On the Causes of and Long Term Changes in Eurasian Heat Waves

Siegfried Schubert
Hailan Wang*, Randy Koster, Max Suarez
NASA/GSFC
Global Modeling and Assimilation Office

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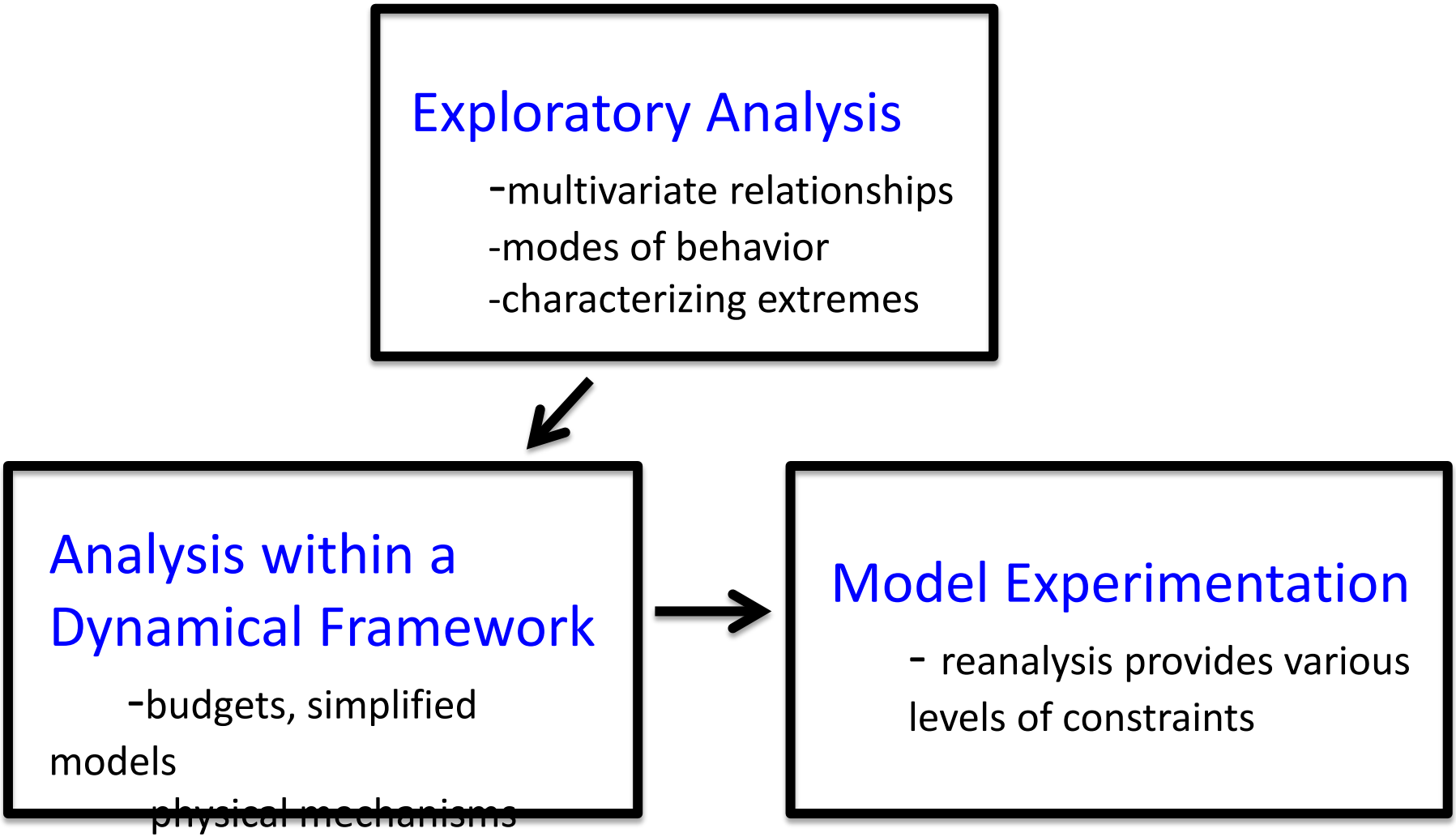
* Also, SCIENCE SYSTEMS AND APPLICATIONS, INC (SSAI)

