Extreme Weather and Climate
Week 2

Presented by

Ken Sinclair

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Overview

Required

- Climate extremes and climate change: The Russian heat wave and other climate extremes of 2010 (Trenberth, 2012)
- Was there a basis for anticipating the 2010 Russian heat wave? (Dole, 2011)
- Increase of extreme events in a warming world (Rahmstorf, 2012)
- Reconciling two approaches to attribution of the 2010 Russian heat wave (Otto, 2012)

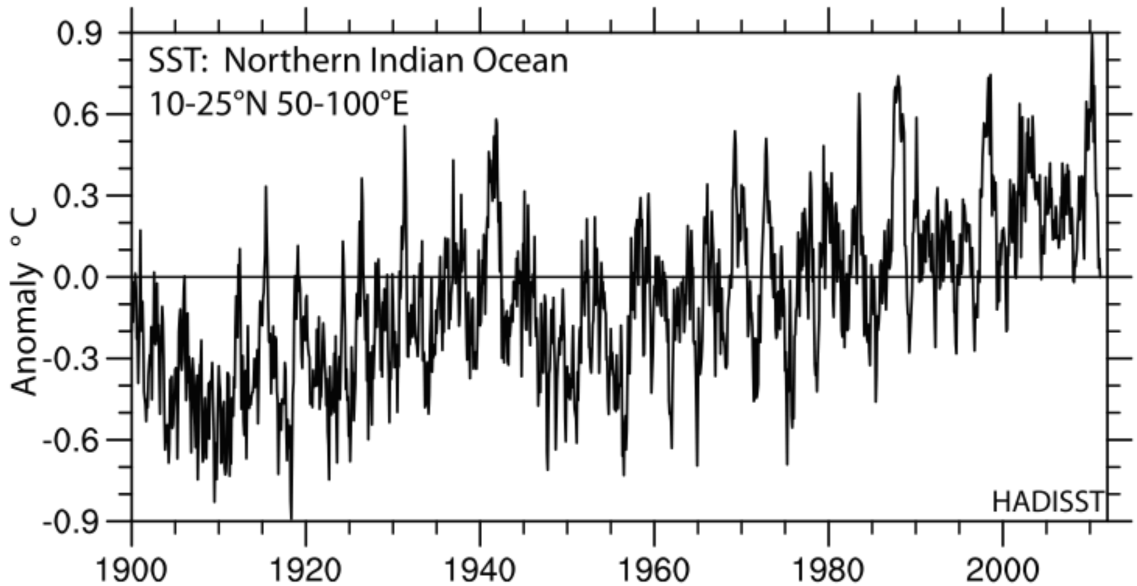
Optional

- European Seasonal and Annual Temperature Variability, Trends,and Extremes Since 1500 (Luterbacher, 2004)
- Doubled length of western European summer heat waves since 1880 (Della-Marta, 2007)

Trenberth 2012

Figure 1

- Natural variability, especially ENSO, and global warming from human influences together resulted in very high sea surface temperatures (SSTs) in several places that played a vital role in subsequent developments.
- In 2010, record high SSTs in many regions were in close proximity to places where record flooding subsequently occurred. As we show here, this is unlikely to be a coincidence.
- For example in the United States, extremes of high temperatures have been occurring at a rate of twice those of cold extremes [Meehl et al., 2009].



- *Monthly anomalies in SST (°C) for 10-25°N 50–100°E encompassing the Arabian Sea and Bay of Bengal. May 2010 is the highest anomaly (0.9°C) on record and the SST was 30.4°C. This figure uses the HADISST data, but values are similar in the ERSST data set.*

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Figure 2

- Positive SST anomalies in the central and eastern Pacific during El Niño tend to focus convective activity into those regions while suppressing activity elsewhere via changes in atmospheric stability and wind shear.
- There are many examples of climate extremes in 2010 but especially notable are those following the demise of the May 2009 to May 2010 El Niño when record high SSTs developed.
  - intense heavy rains and flooding in parts of China and India (June, July) and Pakistan (July, August);
  - the Russian heat wave and wild fires (July, August);
  - the vigorous Atlantic hurricane season;
  - record flooding in Colombia (October–December);
  - drought in Brazil (October);
  - flooding in Queensland, Australia as the year came to an end.

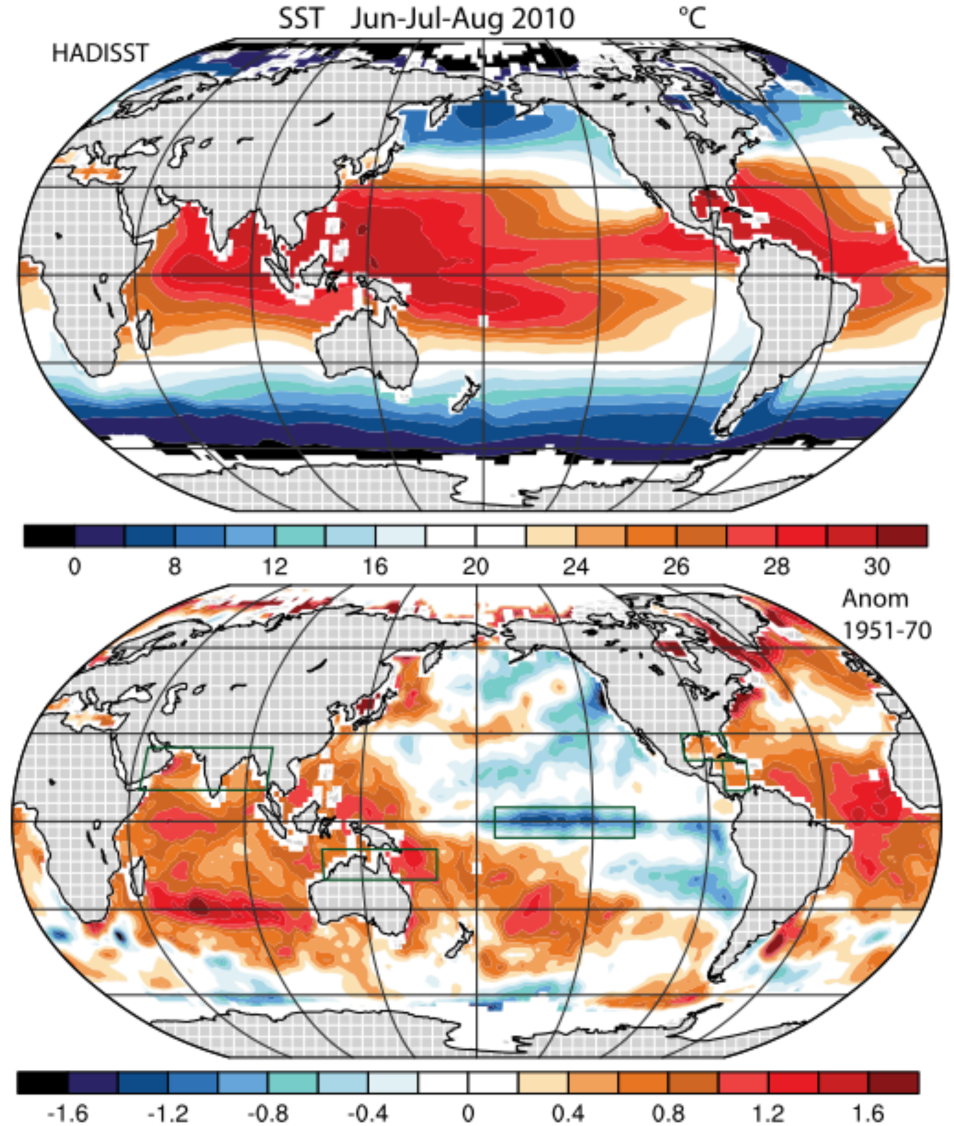

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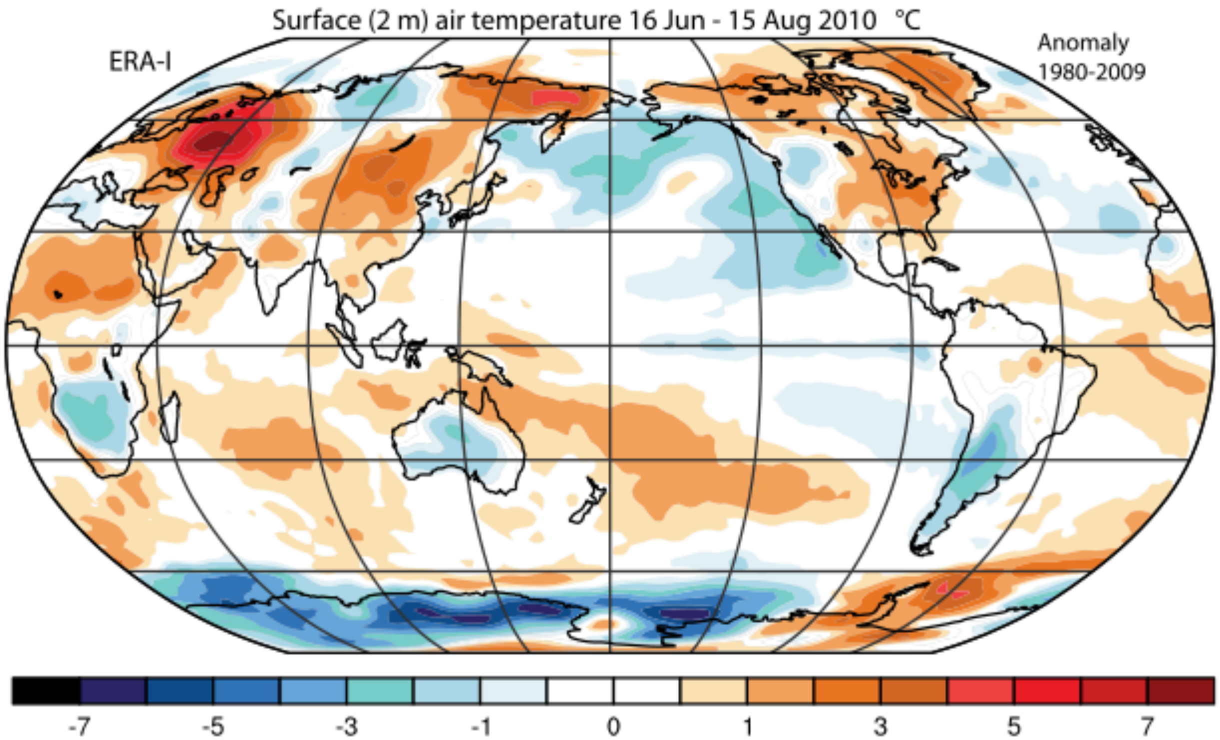
Figure 3



- The associated atmospheric phenomenon was a persistent blocking anticyclone.
- Why was the blocking so persistent and strong?
- Rahmstorf and Coumou [2011] suggest that there was an approximate 80% probability that the 2010 July Russian heat record would not have occurred without climate warming
- The surface air temperature anomalies (Figure 3) are dominated by the RHW, where they exceeded 7C for 16 June to 15 August 2010.

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Figure 4

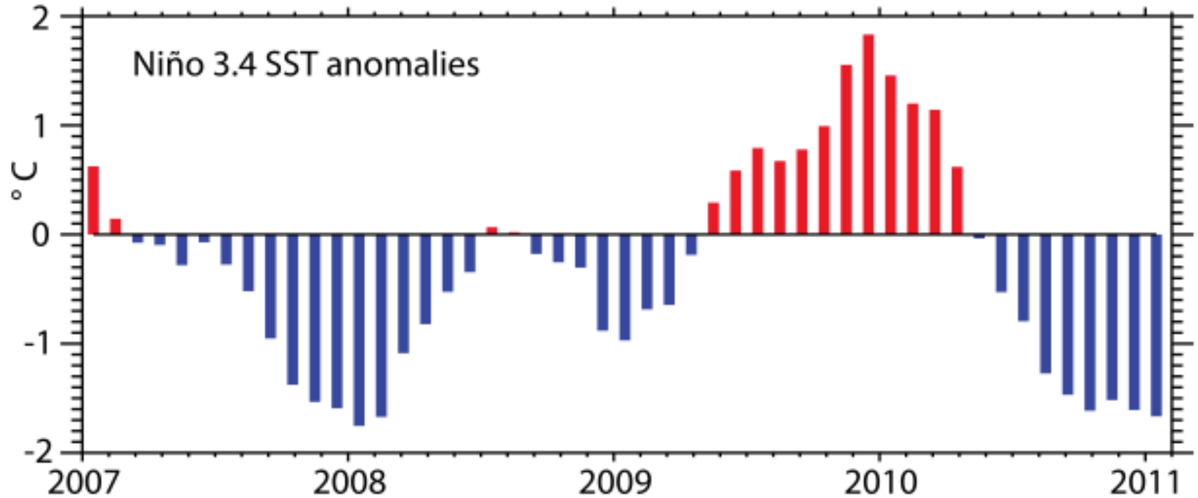

Figure 4. Time series of Niño 3.4 (5°N-5°S, 120–170°W) SST anomalies relative to 1951–2010.

