Extreme weather events and climate change

Lessons from IPCC SREX and AR5 reports

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Outline

- **Observed changes of extremes and future projections**

- **Physical basis of climate change impact on extremes**

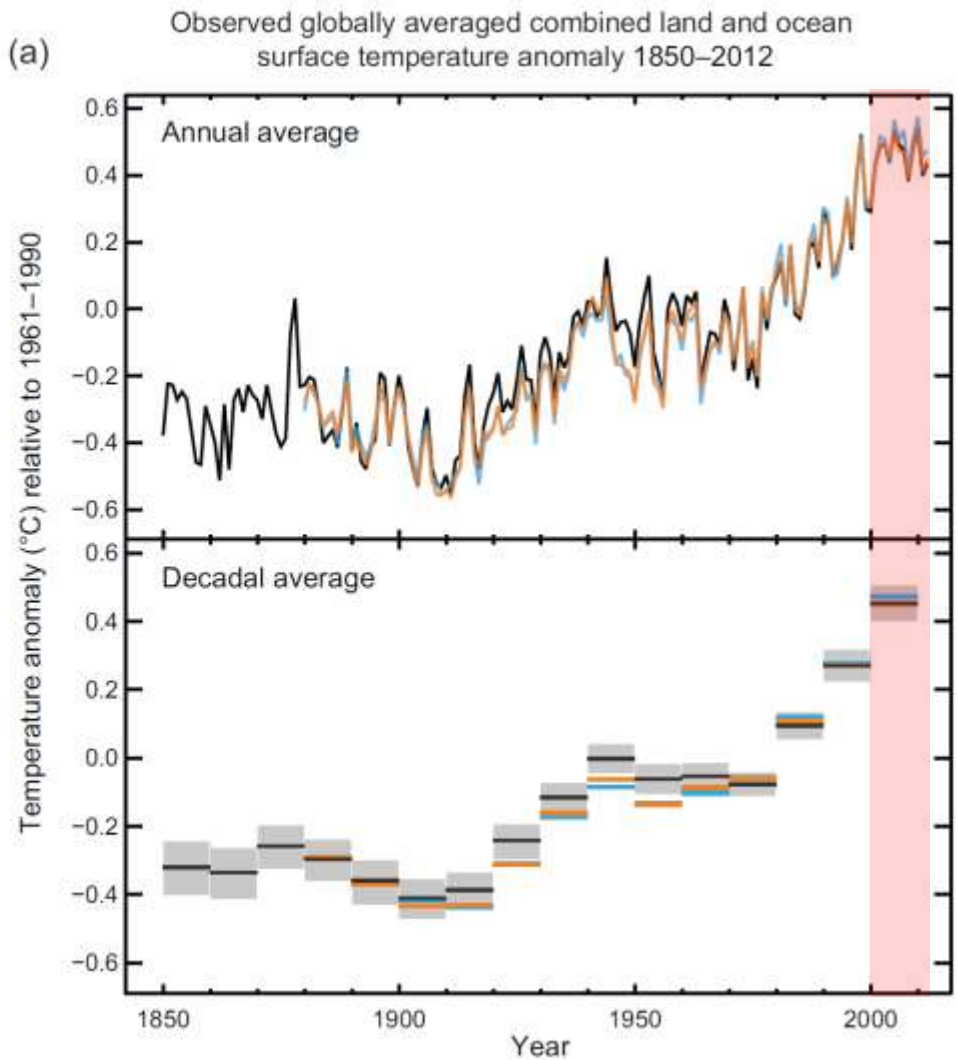
- **Some recent extremes in Russia as showcase examples**

  Krymsk 2012

  "Cold winters" of the 21st century

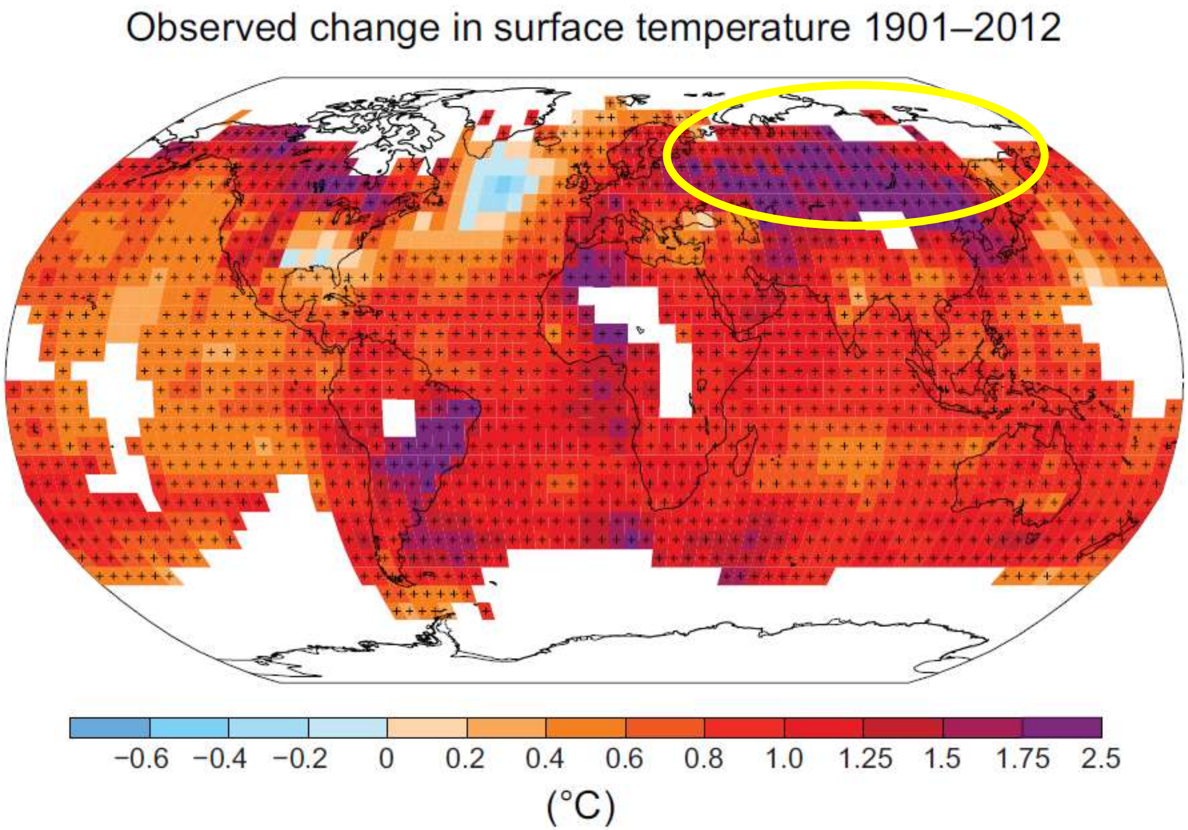
- **Conclusions**

Global surface air temperature change



Beginning of the 21st century is the warmest epoch in instrumental record

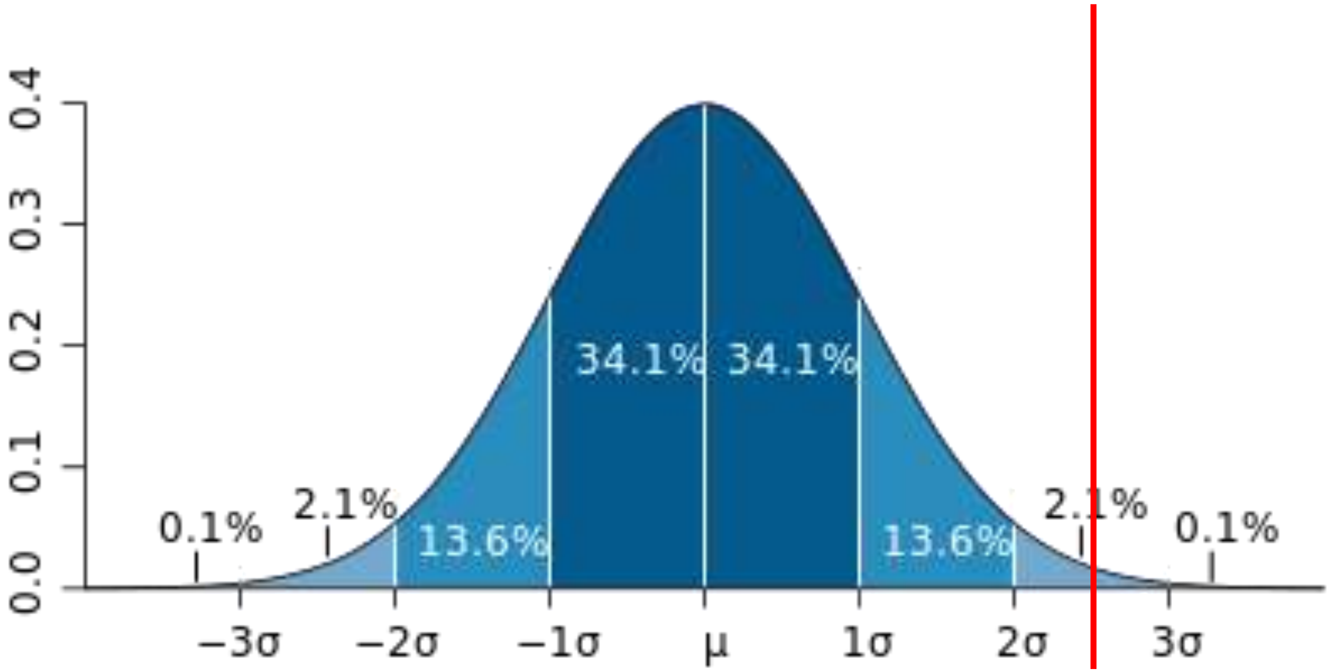
Global surface air temperature change



European part of Russia and Central Siberia are the hot spots of global warming

What is an extreme event?