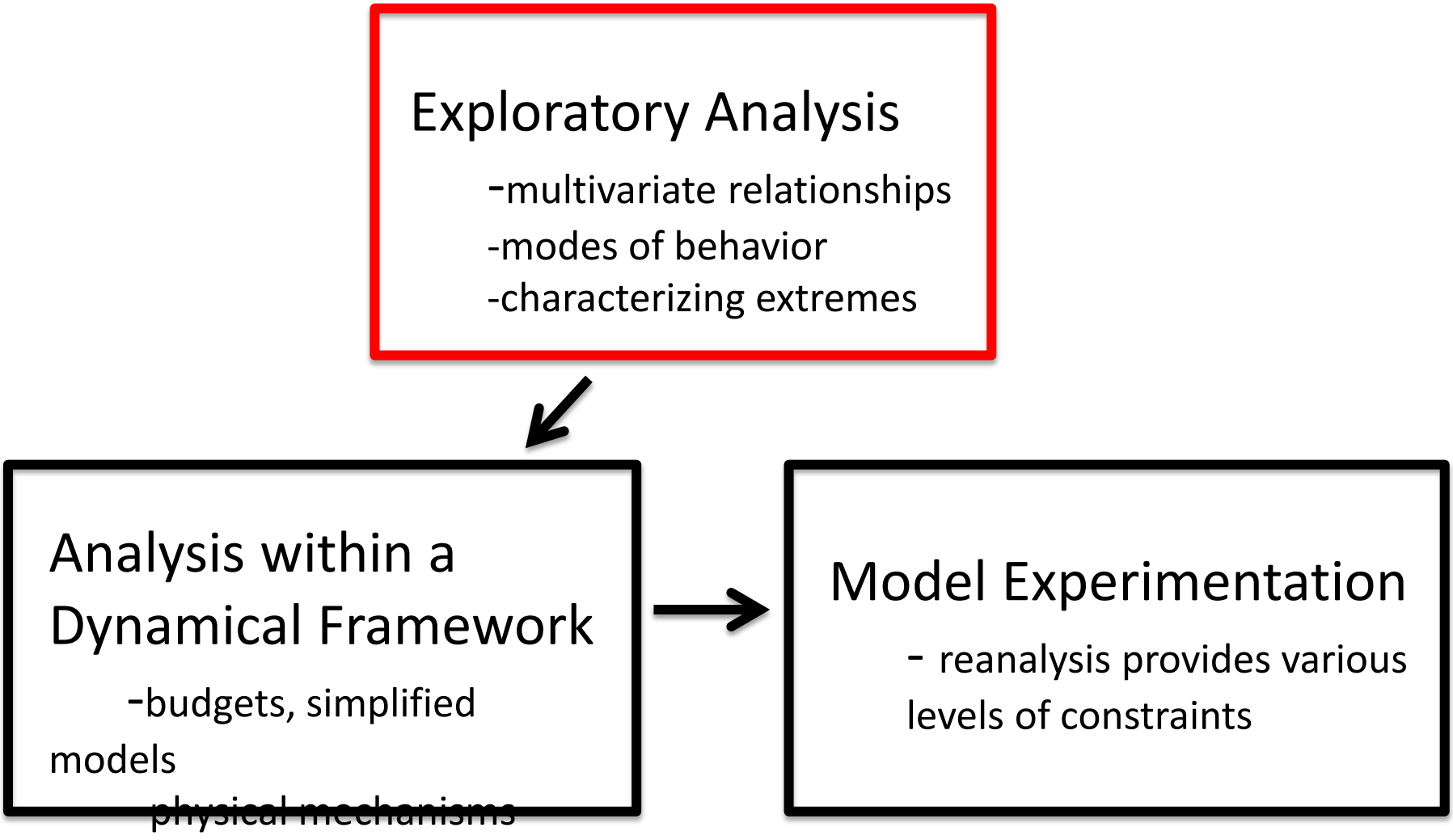
Understanding Causes: The Synergistic Use of Observations (including reanalyses) and Modeling



What are the Causes of and Long Term Changes in Heat Waves in Eurasia?

