficit event is unprecedented.

*The modeled perspective.* To understand how anthropogenic climate change increased the likelihood of such a persistent drought, we use climate simulations to sample the internal climate variability during the rainy season of 2013/14. A well-known issue is the large dry bias in precipitation over this region, which may be due to any combination of 1) the varied land cover/topography and relationship to convection in the region, 2) the representation of Mediterranean storm tracks in models (Anagnostopoulou et al. 2006), or 3) capturing upslope flow of moist air masses (Black 2009). In general, models have trouble capturing all the complex factors contributing to precipitation in this region. Here, we make the plausible assumption that the statistics of observed precipitation are quasi stationary over the 30-year period, and we use this as a climatology to evaluate the regional model. Comparing the cumulative distribution functions (CDFs) of the observations and the model simulations, it is also found that there is a dry bias in the model. In Supplementary Fig. S14.1, we show the CDFs for grid boxes with the lowest and highest biases, respectively. The bias was found to be linearly changing, with no significant difference between the "actual" and "natural" simulations, suggesting that it was not a result of misrepresentation of large-scale climate modes. To correct the bias, we use a nonparametric quantile mapping technique, matching estimated empirical quantiles between the observations and the "actual conditions" model scenario (Boe et al. 2007). The same bias correction is then applied to the natural model scenario. Figure 14.1c shows the bias corrected actual conditions and natural conditions model data plotted as box-and-whisker plots. There is a tendency for the actual conditions scenario to have less extreme precipitation with a persistently drier mean state (at least for January–March). Return level plots of these data averaged over the whole domain are shown in Fig. 14.1d, and the natural forcings scenario shows wetter conditions than the actual conditions throughout.

Figure 14.2a expands on this by showing the region averaged, January–February averaged, and 65-year return levels for the actual scenario and natural scenarios based on the individual estimates of naturalized SSTs. In general, meteorological drought conditions are more frequent in the actual conditions scenario, and this holds true for 9 out of 11 of the estimated naturalized experiments. For instance, the average return level in the natural scenarios is estimated to have around ~10 mm more precipitation than the actual conditions scenario.

To understand these differences in more detail, we calculate the Fraction of Attributable Risk (FAR; Allen 2003), defined as FAR = 1 – ($p_{nat}$ / $p_{act}$), where $p_{nat}$ is the probability of a rainfall deficit as low as or lower than the observed 2014 January–February

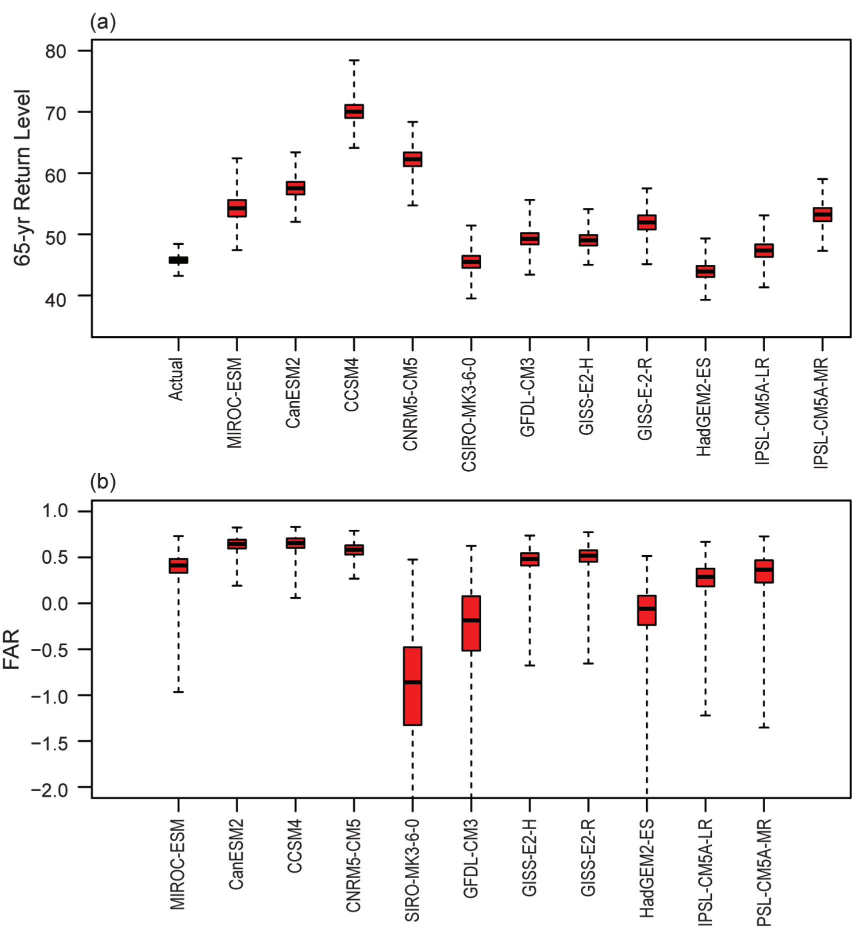


**Fig. 14.2. (a) 65-year return levels over the entire region for the actual conditions (blue) and the individual estimates of natural conditions (red). (b) As in (a), but for estimates of the FAR. The uncertainty estimates are calculated by randomly resampling (with replacement) the underlying distribution 10 000 times. The bars show the median, interquartile range, and range of uncertainty.**

average in the individual natural conditions scenarios, and $p_{act}$ is the same but for the actual conditions. From Fig. 14.2b, it is shown that the persistent drought of 2014 was made more likely because of the anthropogenic climate change signal, indicating that patterns of precipitation are shifting to a drier state in this region. The mean FAR is ~0.45, indicating that anthropogenic climate change made the event ~45% more likely. This is consistent with the predicted weakening of the Mediterranean storm tracks in a warming climate (Hatzaki et al. 2009), a response that is captured in our model (Anagnostopoulou et al. 2006). The increased SSTs between our actual and natural simulations are relatively uniform across the globe (e.g., Schaller et al. 2015, manuscript submitted to *Nat. Climate Change*, their Fig. S3), and Hoerling et al. 2012 showed that this would induce an Eastern Mediterranean drying through circulation changes, also consistent with our detected response.

*Discussion.* In this study, we have used local station data to understand the uniquely persistent drought that occurred in the southern Levant rainy season of 2014. We show that the event was unprecedented for the critical January–February period in the observational record, and through modeling the event, we showed that anthropogenic climate change made it ~45% more likely. However, our model is dry-biased in the region of interest, most likely due to a lack of very intense cyclones in the Mediterranean region (Anagnostopoulou et al. 2006). If changes in these processes are nonlinear under human-induced emissions, our model is unlikely to capture them fully. This wet season is when reservoirs and groundwater systems are recharged and snow pack accumulates to support summer streamflows. The consequent external stresses that came with this drought, such as crop failures, degraded grazing land, and overpumping of nonrenewable groundwater, suggest that water and agriculture authorities in the southern Levant region should have additional fail-safes in place going into the future.

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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.

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