- The time series of Niño 3.4 region (5N-5S; 120–170W) SSTs indicates ENSO conditions and shows the El Niño persisting through April 2010 but rapidly gave way to La Niña conditions by June. During La Niña, convective action moves away from the tropical Pacific into the Indonesian and Indian Ocean sector, and tropical Atlantic.

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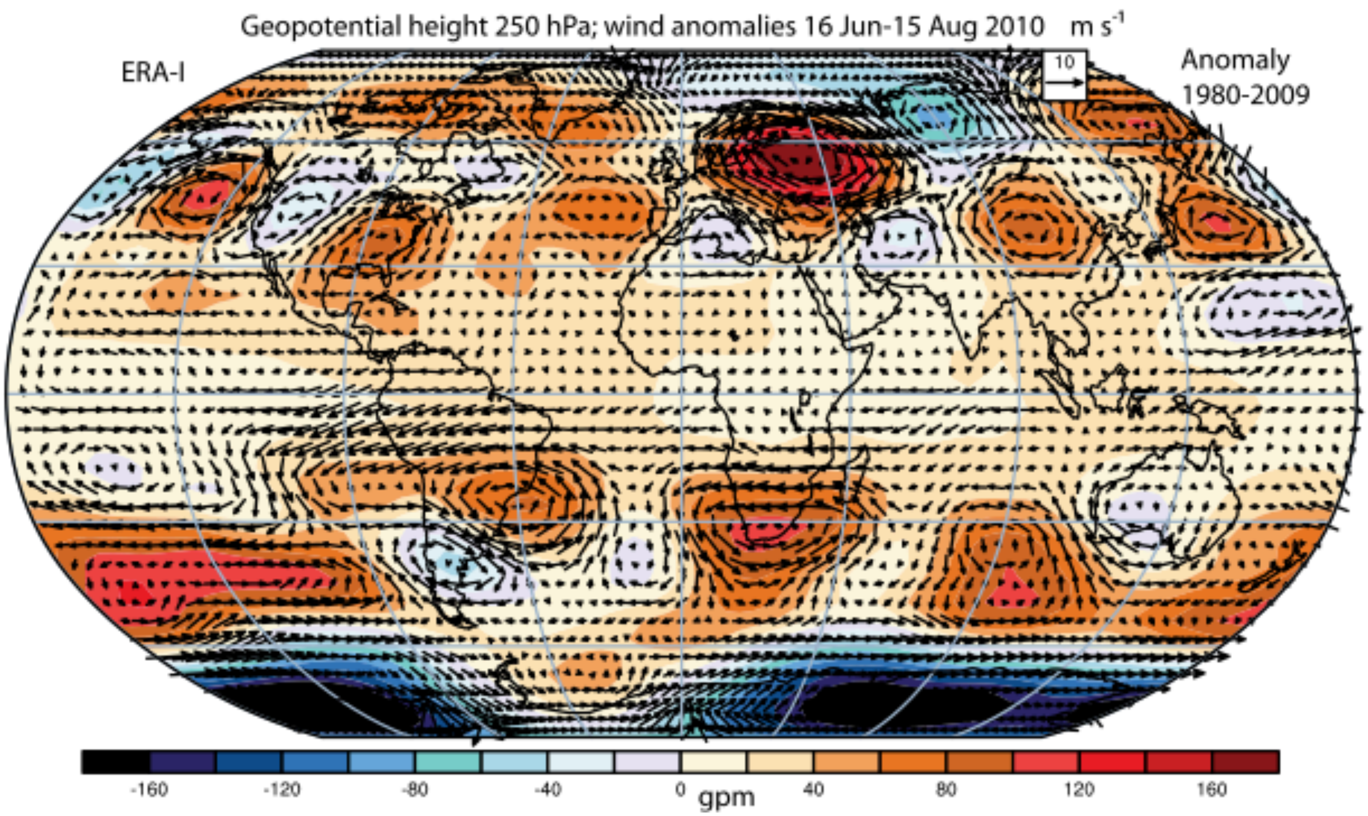
Figure 5



• The anomalous atmospheric circulation is indicated by the winds and geopotential height at 250 hPa (Figure 5). While large anomalies are not unexpected in the winter hemisphere, the strong anticyclonic feature centered over Russia is very unusual mainly due to its exceptional duration and intensity.

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Figure 6

• OLR anomalies show a strong La Niña signature with very high OLR, signaling low cloud tops and less deep convection and precipitation in the tropical Pacific east of 135E, but with anomalous deep convection and high cloud tops west of 135E over Indonesia and extending throughout the northern Indian Ocean.

• The total OLR field (Figure 6) reveals OLR less than 190 W m^2 in the Bay of Bengal as the dominant global feature.

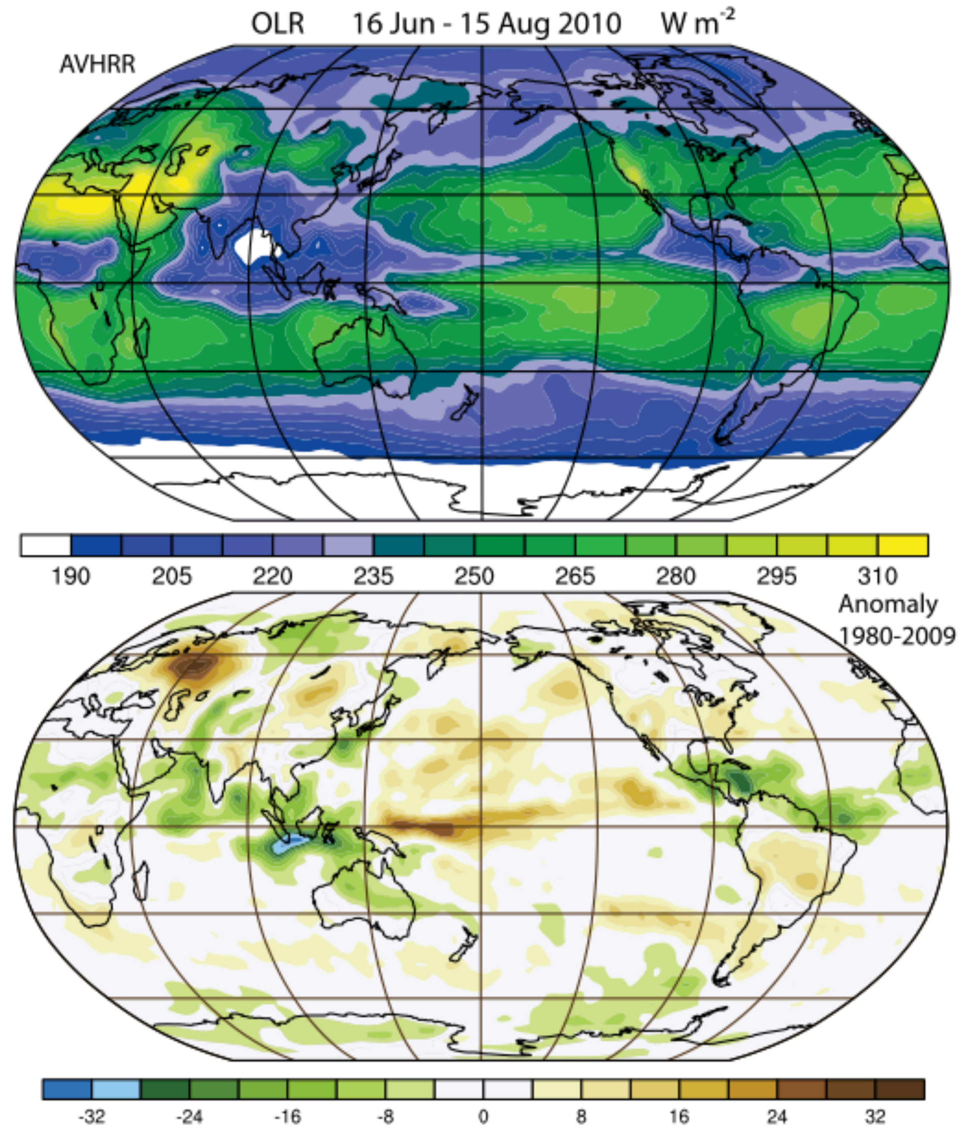

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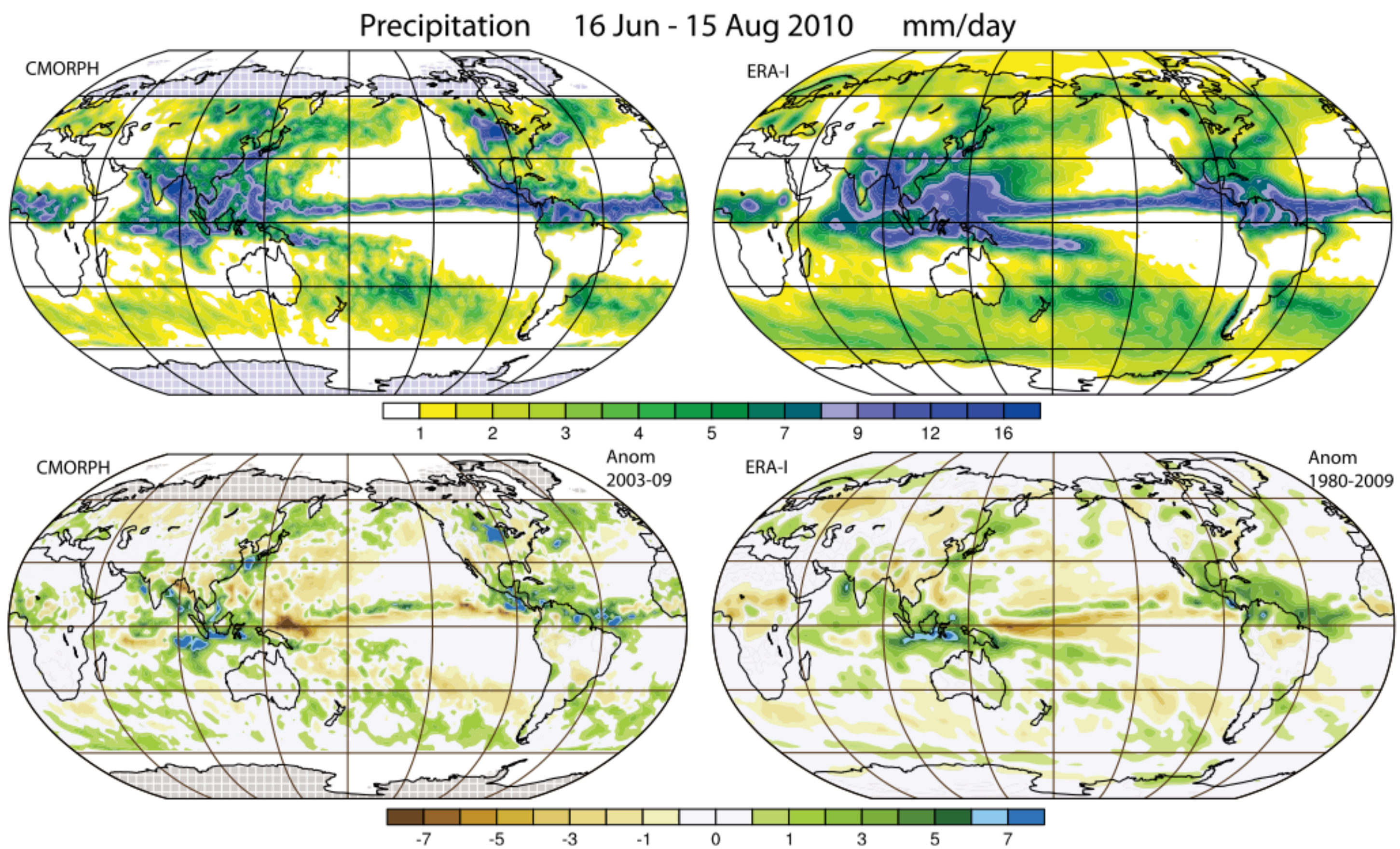
Figure 7



- The precipitation analyses confirm the very heavy rains over the Bay of Bengal and Arabian Sea, extending into Pakistan, and also near the equator northwest of Australia.
- *Precipitation (top) total and (bottom) anomaly for 16 Jun–15 Aug 2010 based on (left) CMORPH and (right) ERA-I reanalyses in mm/day.*

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Figure 8

- The vertically integrated moisture fluxes reveal the low level flow and hence the regions where SSTs are especially important, such as the Arabian Sea. The moisture was advected into the rain areas, and contributed to the heavy rains and flooding in Pakistan that had some predictability up to 8 days in advance.
- Unusual synoptic events in late July 2010 led to the main Pakistan flooding.
- Figure 8 reveals the strong evaporative sources in the sub- tropics and western Arabian Sea and the negative anomalies reveal the excess of precipitation, in good agreement with Figure 7.