Recent examples are the 2010, 2011 Russian Heat Waves and the 2003 European Heat Wave

Steps to Understanding Causes (Attribution)



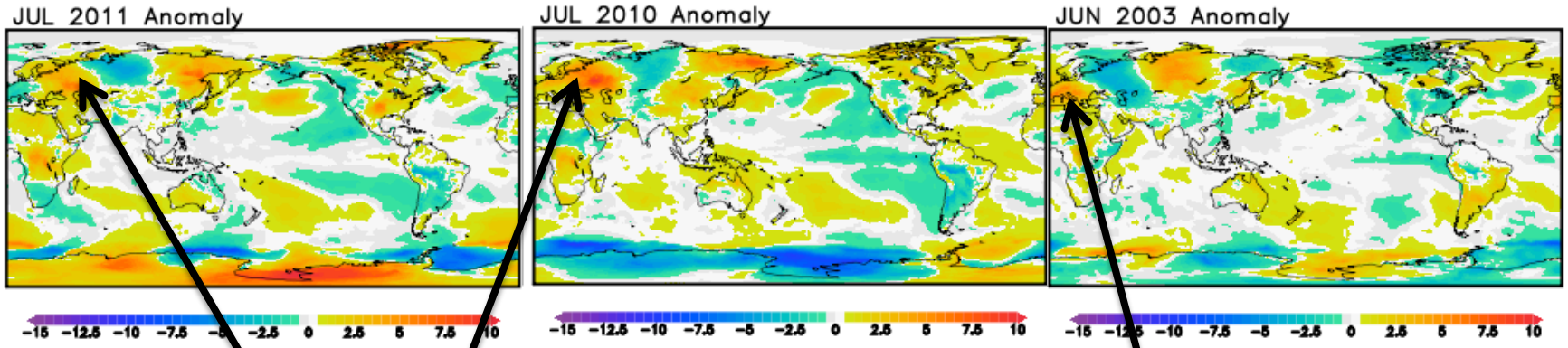
NASA's Modern Era Retrospective-analysis for Research and Applications
(MERRA Atlas)

Temperature at 2 meters (T2m)

July 2011

July 2010

June 2003

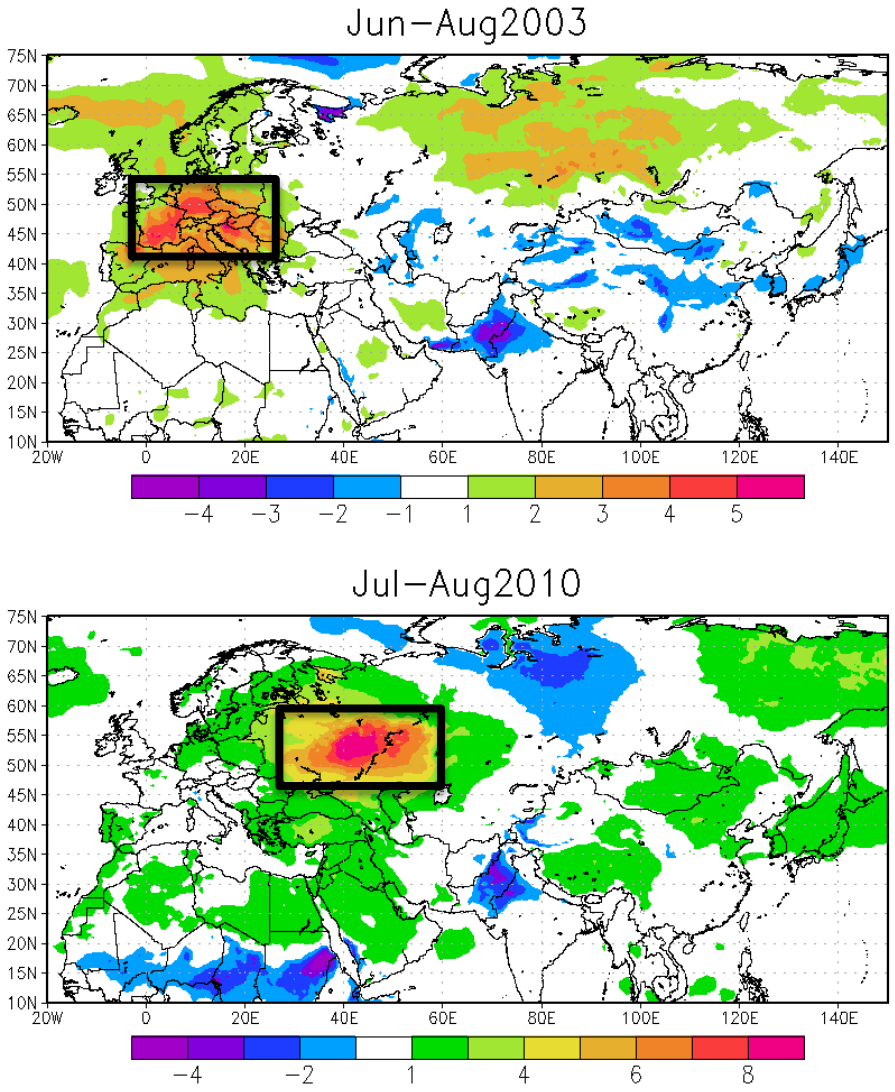


European Heat Wave

Russian Heat Waves

https://gmao.gsfc.nasa.gov/ref/merra/atlas/

MERRA: T2m Anomaly (°C)