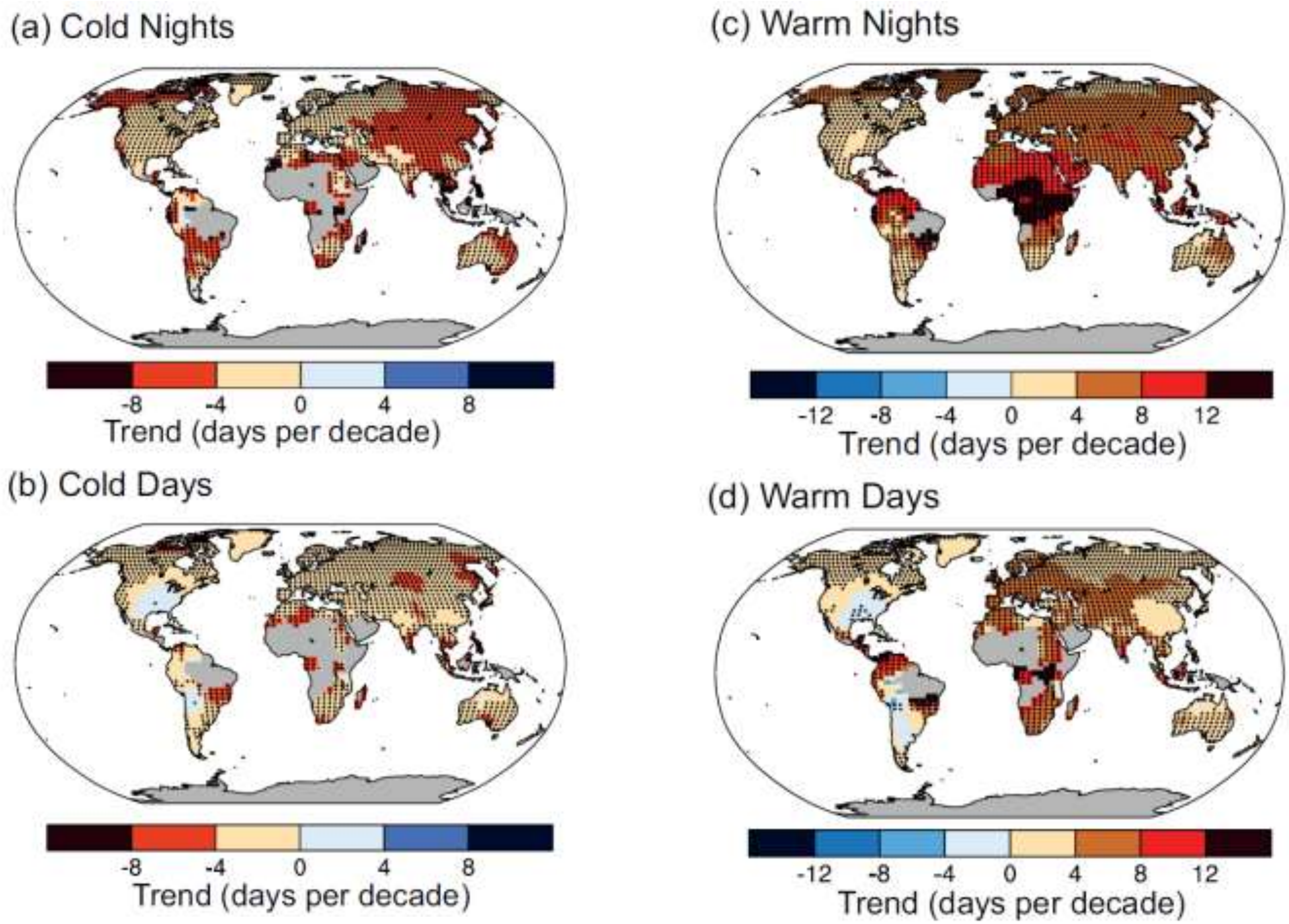
The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. (IPCC SREX 2012)



Upper or lower 10% = “heavy event” or “strong anomaly”
Upper or lower 1-2% = “extreme event”

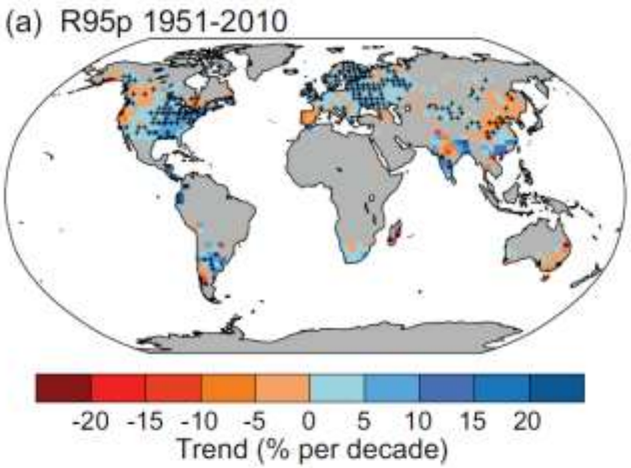
Do we observe changes in extreme or anomalous weather?

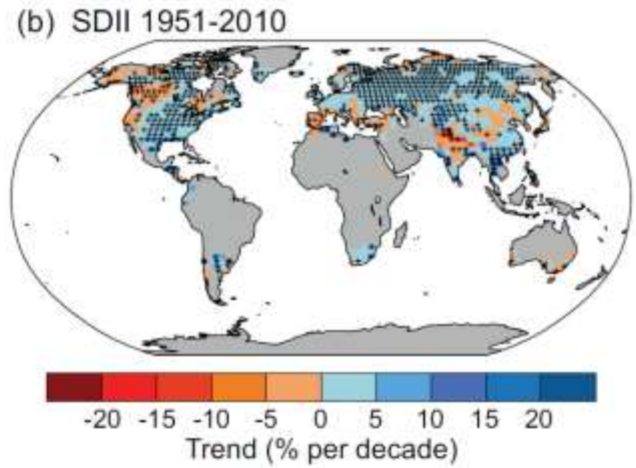
Trends in annual frequency of strong temperature anomalies over the period 1951–2010 (days per decade)

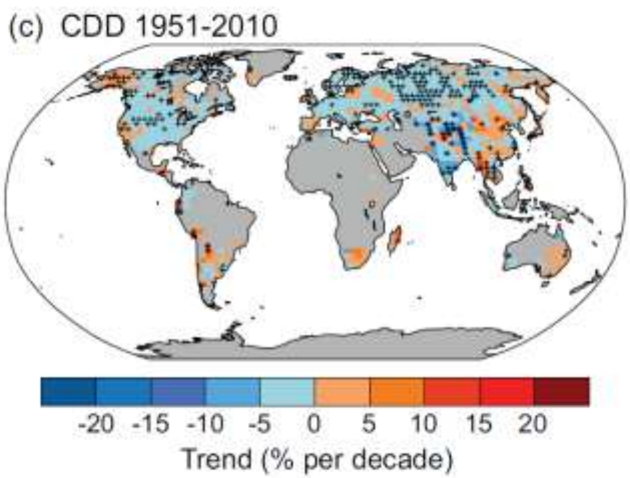


Do we observe changes in extreme or anomalous weather?

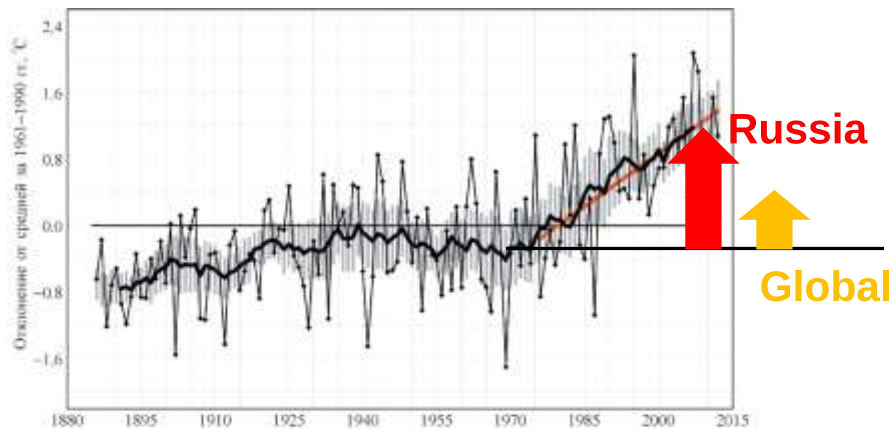
Trends in heavy daily precipitation (R95p), precipitation intensity (SDII), consecutive dry days (CDD) (% per decade) over the period 1951–2010





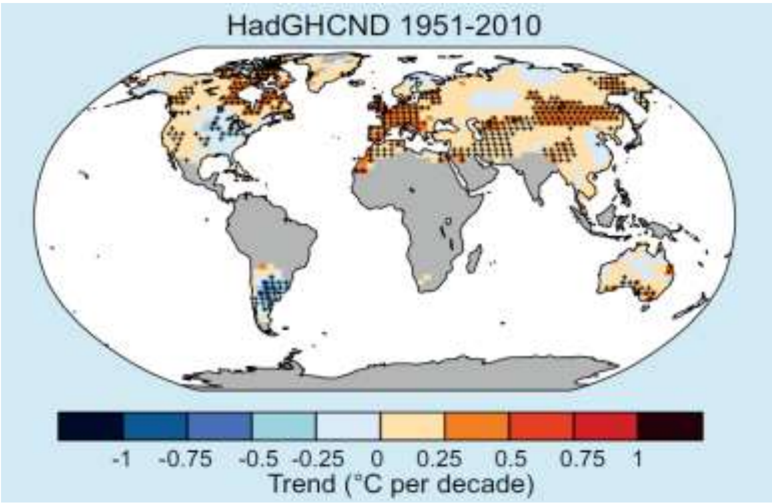


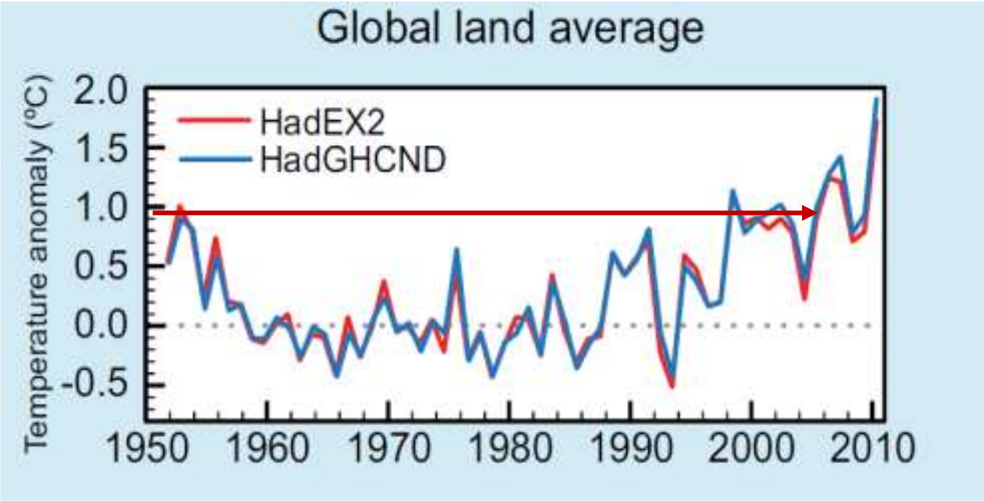
Annual temperature anomalies over Russia, ºC



Do we observe changes in extreme or anomalous weather?