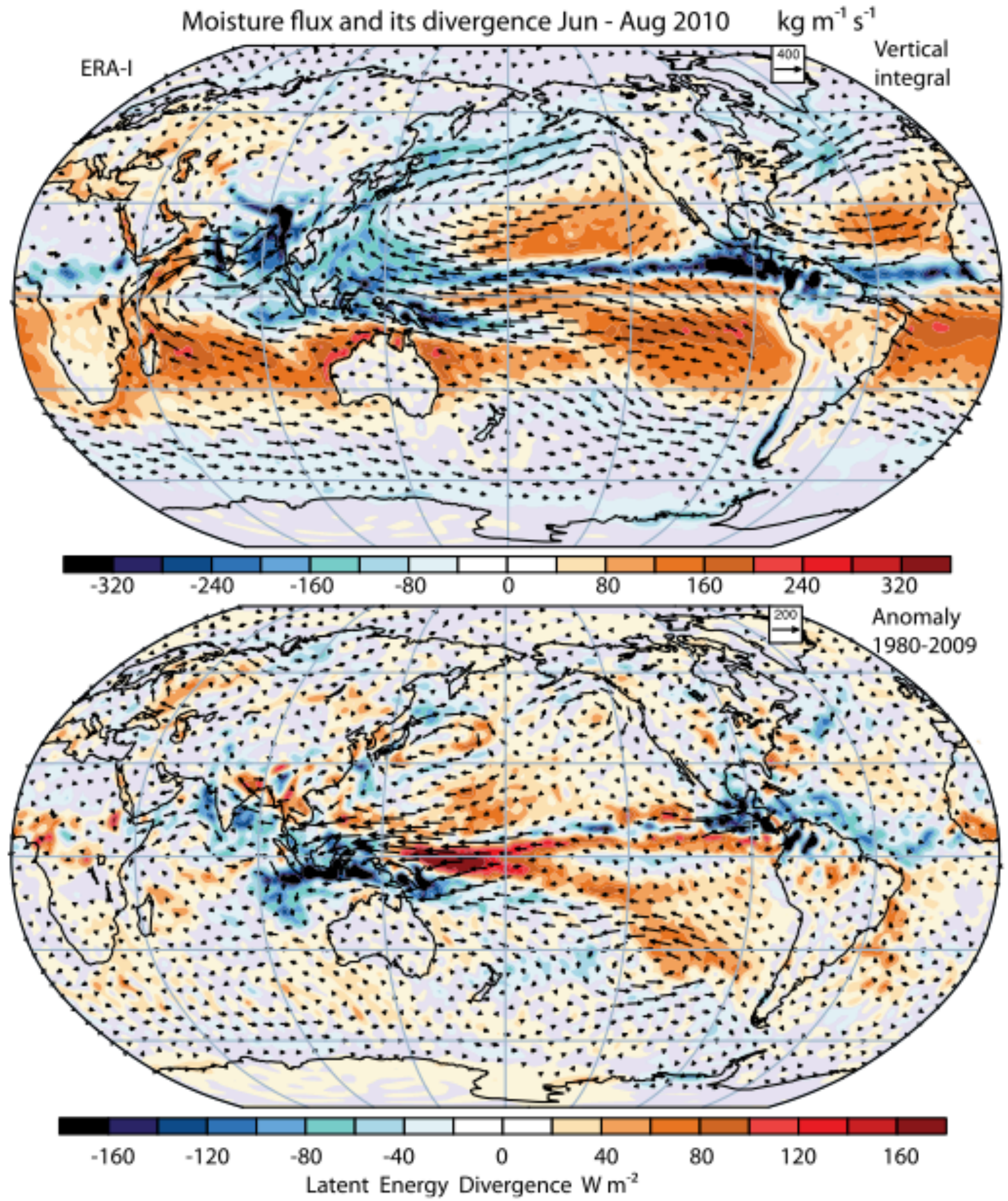

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Figure 9

- Atmospheric diabatic heating computed from the mass balanced energy budget is dominated by latent heating from precipitation and exceeded 100 W m^2 over large areas in the northern Indian Ocean and adjacent monsoon region, the Caribbean and tropical Atlantic, and was >300 W/m^2 in places, with anomalies over 100 W/m^2 over some of these regions.
- The anomalies in diabatic heating confirm that the main anomalous atmospheric heating was associated with latent heating from precipitation.

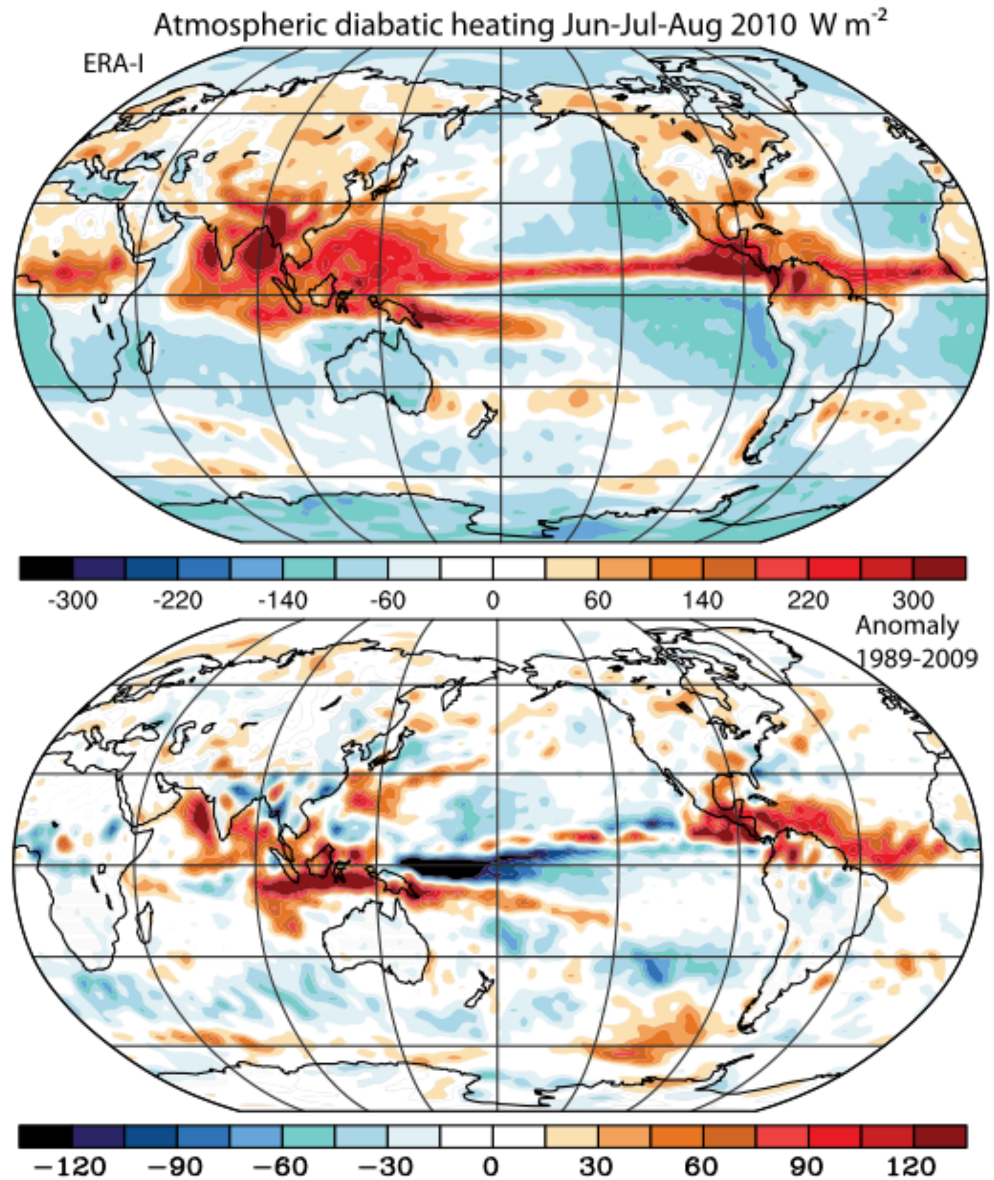

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Figure 10

- The divergent wind flow field and the corresponding velocity potential at 250 hPa and 850 hPa reveal where the low level flow at 850 hPa is largely the reverse of that in the upper troposphere at 250 hPa, indicative of the overturning monsoonal-type circulation.
- These fields reveal the iconic Hadley and Walker Cell circulations embedded in the overall flow as well as the monsoonal link toward the Mediterranean Sea area.

