important general point: even if a particular flood event may have been made more likely by human influence on climate, there is no certainty that all kinds of flood events in that location, country or region have been made more likely.

Rahmstorf and Coumou (2011) provide an example of an empirical approach to the estimation of attributable risk applied to the 2010 Russian heat wave. They fit a nonlinear trend to central Russian temperatures and show that the warming that has occurred in this region since the 1960s has increased the risk of a heat wave of the magnitude observed in 2010 by around a factor of 5, corresponding to an FAR of 0.8. They do not address what has caused the trend since 1960, although they note that other studies have attributed most of the large-scale warming over this period to the anthropogenic increase in GHG concentrations.

Dole et al. (2011) take a different approach to the 2010 Russian heat wave, focussing on attributable magnitude, analysing contributions from various external factors, and conclude that this event was 'mainly natural in origin'. First, observations show no evidence of a trend in occurrence frequency of hot Julys in western Russia, and despite the warming that has occurred since the 1960s, mean July temperatures in that region actually display a (statistically insignificant) cooling trend over the century as a whole, in contrast to the case for central and southern European summer temperatures (Stott et al., 2004). Members of the CMIP3 multi-model ensemble likewise show no evidence of a trend towards warming summers in central Russia. Second, Dole et al. (2011) note that the 2010 Russian event was associated with a strong blocking atmospheric flow anomaly, and even the complete 2010 boundary conditions are insufficient to increase the probability of a prolonged blocking event in this region, in contrast again to the situation in Europe in 2003. This anomaly in the large-scale atmospheric flow led to low-pressure systems being redirected around the blocking over Russia causing severe flooding in Pakistan which could so far not be attributed to anthropogenic causes (van Oldenborgh et al., 2012), highlighting that a global perspective is necessary to unravel the different factors influencing individual extreme events (Trenberth and Fasullo, 2012).

Otto et al. (2012) argue that it is possible to reconcile the results of Rahmstorf and Coumou (2011) with those of Dole et al. (2011) by relating the attributable risk and attributable magnitude approaches to framing the event attribution question. This is illustrated in Figure 10.18c, which shows return times of July temperatures in western Russia in a large ensemble of atmospheric model simulations for the 1960s (in green) and 2000s (in blue). The threshold exceeded in 2010 is shown by the solid horizontal line which is almost 6°C above 1960s mean July temperatures, shown by the dashed line. The difference between the green and blue lines could be characterized as a 1.5°C increase in the magnitude of a 30-year event (the vertical red arrow, which is substantially smaller than the size of the anomaly itself, supporting the assertion that the event was 'mainly natural' in terms of attributable magnitude. Alternatively, it could be characterized as a threefold increase in the risk of the 2010 threshold being exceeded, supporting the assertion that risk of the event occurring was mainly attributable to the external trend, consistent with Rahmstorf and Coumou (2011). Rupp et al. (2012) and Hoerling et al. (2013) reach similar conclusions about the 2011 Texas heat wave, both noting the importance of La Niña conditions in the Pacific, with anthropogenic warming making a relatively small contribution to the magnitude of the event, but a more substantial contribution to the risk of temperatures exceeding a high threshold. This shows that the quantification of attributable risks and and changes in magnitude are affected by modelling error (e.g., Visser and Petersen, 2012) as they depend on the atmospheric model's ability to simulate the observed anomalies in the general circulation (Chapter 9).

Because much of the magnitude of these two heat waves is attributable to atmospheric flow anomalies, any evidence of a causal link between rising GHGs and the occurrence or persistence of flow anomalies such as blocking would have a very substantial impact on attribution claims. Pall et al. (2011) argue that, although flow anomalies played a substantial role in the autumn 2000 floods in the UK, thermodynamic mechanisms were primarily responsible for the change in risk between their ensembles. Regardless of whether the statistics of flow regimes themselves have changed, observed temperatures in recent years in Europe are distinctly warmer than would be expected for analogous atmospheric flow regimes in the past, affecting both warm and cold extremes (Yiou et al., 2007; Cattiaux et al., 2010).

In summary, increasing numbers of studies are finding that the probability of occurrence of events associated with extremely high temperatures has increased substantially due to the large-scale warming since the mid-20th century. Because most of this large-scale warming is *very likely* due to the increase in atmospheric GHG concentrations, it is possible to attribute, via a multi-step procedure, some of the increase in probability of these regional events to human influence on climate. Such an increase in probability is consistent with the implications of single-step attribution studies looking at the overall implications of increasing mean temperatures for the probabilities of exceeding temperature thresholds in some regions. We conclude that it is *likely* that human influence has substantially increased the probability of occurrence of heat waves in some locations. It is expected that attributable risks for extreme precipitation events are generally smaller and more uncertain, consistent with the findings in Kay et al. (2011a) and Pall et al. (2011). The science of event attribution is still confined to case studies, often using a single model, and typically focussing on high-impact events for which the issue of human influence has already arisen. While the increasing risk of heat waves measured as the occurrence of a previous temperature record being exceeded can simply be explained by natural variability superimposed by globally increasing temperature, conclusions for holistic events including general circulation patterns are specific to the events that have been considered so far and rely on the representation of relevant processes in the model.

Anthropogenic warming remains a relatively small contributor to the overall magnitude of any individual short-term event because its magnitude is small relative to natural random weather variability on short time scales (Dole et al., 2011; Hoerling et al., 2013). Because of this random variability, weather events continue to occur that have been made less likely by human influence on climate, such as extreme winter cold events (Massey et al., 2012), or whose probability of occurrence has not been significantly affected either way. Quantifying how different external factors contribute to current risks, and how risks are

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Rahmstorf und Coumou (2011) geben ein Beispiel eines empirischen Ansatzes zur Abschätzung des zurechenbaren Risikos, angelehnt an die Russische Hitzewelle 2010. Sie passen einen nicht-linearen Trend an die Temperaturen von Zentralrussland an und zeigen, dass die Erwärmung, die in dieser Region seit den 1960er Jahren aufgetreten ist, das Risiko einer Hitzewelle, die im Jahr 2010 beobachtet wurde, in der Größenordnung um etwa einen Faktor 5 erhöht hat, entsprechend einer FAR[*] von 0,8. Sie [Rahmstorf und Coumou] befassen sich nicht damit, was den Trend seit 1960 verursacht hat, obwohl sie beachtet haben, dass andere Studien die umfangreiche Erwärmung in diesem Zeitraum meistens dem anthropogenen Anstieg an der Treibhausgas (GHG)-Konzentrationen zugeschrieben haben.

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FAR = **F**ALSE **A**LARM **R**ATE