Trends in the warmest day of the year for the period 1951–2010 (ºC per decade)





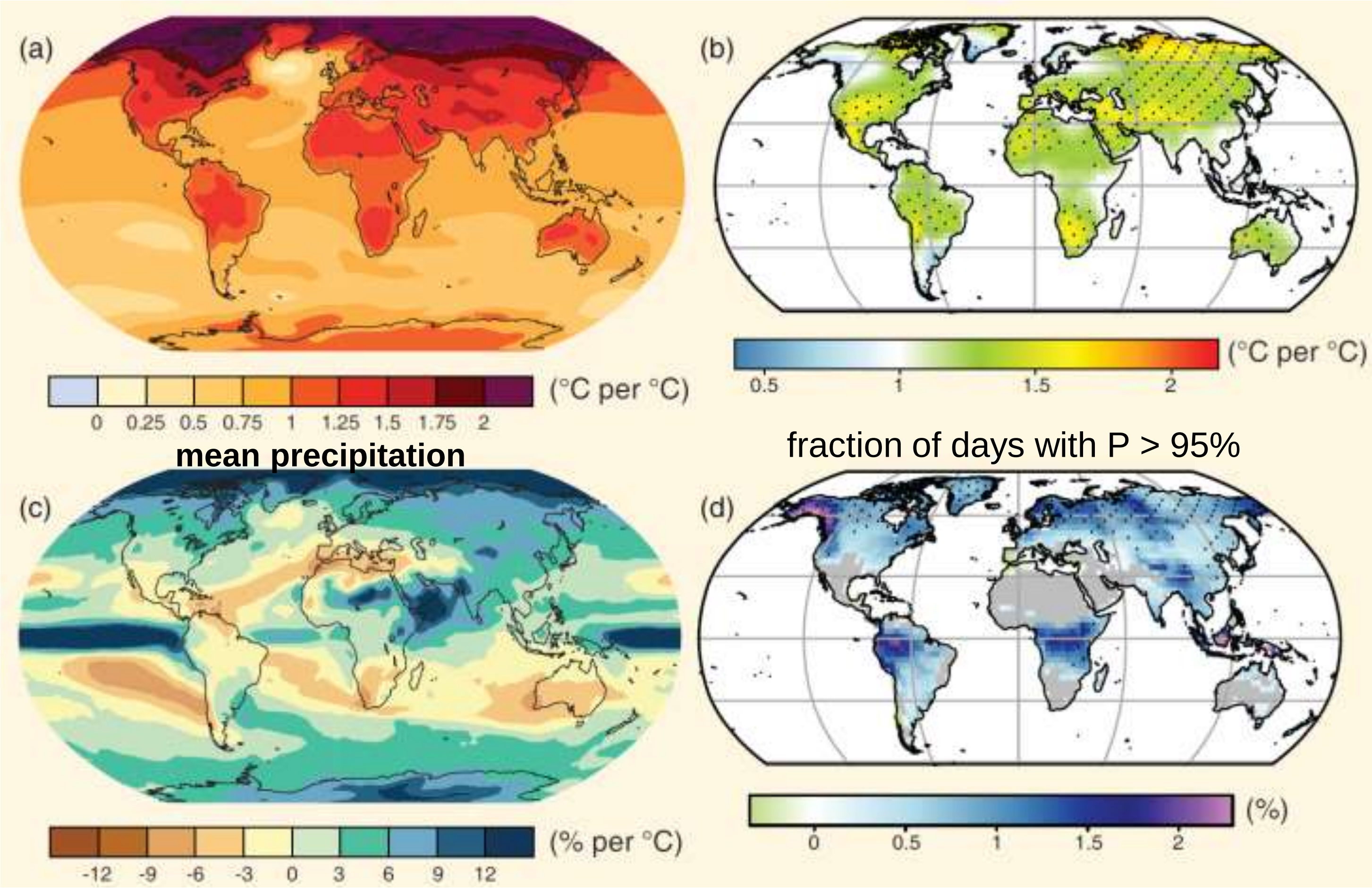
Uncertainty of estimates of changes in extremes is higher

What shell we face in the warmer climate?

Projected 21st century changes in annual mean and annual extremes (over land) of surface air temperature and precipitation (2081-2100) – (1980-1999)

mean surface temperature

90th percentile of daily max. temperature

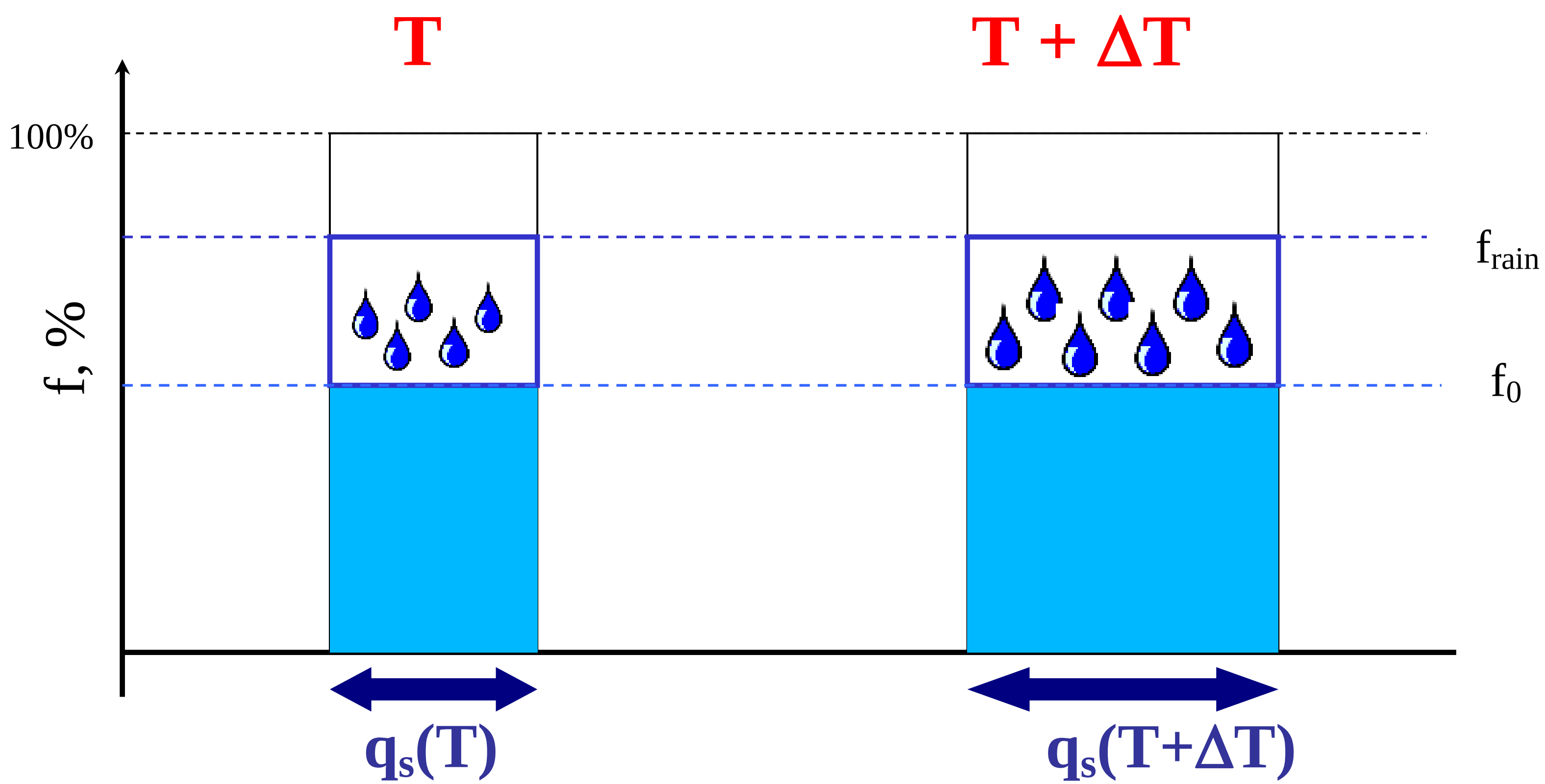


Which physical mechanisms determine response of extremes to warming?

Precipitation

Absolute humidity $q_s(T)$ scales exponentially with temperature

1°C warming leads to **7%** increase of moisture content

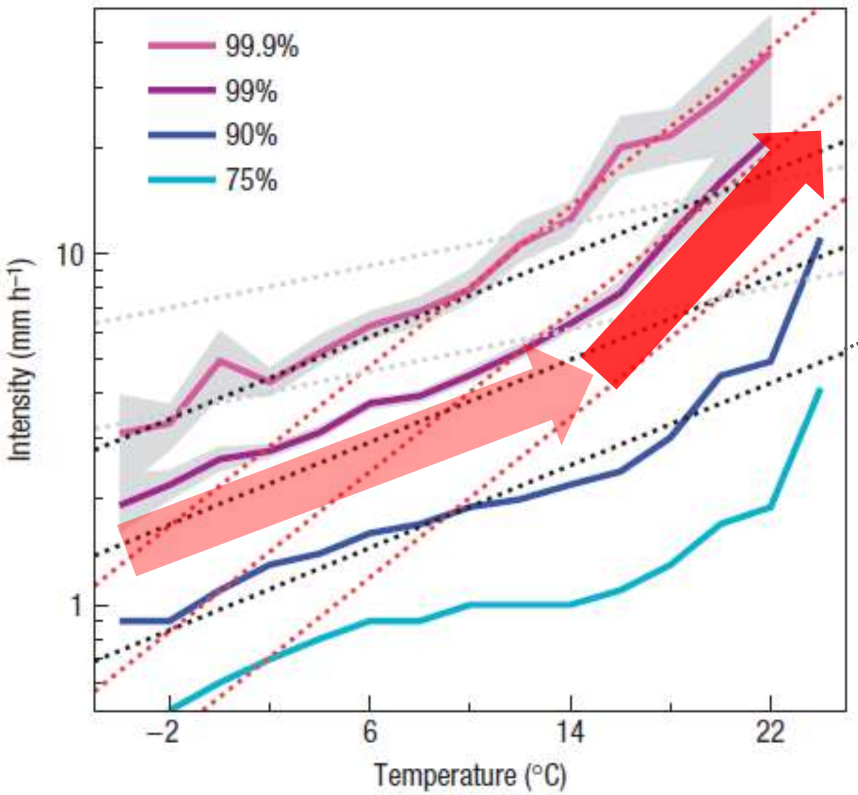


Precipitation intensity should increase

Which physical lows determine response of extremes to warming?