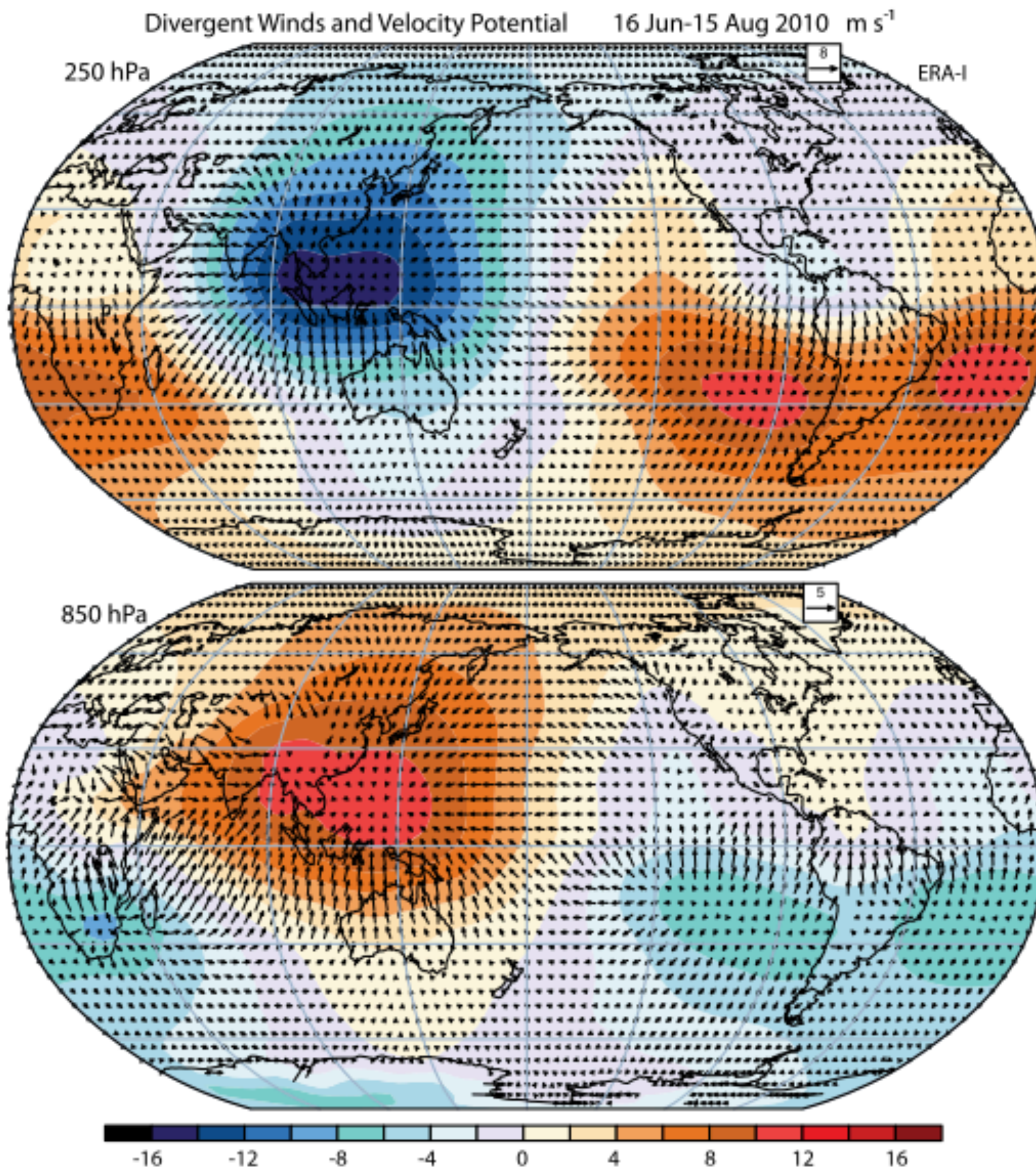

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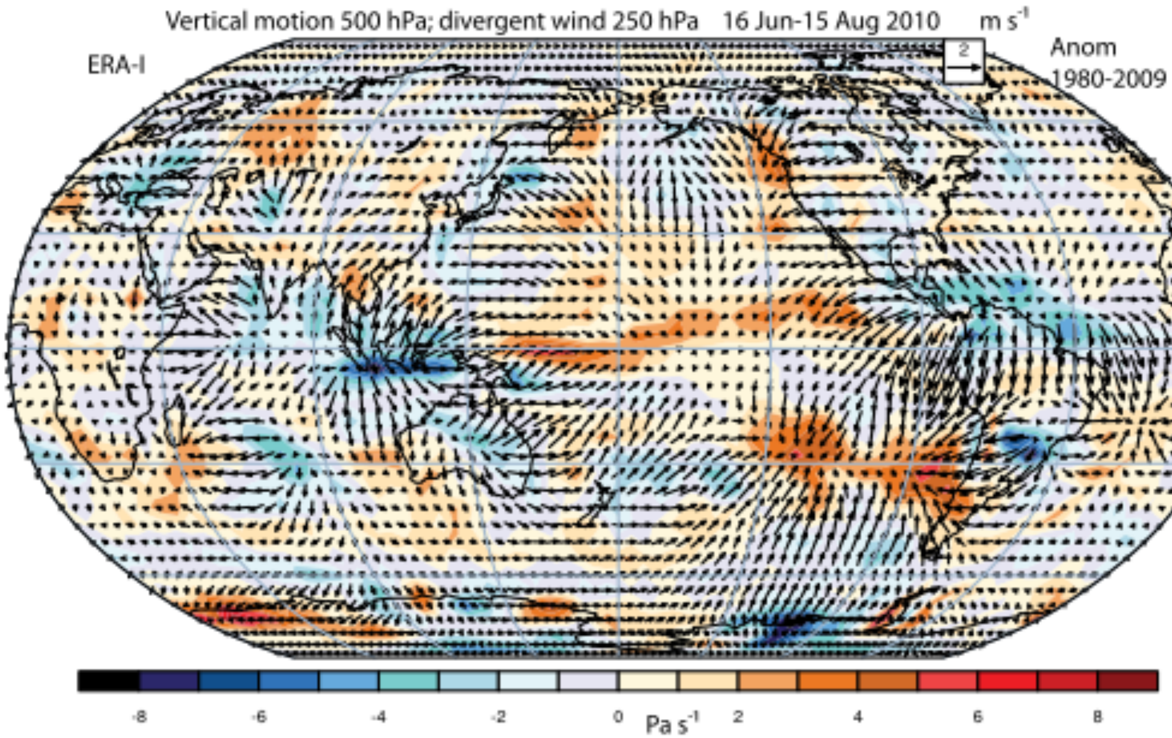
Figure 11



- Figure 11 shows the anomalous vertical motion (omega) field at 500 hPa with the anomalous divergent velocity vectors at 250 hPa superposed. These fields may include some effects from spurious changes in the observing system.
- It indicates the exceptional vigor of the outflow region in the Asian monsoon with some penetration to the region northeast of the Caspian Sea, while the cyclonic structure over the northern Mediterranean and Black Sea region (Figure 5) suggests that the normal anticyclonic subsidence there has been shifted to the RHW region.

Trenberth 2012

Figure 13

- Figure 13 presents the regional circulation anomalies at 250 hPa for 16 Jun–15 Aug 2010 for the stream function field, which is similar to the geopotential height field but accounts for the variations in the Coriolis parameter with latitude, and hence the anomalies are more uniform with latitude in magnitude.
- The second part of this figure shows a time slice along this line of the stream function anomalies for Jun–Aug 2010.
- Note in particular the strong anticyclonic disturbance originating in the tropical North Atlantic in the second half of June that led directly to the main intensification of the blocking anticyclone over Russia in mid-July.
- The structures revealed are strongly suggestive of a quasi-stationary Rossby wave that is enhanced by converging wave-activity with the strong tendency for the blocking high to reform in the same location

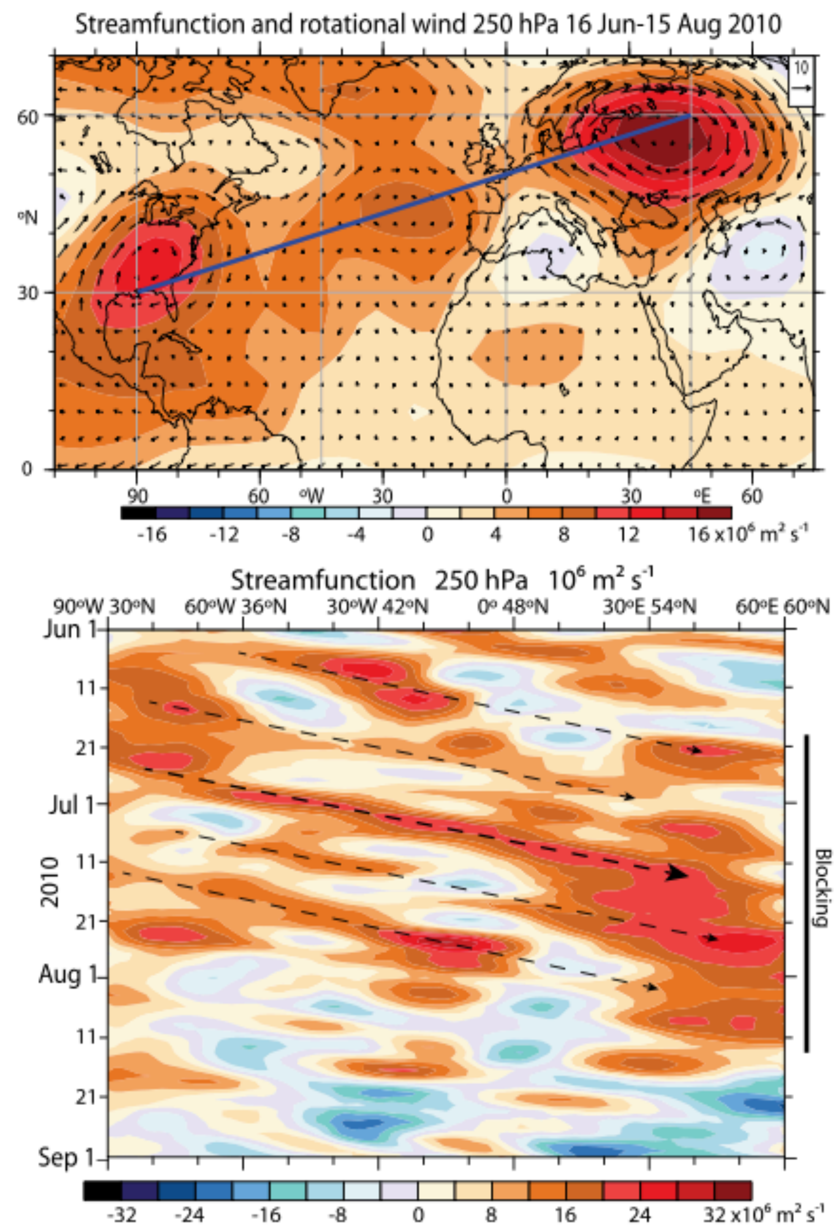


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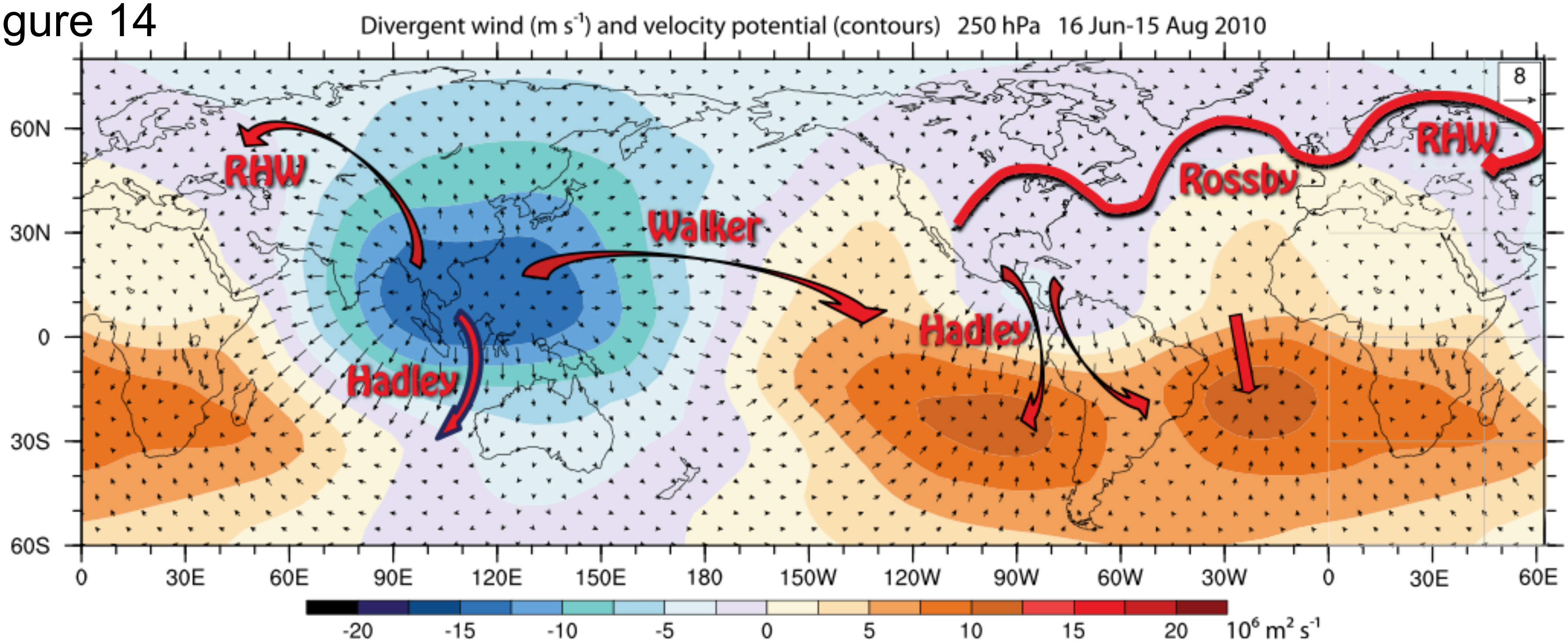
Figure 14



- An interpretation of the RHW in 2010 is that the canonical settled weather regime associated with the downward branch of Asian summer monsoon was extended eastward over southern Russia partly in response to the wave train from the strong persistent anomalous convection in the tropical Atlantic and the intensity was enhanced by the anomalous monsoon heating and circulation.
- It shows the direct link between the monsoon rains and the subsiding air in the blocking anticyclone over Russia.
- It also reveals the Hadley circulation to the south, and the Walker circulation to the east, made stronger by the La Niña conditions

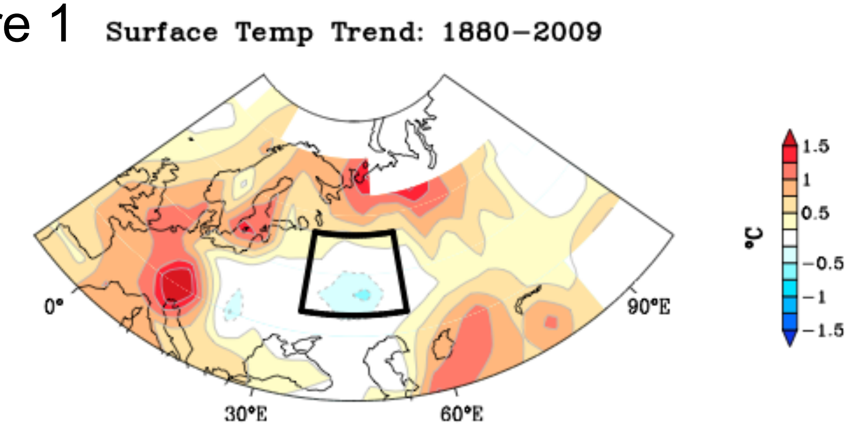
Dole 2011

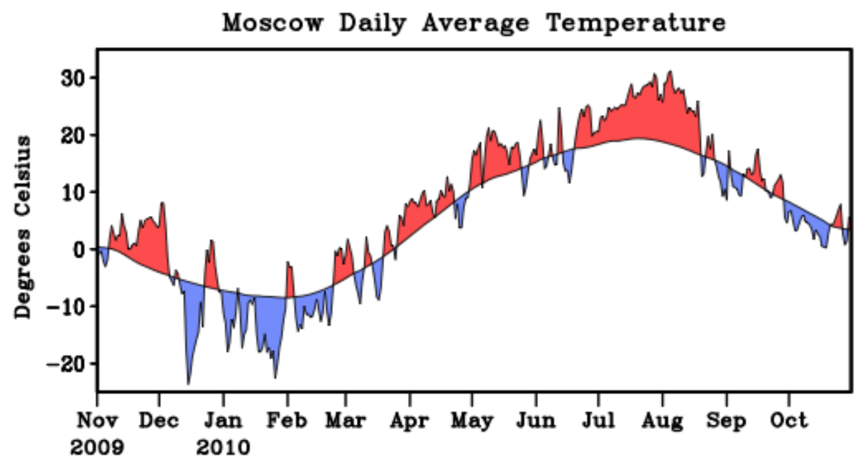
Was there a basis for anticipating the 2010 Russian heat wave?

- This study explores whether early warning could have been provided through knowledge of natural and human-caused climate forcings.
- Analysis of forced model simulations indicates that neither human influences nor other slowly evolving ocean boundary conditions contributed substantially to the magnitude of this heat wave.
- They also provide evidence that such an intense event could be produced through natural variability alone.
- Analysis of observations indicate that this heat wave was mainly due to internal atmospheric dynamical processes that produced and maintained a strong and long-lived blocking event, and that similar atmospheric patterns have occurred with prior heat waves in this region.
- We conclude that the intense 2010 Russian heat wave was mainly due to natural internal atmospheric variability. Slowly varying boundary conditions that could have provided predictability and the potential for early warning did not appear to play an appreciable role in this event.

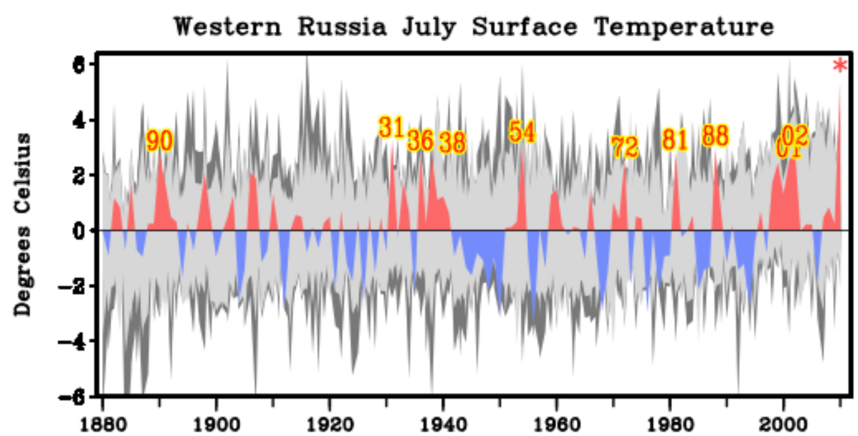
Dole 2011

Figure 1





- Moscow experienced an unusually cold winter and a relatively mild but variable spring, providing no hint of the record heat yet to come.
- The July surface temperatures for the region impacted by the 2010 Russian heat wave shows no significant warming trend over the prior 130-year period from 1880 to 2009.
- Map of observed July temperature trend [°C/130yrs] for July 1880–2009. Box shows the area used to define “western Russia” surface temperatures.



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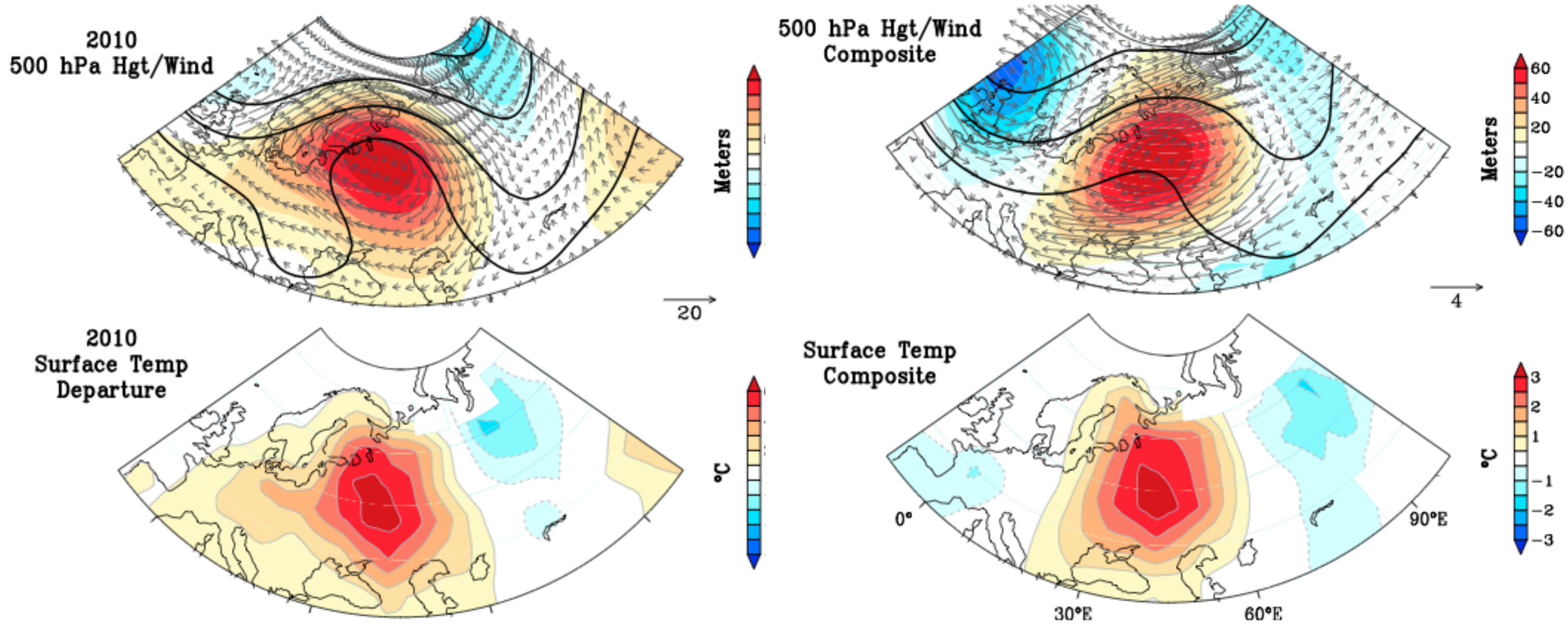
Dole 2011

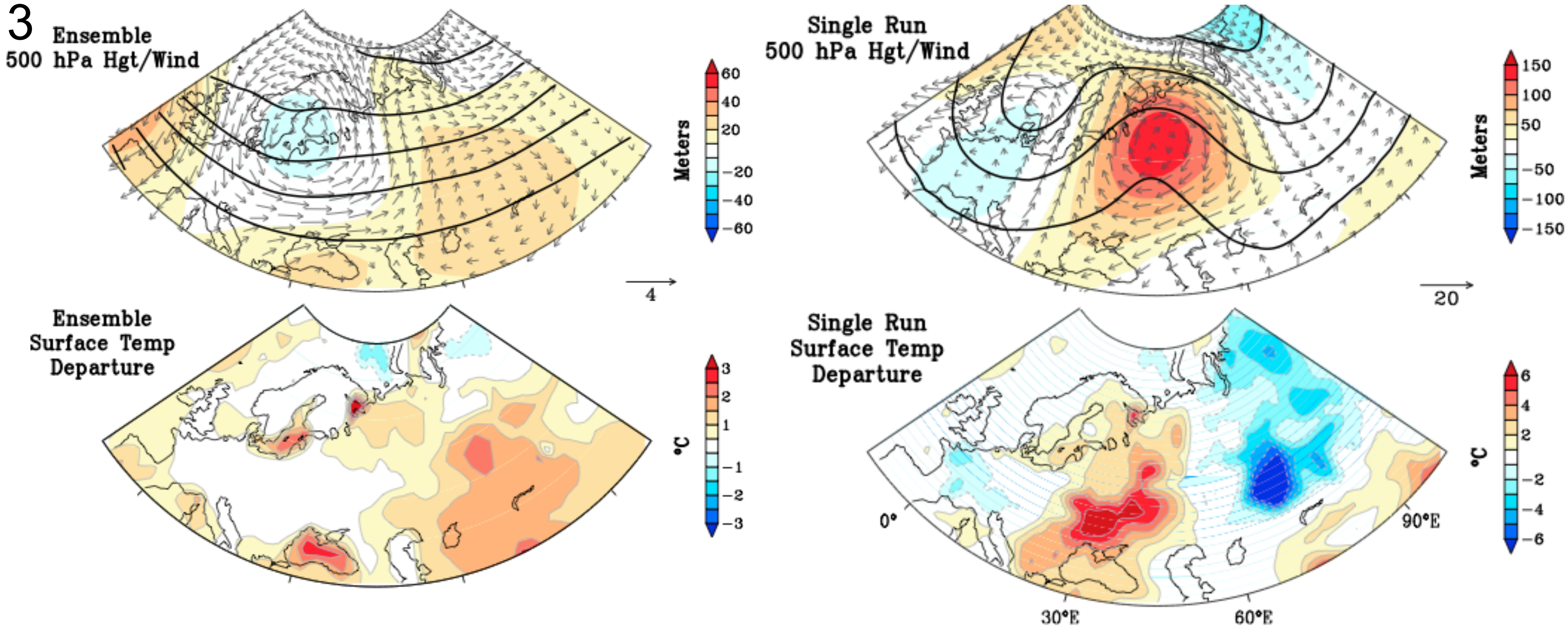
Figure 2



- The 500 hPa July flow (Figure 2, top) was characterized by a classic “omega” blocking pattern
- The highest July 2010 surface temperature anomalies occurred near the center of the block, where northward displaced subtropical air, descending air motions and reduced cloudiness all contributed to abnormally warm surface temperatures.
- Russia is climatologically disposed toward blocking events during summer.
- Consistent with this, a composite analysis of the average temperature anomalies and 500 hPa heights associated with the ten largest prior heat waves in this region since 1880 shows patterns similar to 2010, although features are weaker as expected from such a composite analysis.