Precipitation

Higher temperatures lead to stronger increase of precipitation intensity



Hourly precipitation intensity as a function of temperature (in Netherlands)

(Lenderink and Meijgaard 2008; Berg et al. 2013)

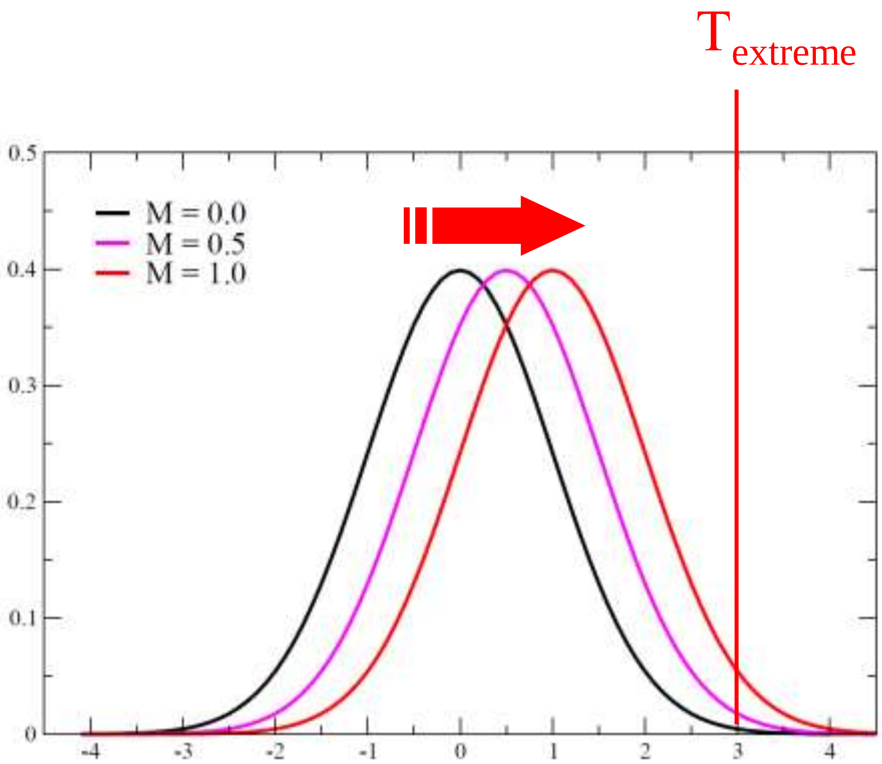
Exponential dependence

A reason –

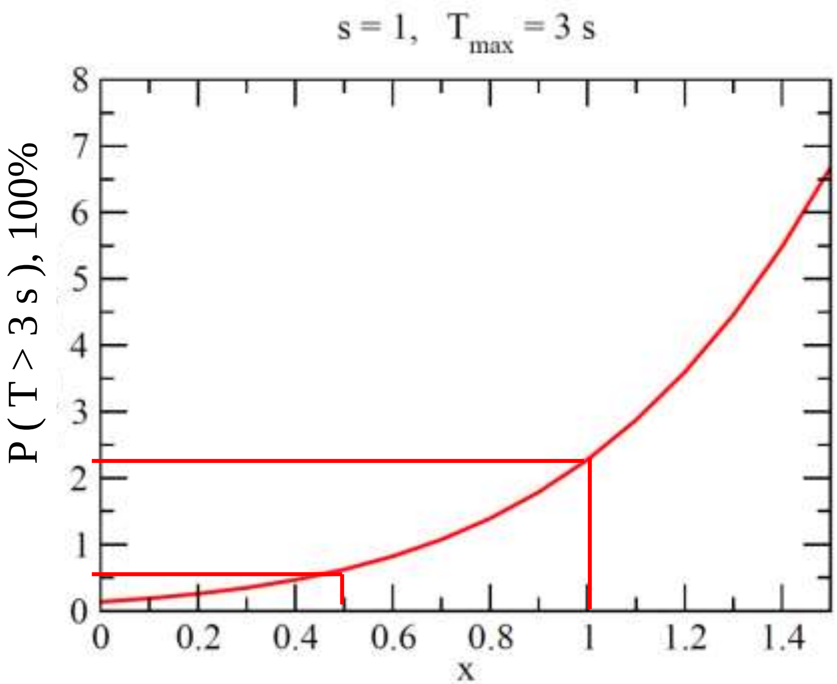
"dynamical factors"

Which physical lows determine response of extremes to warming?

Temperature



Exceedance probability for T > 3 sigma (s) as a function of mean temperature increase **x**

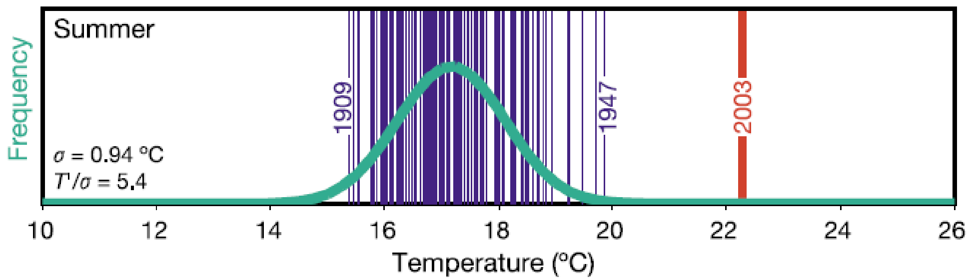


Given constant variability, mean temperature increase lead to exponential growth of extreme temperatures probability

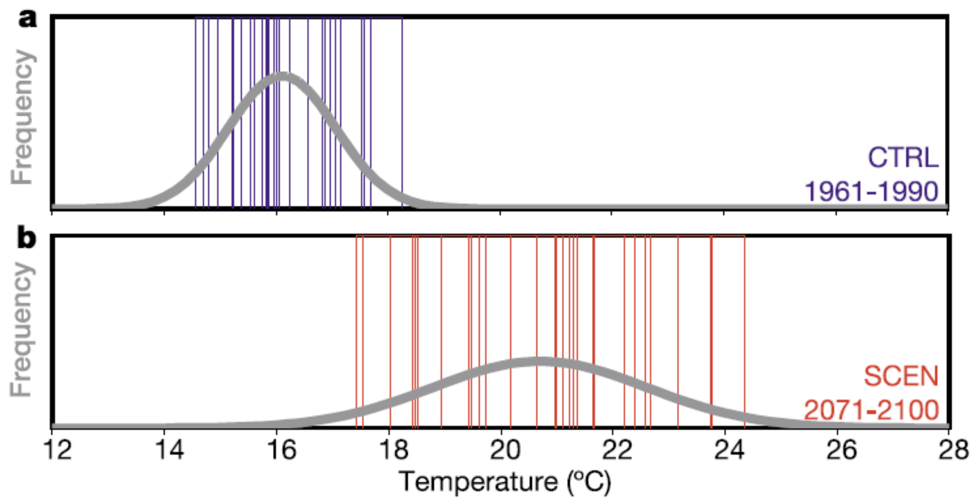
Which physical lows determine response of extremes to warming?

Temperature

Warming may results in increase of variability (Schaer et al. 2004)



Probability of European heat wave in 2003 is negligibly small



Regional climate model shows increase of variability alone with increase of mean temperature

A reason –

“dynamical factors”

Can we attribute extreme events to global warming?

We can search for statistically significant changes in extremes events characteristics associated with global warming

Extreme events are rare by definition, data records are too short

We can (objectively) compare observed changes with climate models projections under anthropogenic forcing

Models are imperfect, scenarios are uncertain, natural variability masks the signal

We can study physics behind the extremes and establish mechanisms that link extremes to global warming

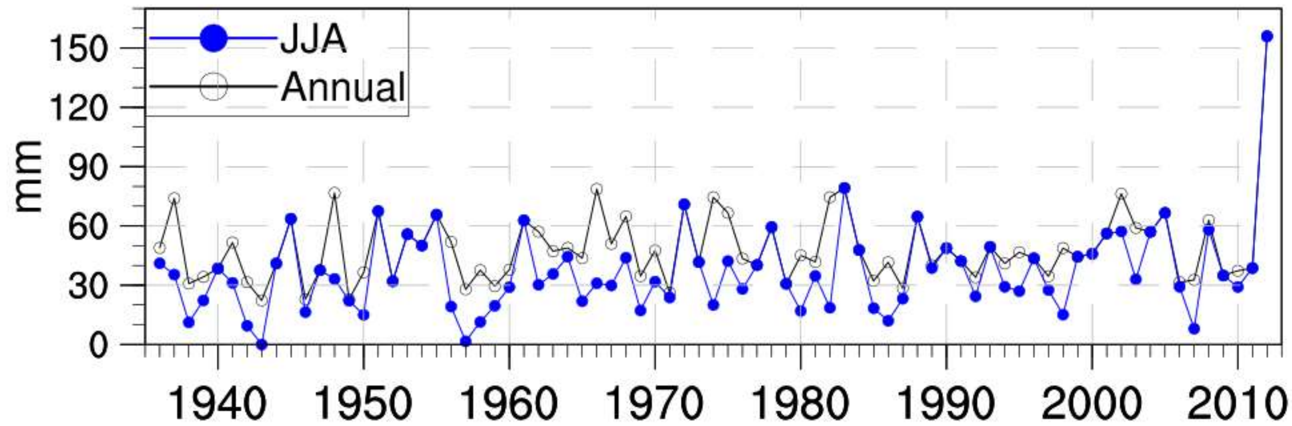
The object under study is extremely complex