Dole 2011

Figure 3

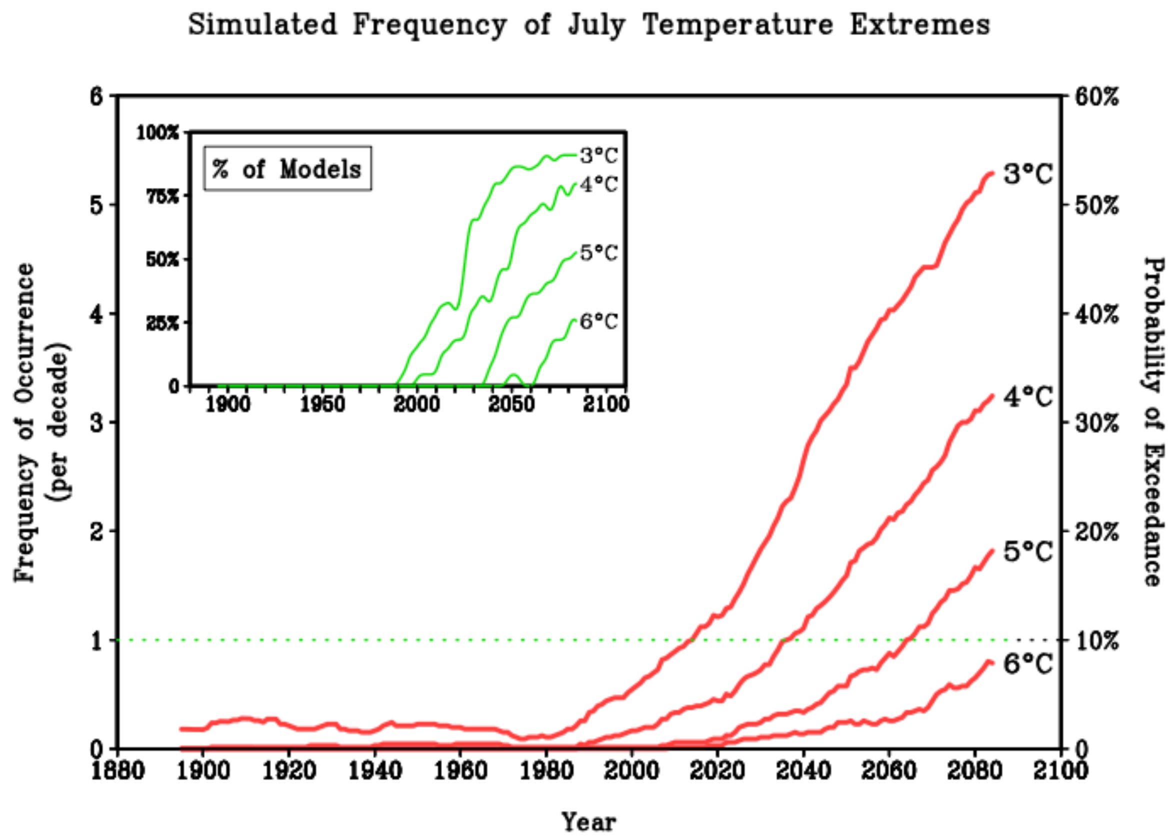


- July 2010 climate conditions simulated with GFDL AM2.1 (top, left)
- The 50 member ensemble mean of 500 hPa height (contour, contour interval: 100 m), anomalies (shading), and wind vector anomalies (arrows). (bottom, left)
- Ensemble-mean surface temperature anomalies. (top and bottom, right) As in Figures 3 (top) and 3 (middle top), but for a single model run selected from the ensemble.
- The ensemble-mean responses of the atmospheric circulation and surface temperatures are far weaker and their patterns are inconsistent with the observed blocking and heat wave
- Results using very high-resolution climate models suggest that the number of Euro-Atlantic blocking events will decrease by the latter half of the 21st century

Dole 2011

Figure 4

- To assess this possibility for the region of western Russia, we have used the same IPCC model simulations to estimate the probability of exceeding various July temperature thresholds over the period 1880–2100
- The results suggest that we may be on the cusp of a period in which the probability of such events increases rapidly, due primarily to the influence of projected increases in greenhouse gas concentrations.
- Uncertainty in timing is nonetheless evident, due in part to different model sensitivities to greenhouse gas forcing.



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Rahmstorf 2011

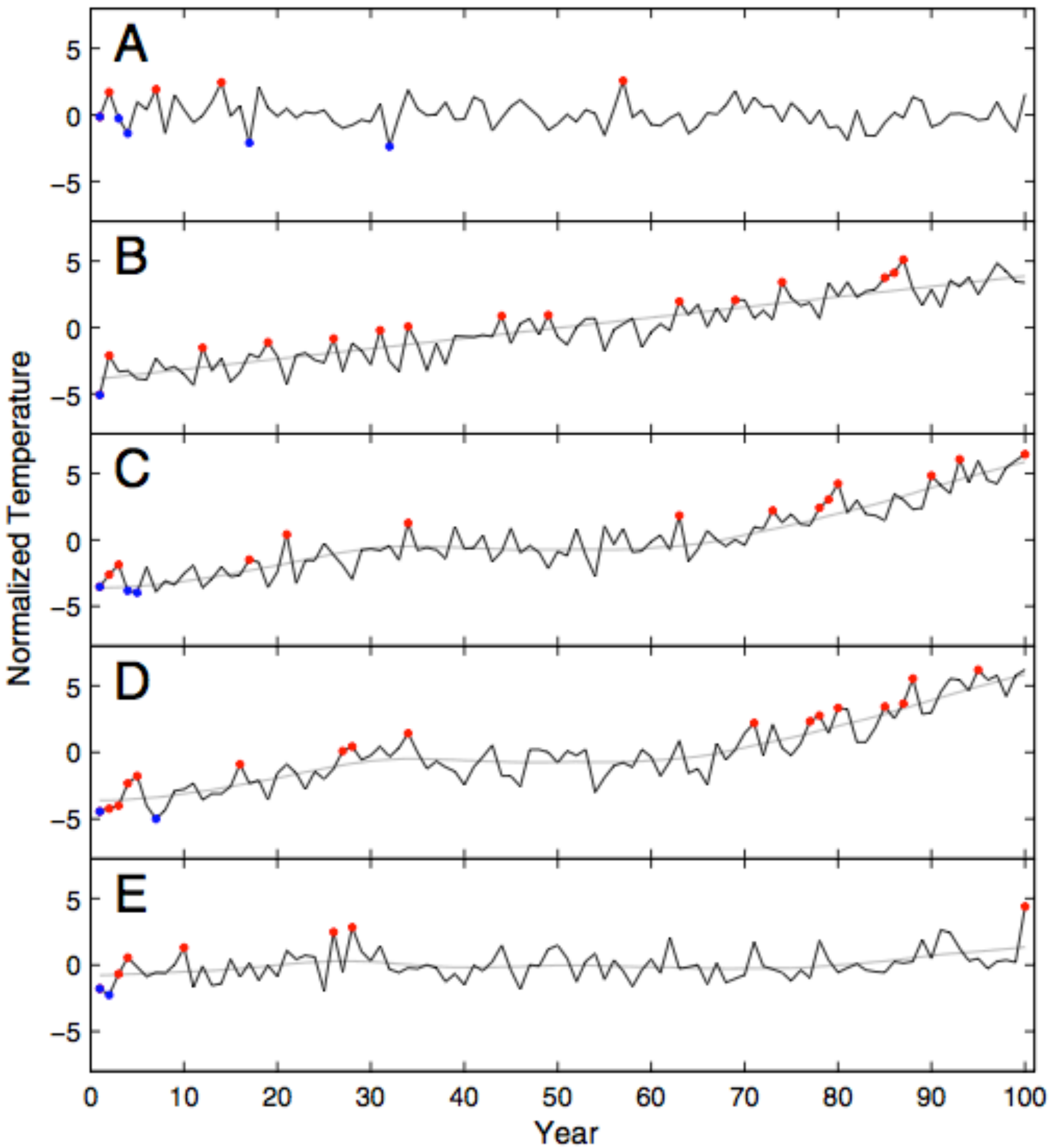
Increase of extreme events in a warming world

- We develop a theoretical approach to quantify the effect of long-term trends on the expected number of extremes in generic time series
- We find that the number of record-breaking events increases approximately in proportion to the ratio of warming trend to short-term standard deviation.
- Short-term variability thus de- creases the number of heat extremes, whereas a climatic warming increases it.
- We estimate that climatic warming has increased the number of new global-mean temperature records expected in the last decade from 0.1 to 2.8.
- For July temperature in Moscow, we estimate that the local warming trend has increased the number of records expected in the past decade fivefold, which implies an approximate 80% probability that the 2010 July heat record would not have occurred without climate warming.
- Our results thus explicitly contradict those of Dole et al. (16), who did not find any basis for anticipating the Russian heat record of July 2010.

Rahmstorf 2011

Figure 1

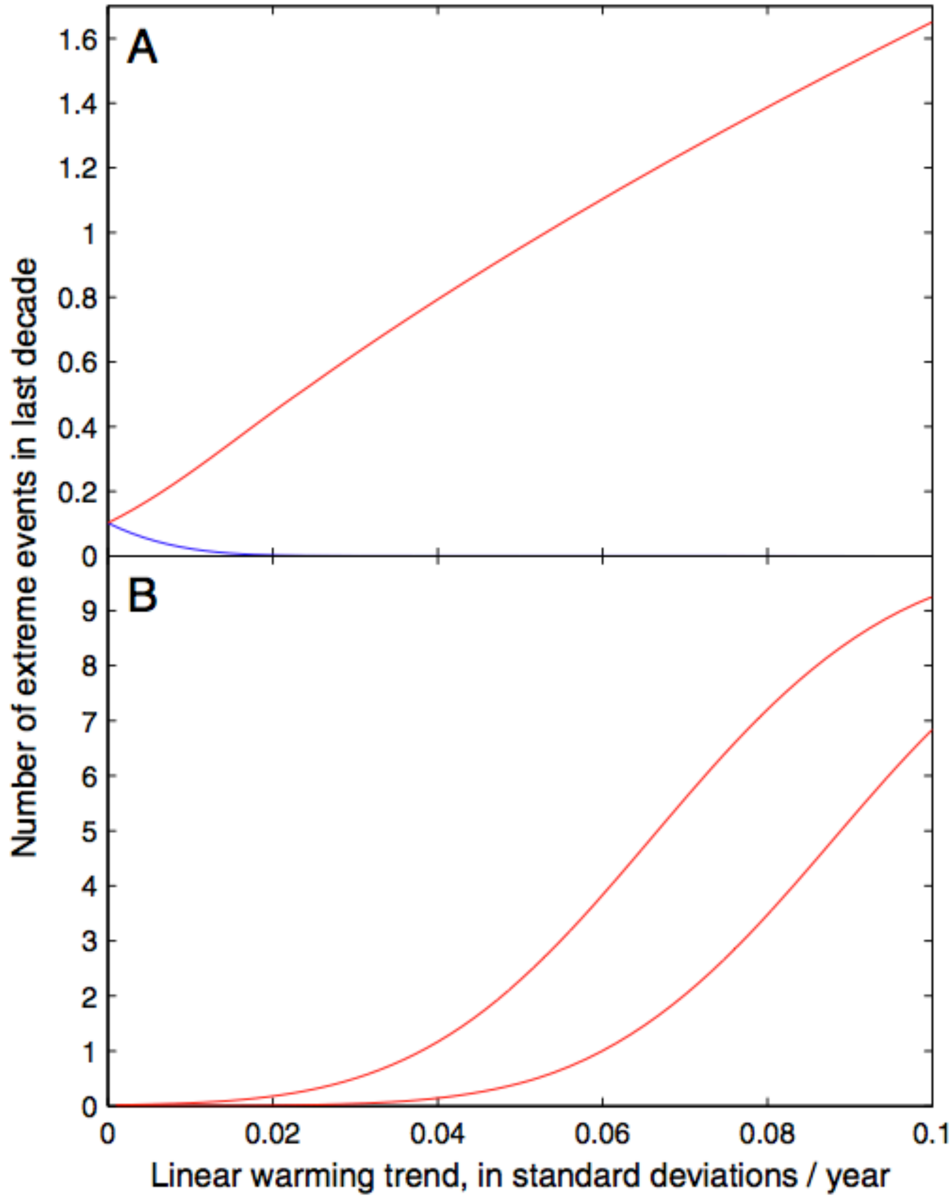
- Generate synthetic temperature time series of 100 values as random uncorrelated “noise” with various trends added.
- In a stationary climate (Fig. 1A), the number of records of a given type (e.g., heat extremes) declines as 1/n
- The case with warming trend (Fig. 1B) has more unprecedented heat extremes overall, in particular in the last decades of the series.



Rahmstorf 2011

Figure 2

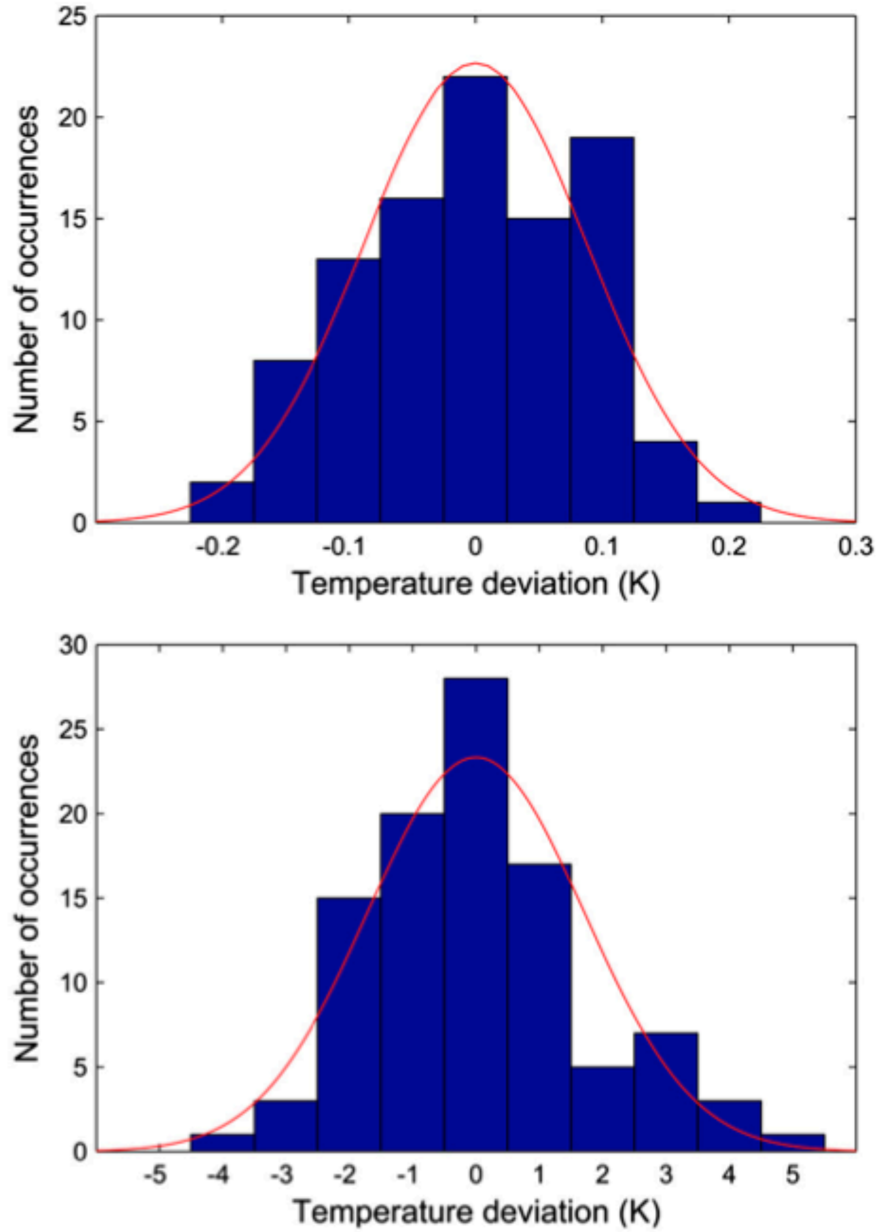
- Over a wide range of trend values, the number of unprecedented heat extremes increases approximately linearly from its stationary value of 0.105 (Fig. 2A). The number of cold records drops off quickly to near zero.
- One can consider extremes that surpass a predefined, fixed threshold value (e.g., three or four standard deviations from the mean). In this case, we find a much more non-linear increase of the number of extremes with the trend (Fig. 2B).
- A fundamental asymmetry between the increase in heat extremes and decrease in cold extremes.



Rahmstorf 2011

Figure 3

- Histogram of the deviations of temperatures of the past 100 y from the nonlinear climate trend lines shown in Fig. 1 D and E, together with Gaussian distributions with the same variance and integral. (Upper) Global annual mean temperatures from NASA GISS, with a standard deviation of 0.088 oC. (Lower) July mean temperature at Moscow station, with a standard deviation of 1.71 oC.



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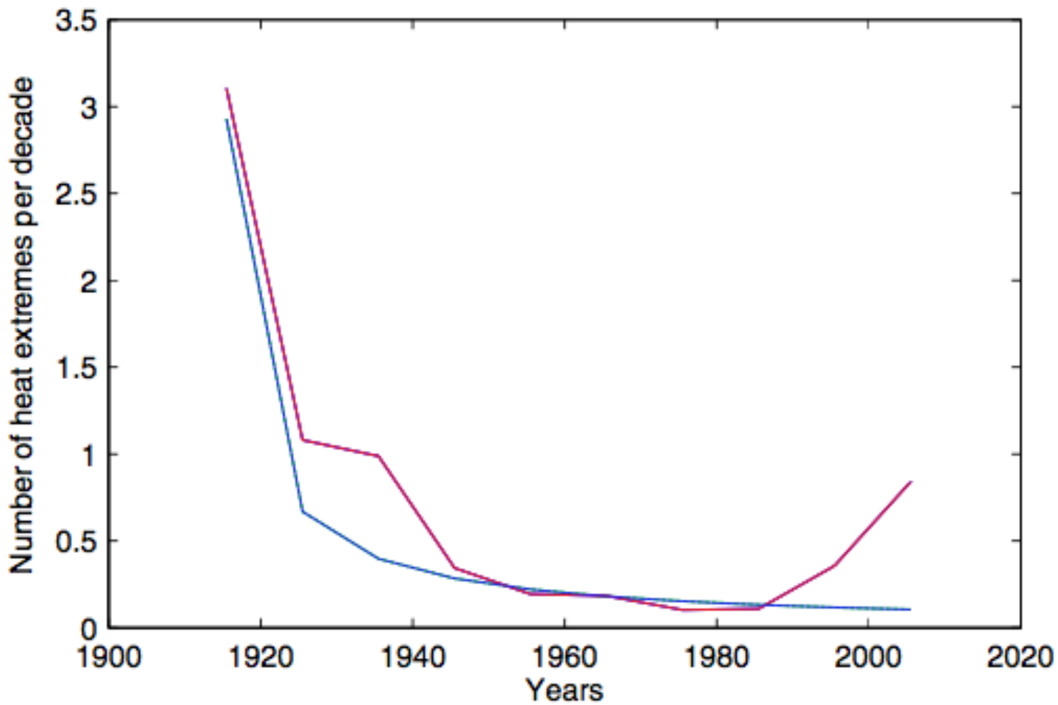
Rahmstorf 2011

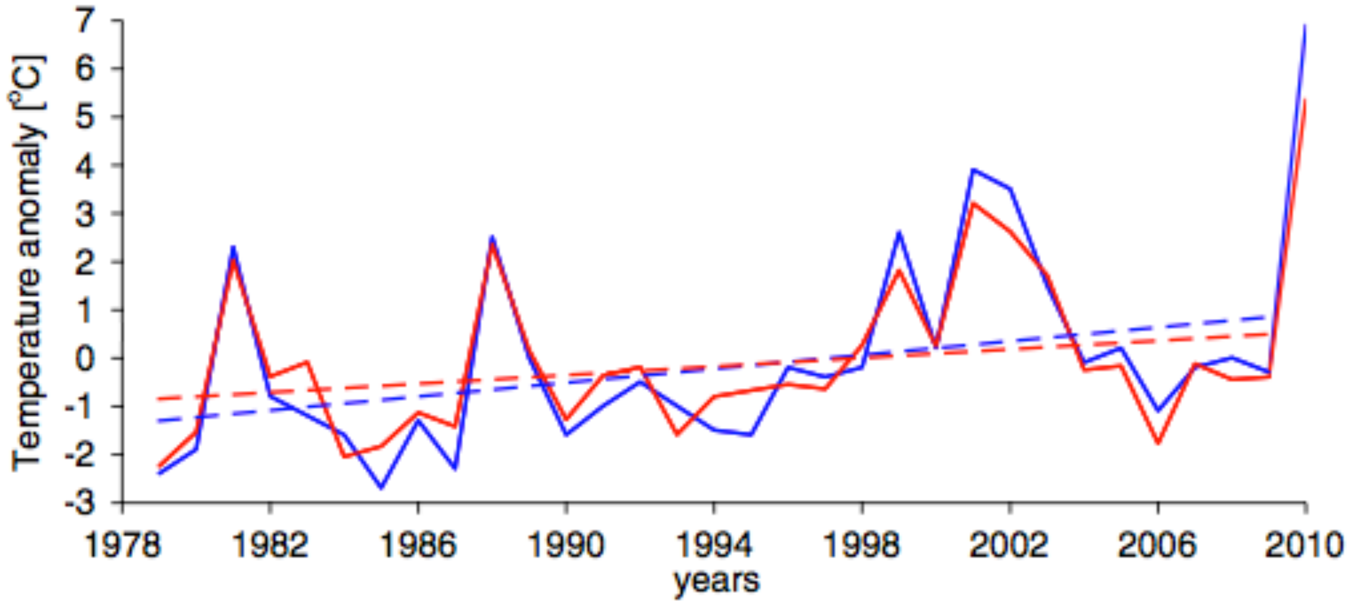
Figure 4

- Expected number of unprecedented July heat extremes in Moscow for the past 10 decades. Red is the expectation based on Monte Carlo simula- tions using the observed climate trend shown in Fig. 1E. Blue is the number expected in a stationary climate (1/n law). Warming in the 1920s and 1930s and again in the past two decades increases the expectation of extremes during those decades.
- Because temperatures stag- nated until the 1980s, the expectation for new records was low from the 1940s through to the 1990s.
- Clearly shows that the warming trend after 1980 has multiplied the likelihood of a new heat record in Moscow and would have provided a strong reason to expect it before it occurred.



Rahmstorf 2011

Figure 5



• Comparison of temperature anomalies from remote sensing systems surface data (red; ref. 15) over the Moscow region (35oE–40oE, 54oN–58oN) versus Moscow station data (blue; ref. 21). The solid lines show the average July value for each year, whereas the dashed lines show the linear trend of these data for 1979–2009 (i.e., excluding the record 2010 value). The satellite data have a trend of 0.45 oC per decade for 1979–2009, as compared to 0.72 oC per decade for the Moscow station data.

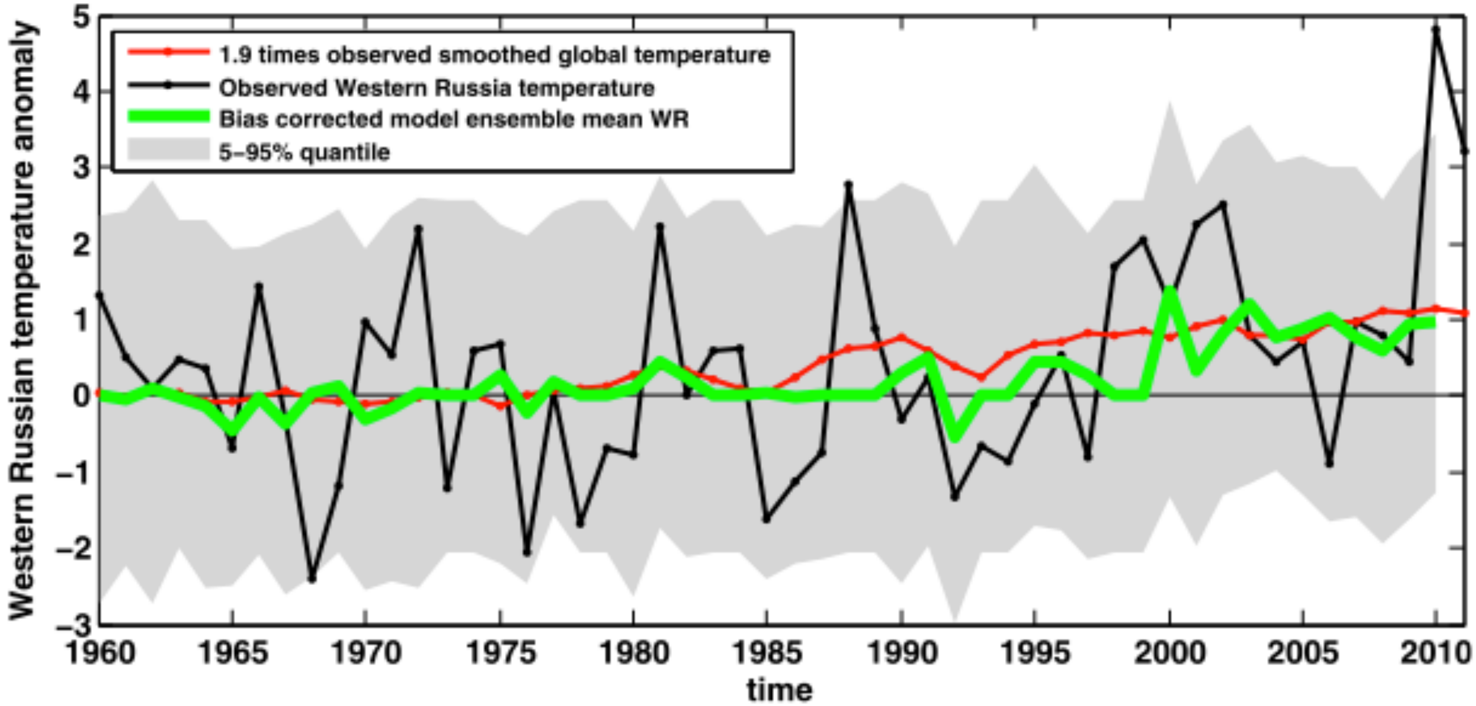
• The fact that observed warming in western Russia is over twice the global-mean warming is consistent with observations from other continental interior areas as well as with model predictions for western Russia under greenhouse gas scenarios