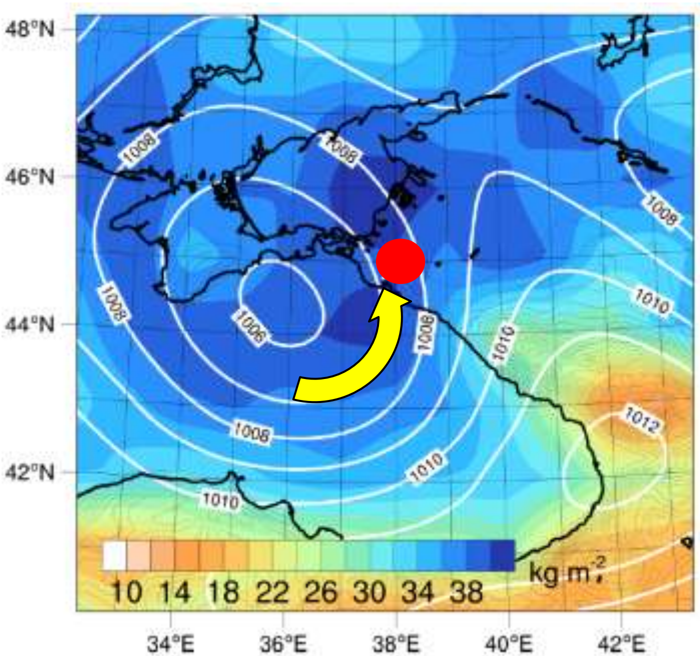
We can use state of the art climate model to reproduce the observed extremes and study their sensitivity to global warming in dedicated numerical simulations

Models are imperfect, often high resolution is required, only case study possible

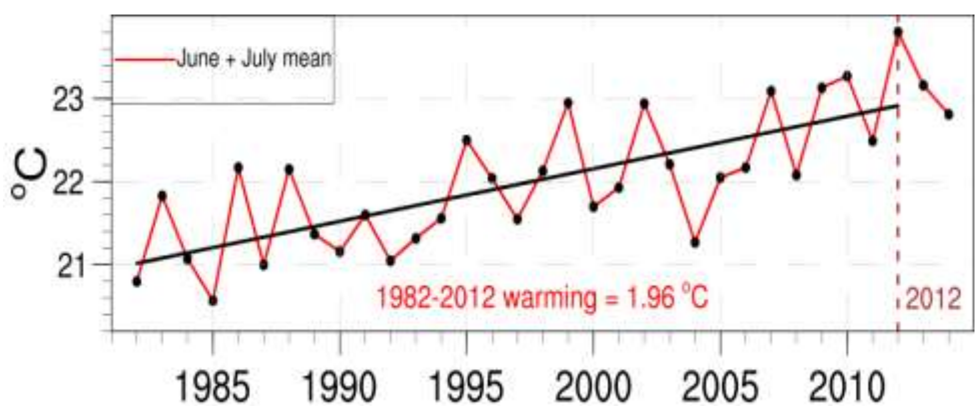
Extreme precipitation in Krymsk July 2012

Krymsk maximum daily precipitation (mm/day)





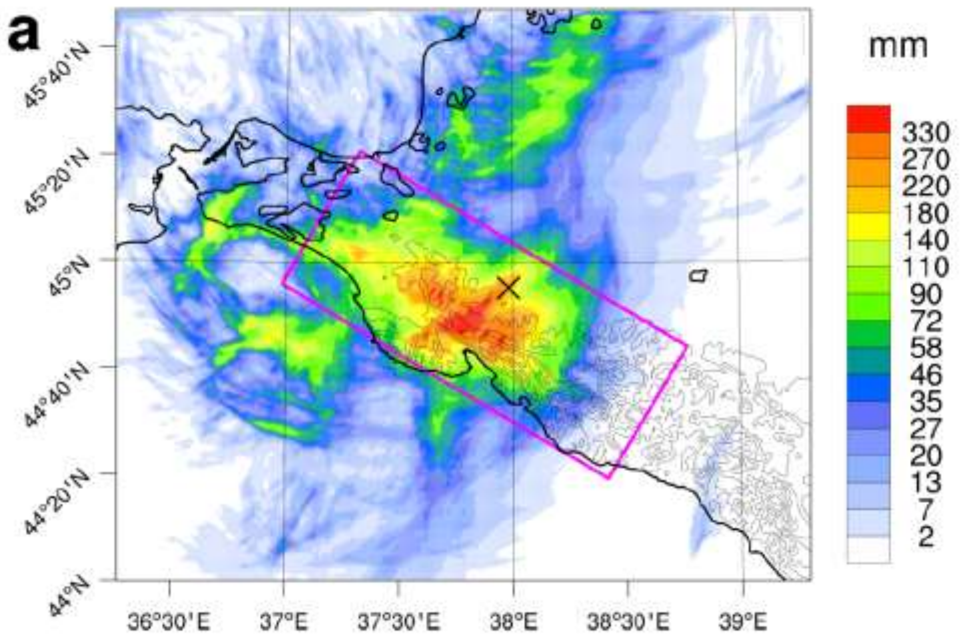
Temperature of Black Sea surface in June-July, °C



Extreme precipitation in Krymsk July 2012

Simulations with high resolution regional atmosphere model (Meredieth et al. 2015)

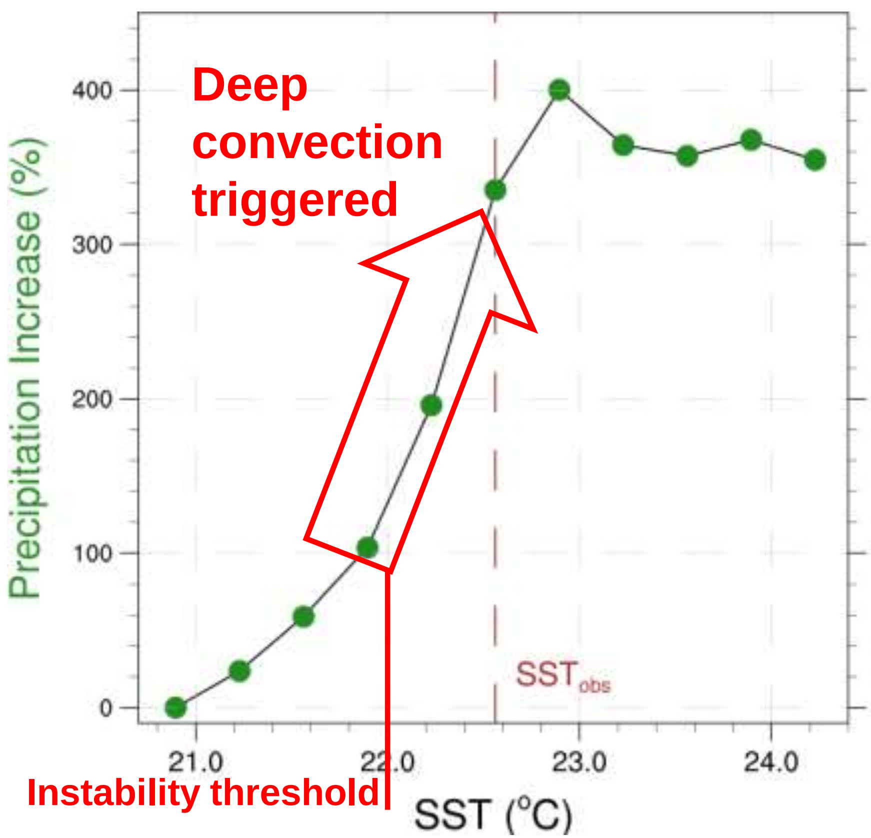
Daily precipitation on 6th of July simulated using observed Black Sea temperature on the day of the event



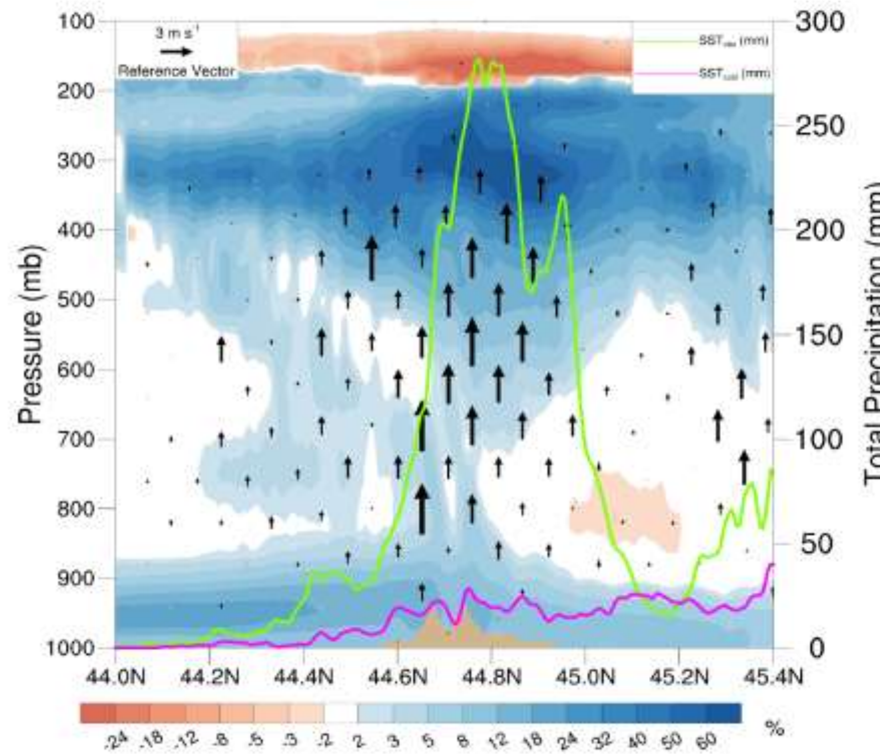
No extreme precipitation if cyclone would come over colder Black Sea

Extreme precipitation in Krymsk July 2012

Kryms precipitation as a function of Black Sea temperature: non-linear response



Changes in specific humidity, vertical velocity and precipitation between simulation with realistic and “cold” Black Sea temperatures

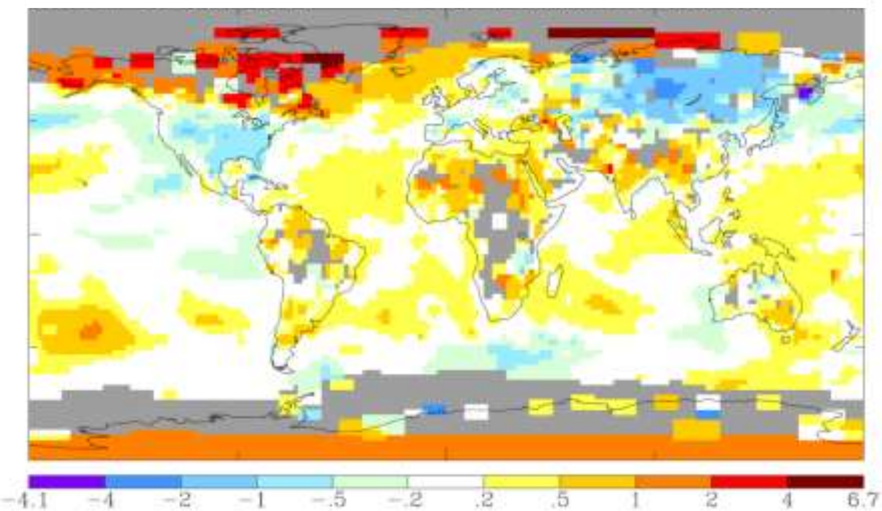


The explosive growth of precipitation is related to transition to deep convection regime made possible by the Sea warming in the beginning of the 21st century

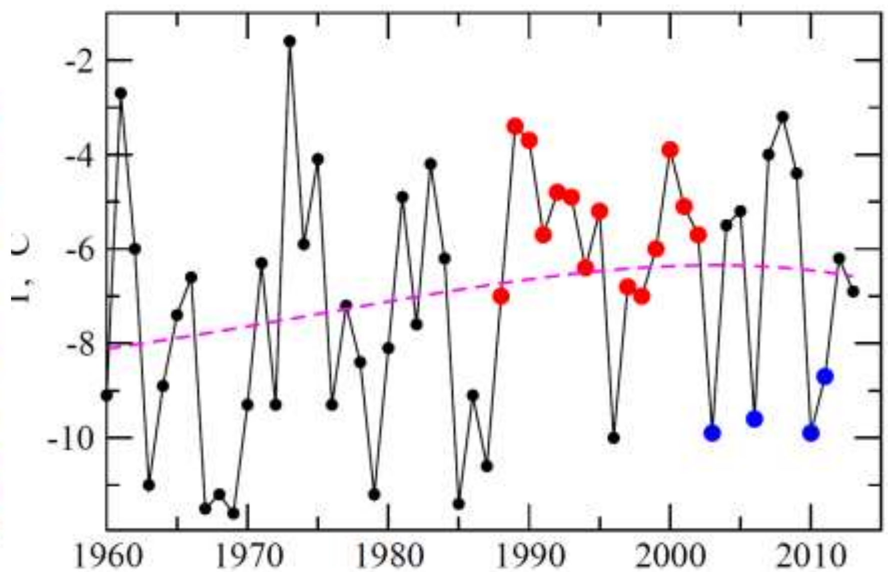
“Cold winters” of the 21st century

DJF temperature anomalies (2001-2010) – (1991-2000)

Observed (GISS) DJF (2001-2010) – (1991-2000), K



Moscow DJF temperatures



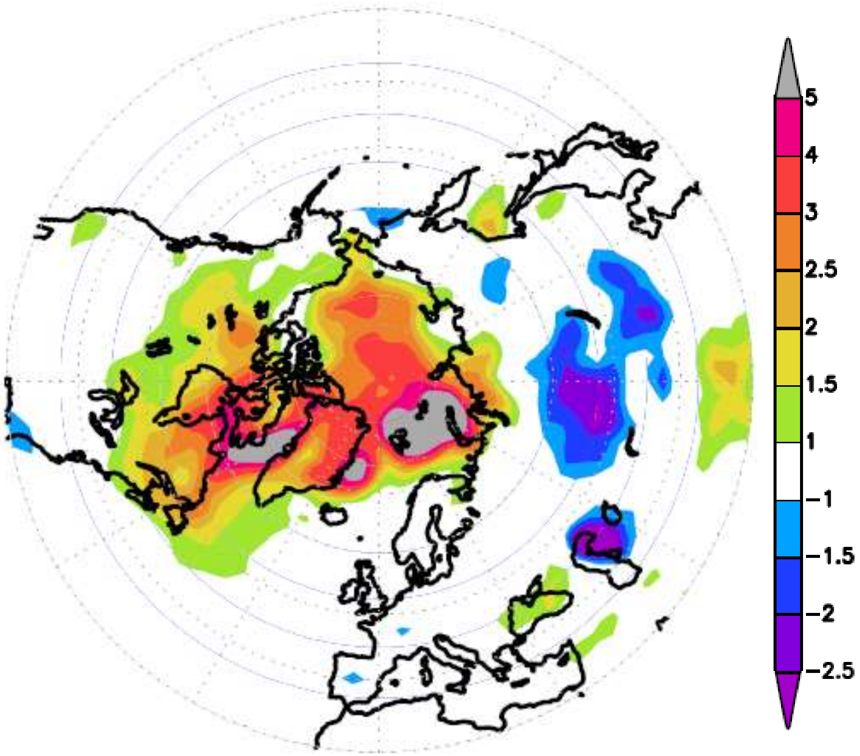
Probability of strong negative Moscow winter temperature anomalies in the 21st century is 3 times higher than two decades before

period	Hamburg “cold yrs” < 0 °C		Moscow “cold yrs” < -8 °C	
	N	Prob.	N	Prob.
1950-1987	11	0.29	18	0.47
1988-2002	1	0.07	1	0.07
2003-2013	3	0.21	4	0.36

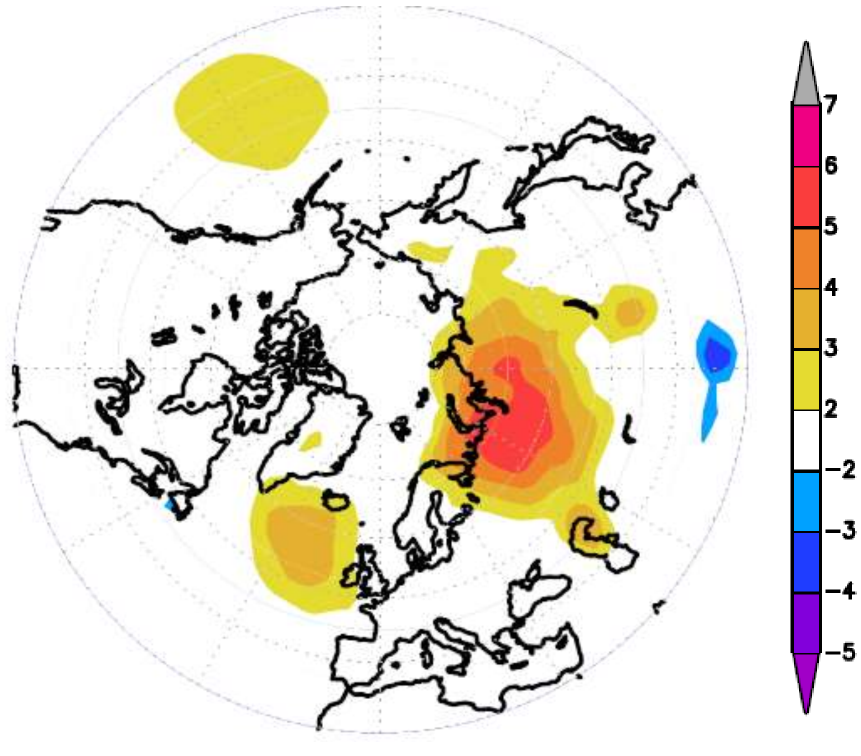
"Cold winters" of the 21st century

Winter temperature (T) and sea level pressure (P) anomalies for 2005-2012
(NCEP reanalysis data)

T, °C



P, hPa

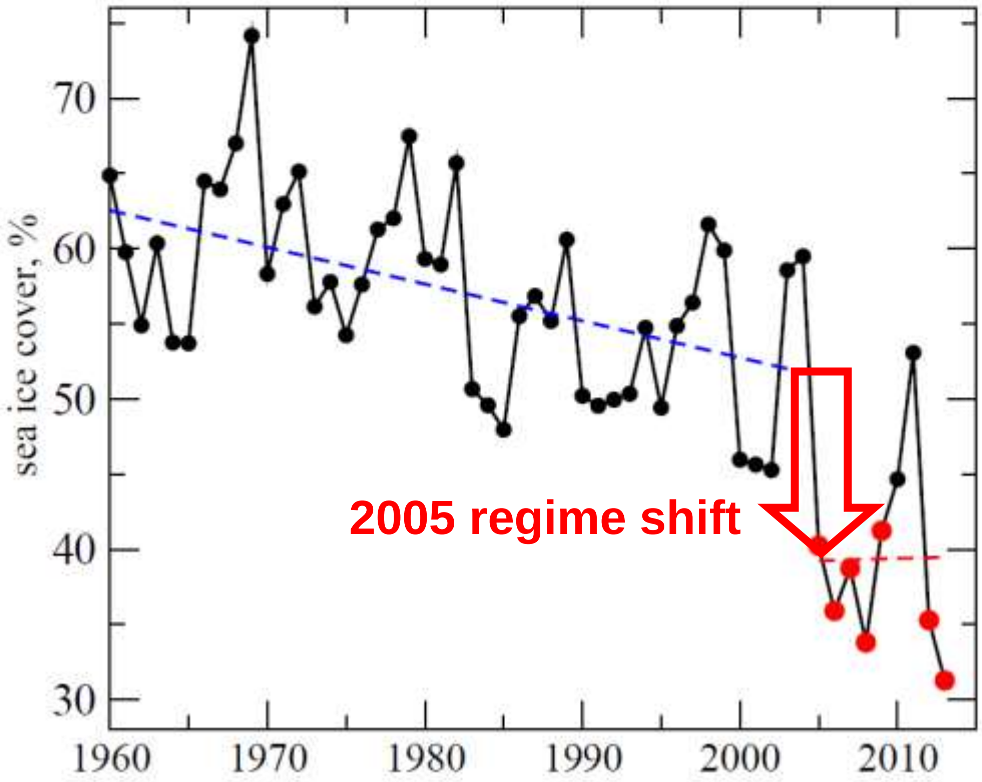


"Hot Arctic – Cold Continent"