Otto 2012

- Apparently contradictory answers have been given to the question of whether the Russian heat wave might have been anticipated.
- Here we use the results from a large ensemble simulation experiment with an atmospheric general circulation model to show that there is no substantive contradiction between these two papers, in that the same event can be both mostly internally-generated in terms of magnitude and mostly externally-driven in terms of occurrence-probability.
- The natural climate variability can account for an event of this magnitude. However, the frequency of occurrence of such an event is likely to have increased due to a global warming trend which is attributed to anthropogenic increase of greenhouse gas forcing,

Otto 2012

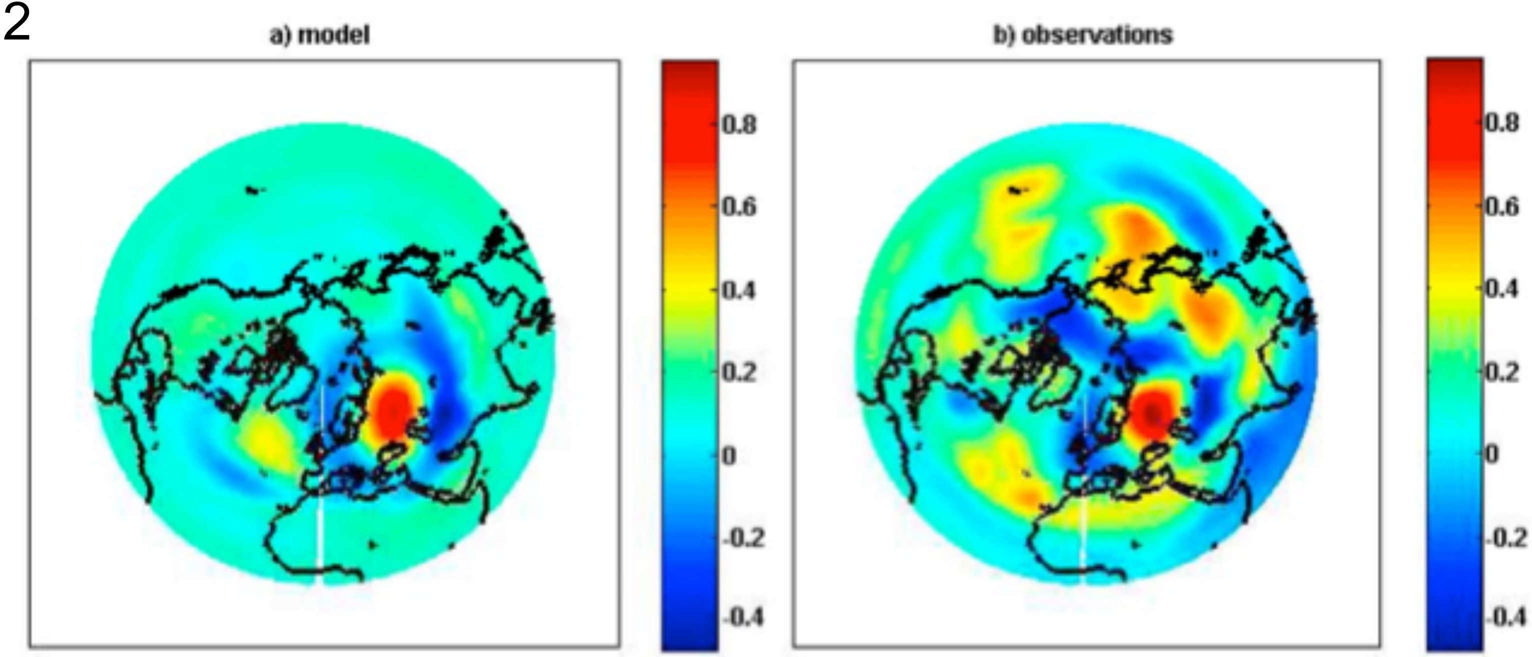
Figure 1



- Modeled and observed temperature anomalies averaged over 50°–60°N, 35°–55°E. Also shown is the smoothed global mean temperature multiplied by the regression coefficient of Western Russian temperatures. The reference period is 1950–2009 for observed data and 1960–2009 for the model.
- Assuming a stationary climate with no rise in yearly mean temperature, the observed monthly mean temperatures for July 2010 would be very improbable in relation to the distribution defined over 1950–2009. (return time of the value observed in July 2010 is about 1000 years, with a lower bound of the 95% confidence interval of about 250 years)

Otto 2012

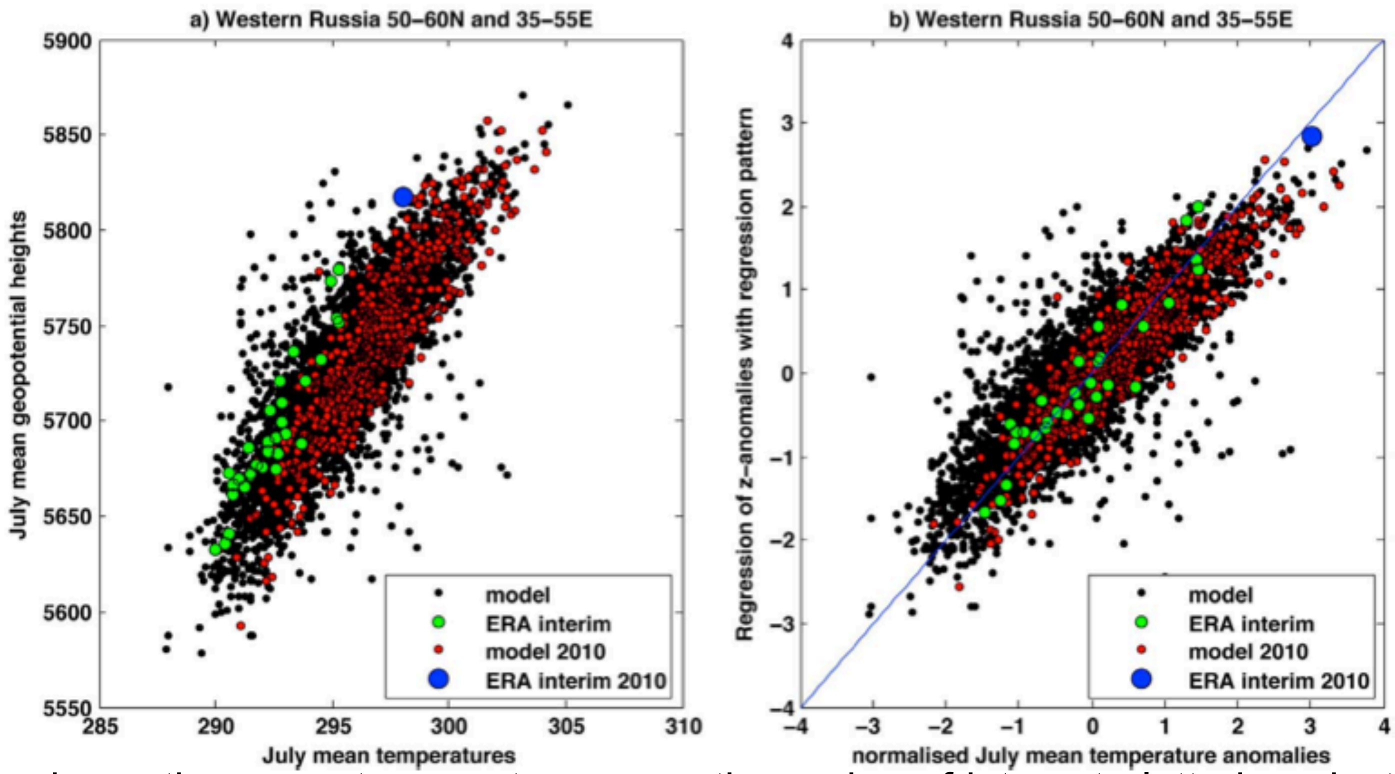
Figure 2



- Regression maps on synoptic structure of northern hemisphere 500 hPa geopotential height patterns associated with July mean temperatures in (a) the model and (b) observations.
- These regression maps show the synoptic pattern in July over the northern hemisphere and compare well with reanalysis data.

Otto 2012

Figure 3

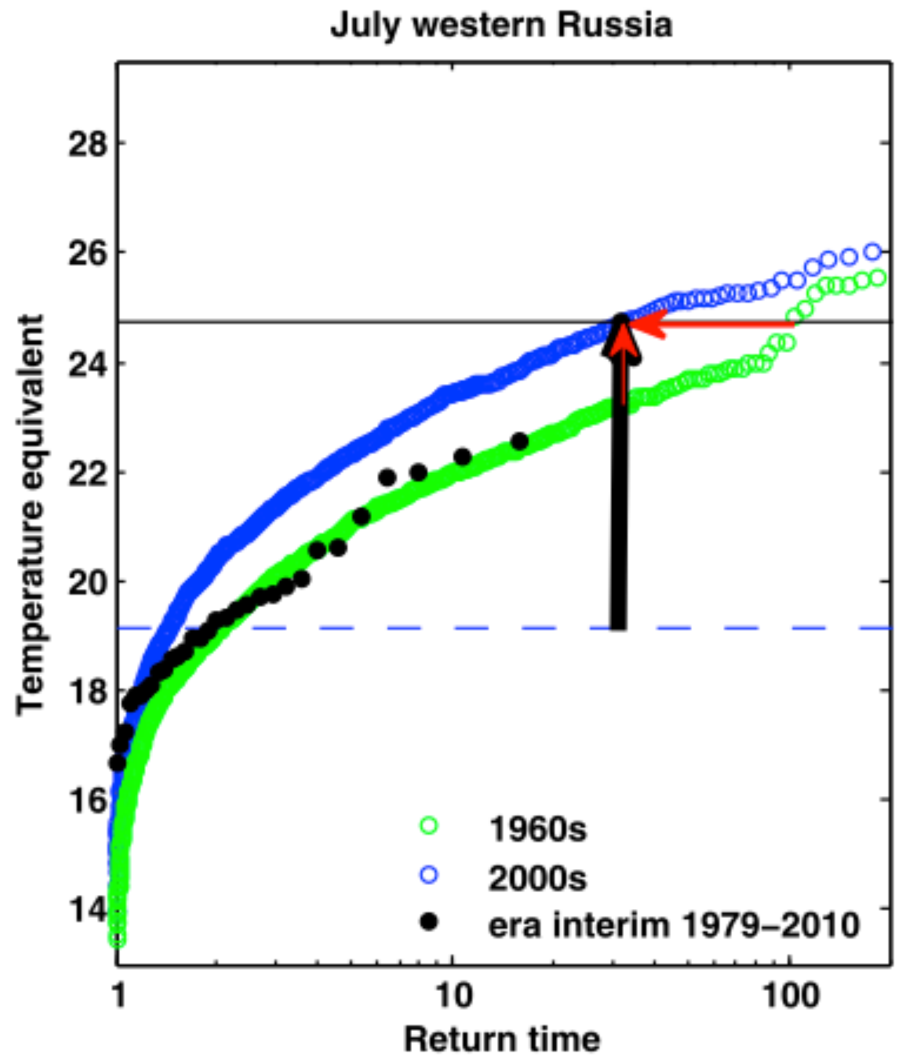


- Figure 3a shows the mean temperatures over the region of interest plotted against the mean geopotential height.
- Figure 3b shows that the geopotential height anomalies are scattered along that line, indicating that the regression pattern is an effective, but far from perfect, predictor for Russian temperatures.
- The dot representing the observed conditions in 2010 is located close to the one-to-one line and much more towards the right upper corner accounting for the exceptional heat wave.
- The simulated expected frequency of occurrence of an extreme Russian heat wave has tripled due to the large-scale warming within the last four decades.

Otto 2012

Figure 4

- Return periods of temperature-geopotential height conditions in the model for the 1960s (green) and the 2000s (blue) and in ERA-Interim for 1979–2010 (black).
- The vertical black arrow shows the anomaly of the Russian heat wave 2010 (black horizontal line) compared to the July mean temperatures of the 1960s (dashed line). The vertical red arrow gives the increase in the magnitude of the heat wave due to the shift of the distribution whereas the horizontal red arrow shows the change in the return period.



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