"Barents Anti-cyclone"

“Cold winters” of the 21st century

Fraction of the Barents Sea covered by sea ice in winter (%)

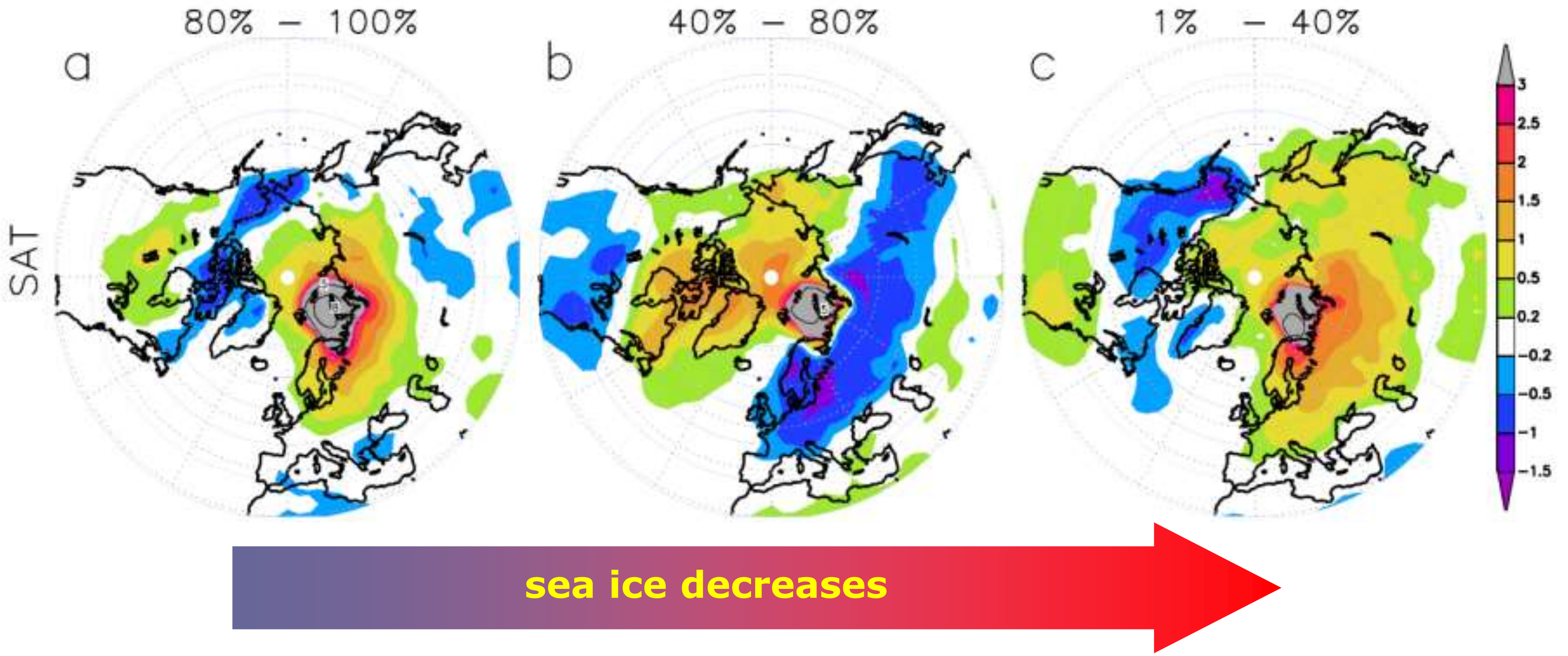


Is there a link between the sharp sea ice reduction and European weather?

“Cold winters” of the 21st century

Simulations with atmospheric model forced by sea ice anomalies in the Barents Sea revealed a **non-linear** response to sea ice reduction with a cooling as a response to present-day sea ice reduction (Petoukhov and Semenov 2010)

Temperature changes induced by gradual sea ice reduction as simulated by climate model, ºC



Conclusions

Statistically significant changes of magnitude and frequency of strong weather anomalies have been observed in some Russian regions since 1950s, in particular increase of heavy precipitation in European part of Russia.

Uncertainty of extreme events changes is higher.

Climate model project increase of extreme precipitation and high temperatures in the course of the 21st century.

There is a general physical basis for the increase of magnitude of hydrological and temperature anomalies with global warming.

Extremes are usually related to anomalies in atmospheric circulation. The response to atmospheric circulation to global warming is complicated, still, at large extent, uncertain and can be essentially non-linear.

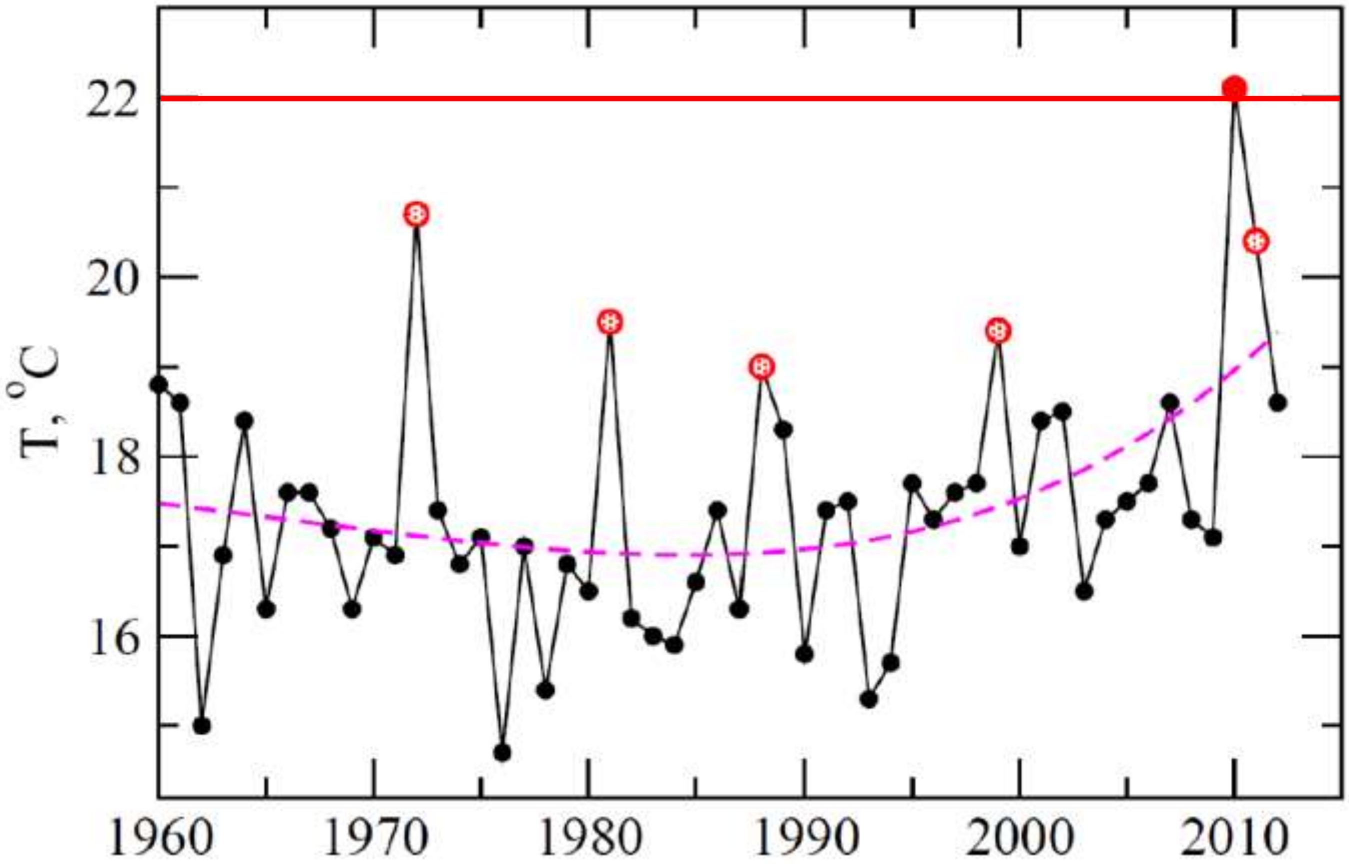
It is possible to attribute particular extremes to changing climate using state of the art climate models and theoretical results.

Thank you for your attention!

Спасибо за внимание!

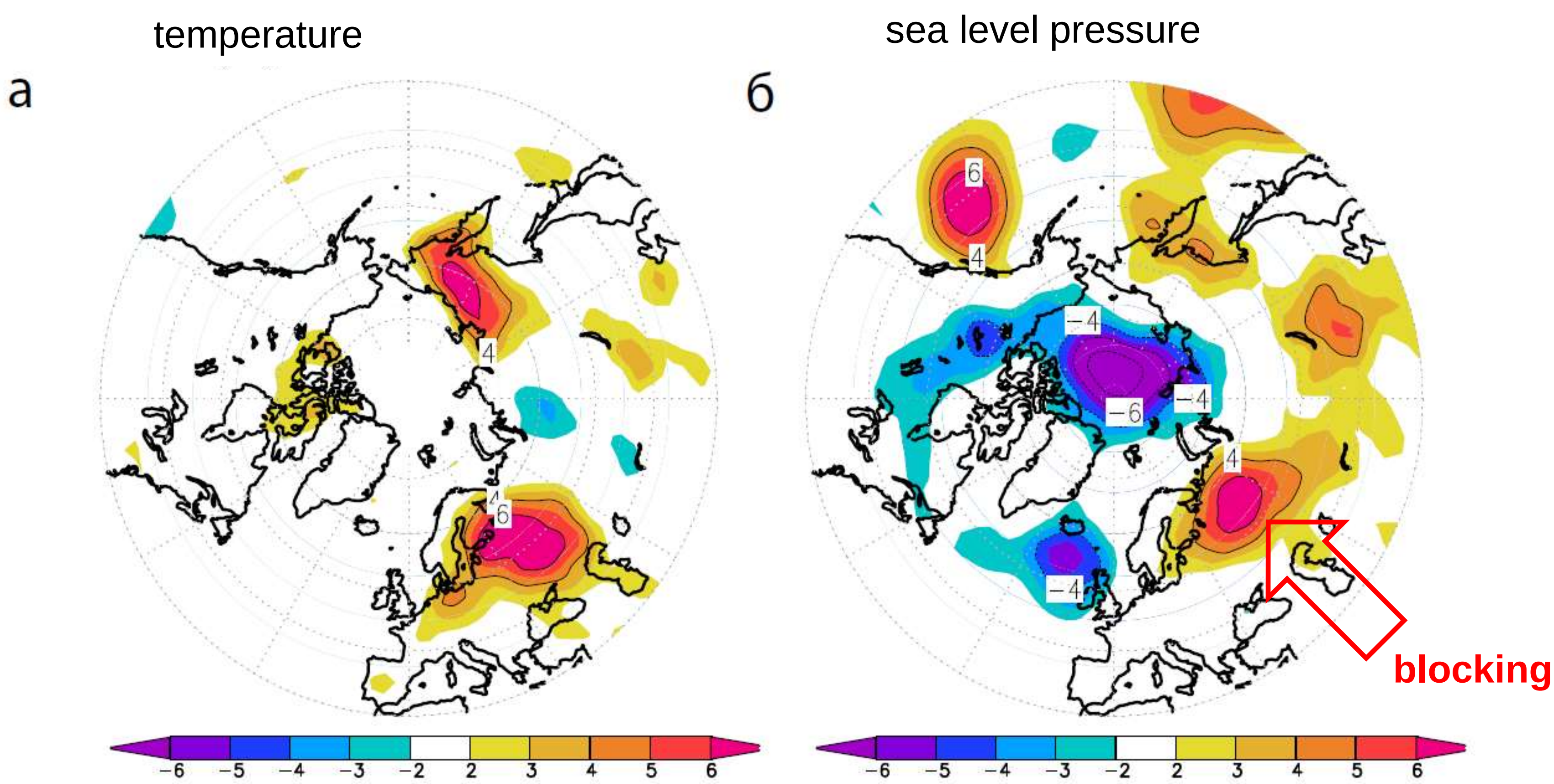
Russian heat wave in July 2010

Moscow summer mean temperature, °C



Russian heat wave in July 2010

Temperature (ºC) and sea level pressure (hPa) anomalies July 2010



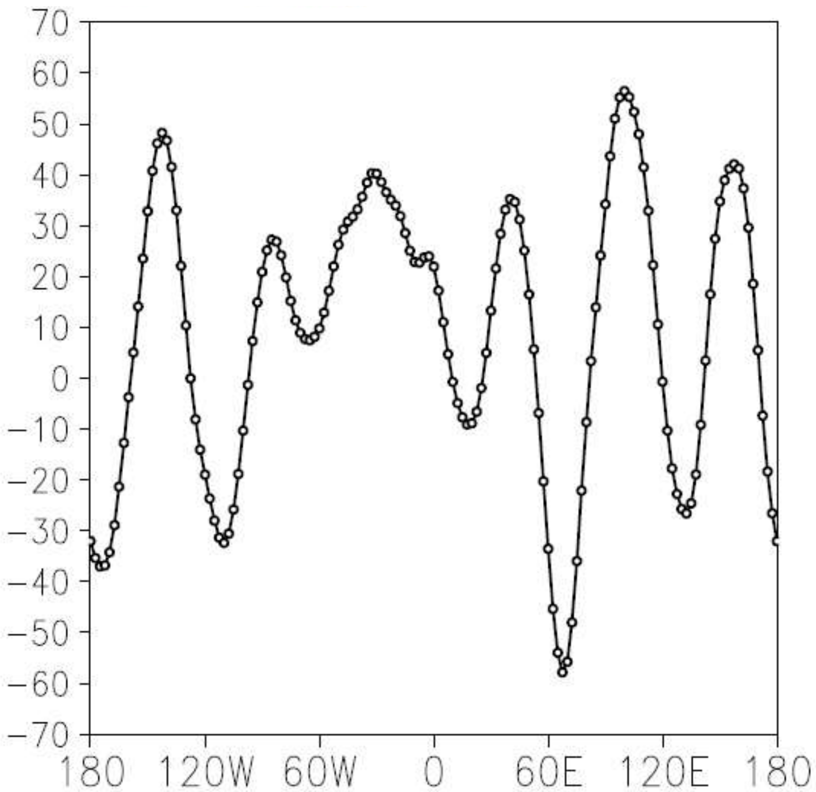
Theoretical studies suggest prolonged blocking events with global warming

(e.g., Mokhov and Petoukhov 1997)

Russian heat wave in July 2010

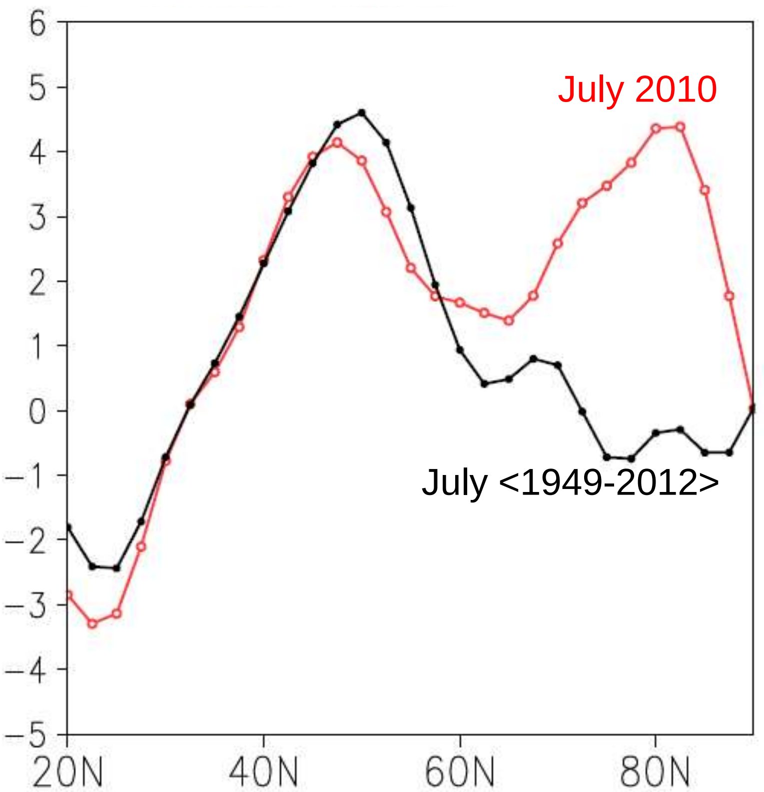
Stationary wave (m=6) at 40ºN

Geopotential height 300hPa anomalies, m



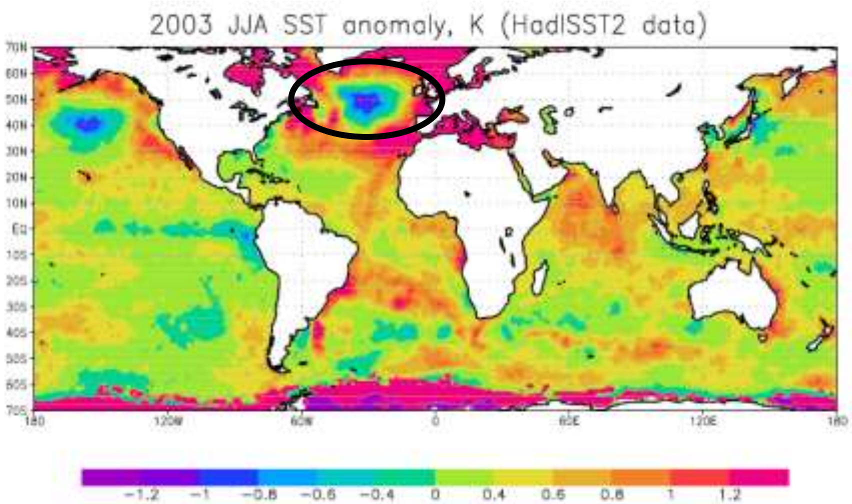
Bi-modal zonal velocity distribution

U at 850hPa, m/s

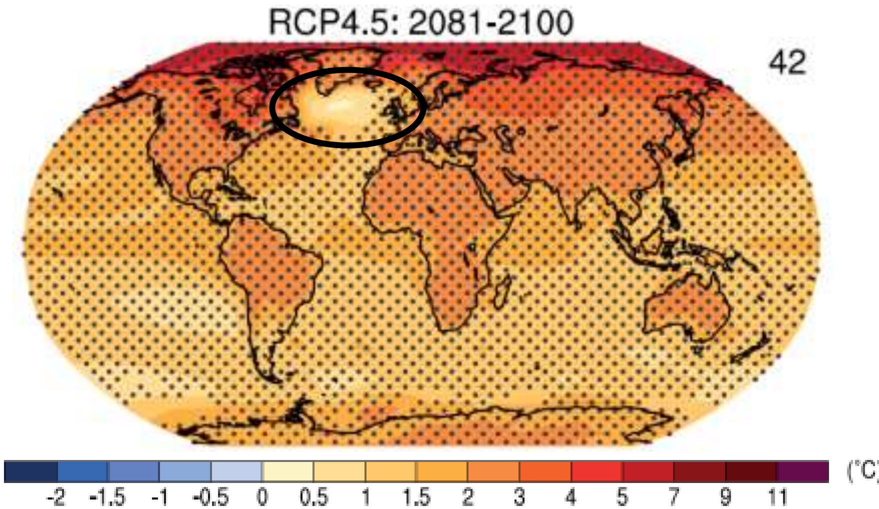


Russian heat wave in July 2010

Ocean surface temperature anomaly July 2010



Projected ocean temperature trends



- Negative anomaly in North Atlantic caused bi-modal zonal velocity profile
- Bi-modal zonal velocity profile trapped synoptic planetary waves
- Synoptic planetary waves came in resonance with stationary planetary waves
- Resonant high amplitude stationary planetary wave favored formation of blocking
- Blocking resulted in heat wave (Petoukhov et al. 2012)
- Heat wave was amplified by preceding negative soil moisture anomaly (Volodin 2010)