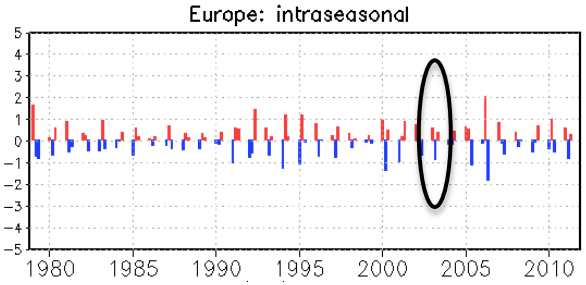


Area Averages: European region: 0-25E; 40N-55N;
western Russia region: 25E-60E;46N-62N

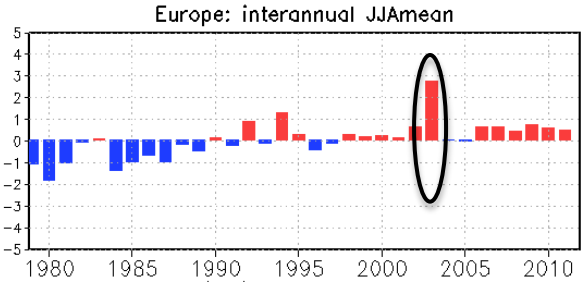
1979-2011 JJA T2m Anomalies (°C) based on MERRA

Europe

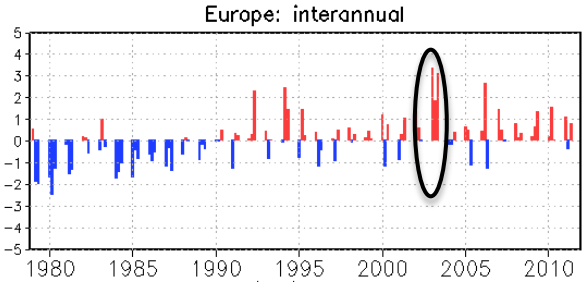
JJA intraseasonal



JJA Seasonal Mean

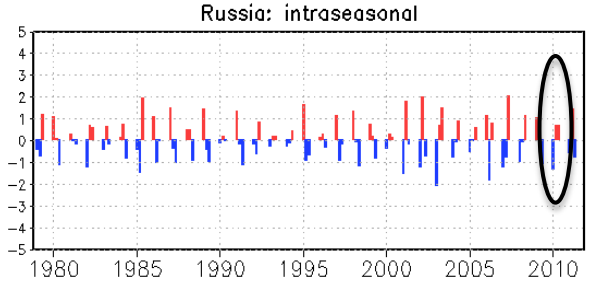


JJA Total Interannual

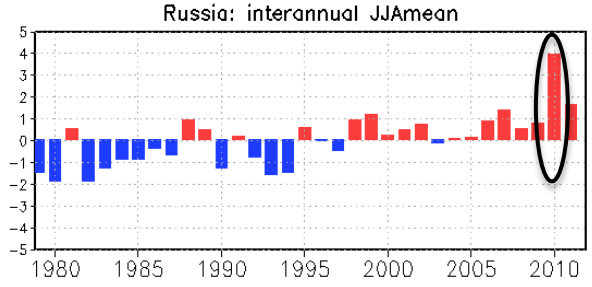


Western Russia

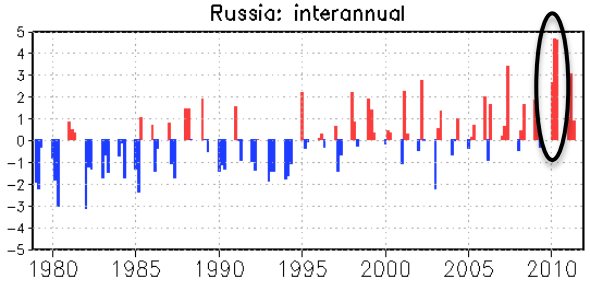
JJA intraseasonal



JJA Seasonal Mean

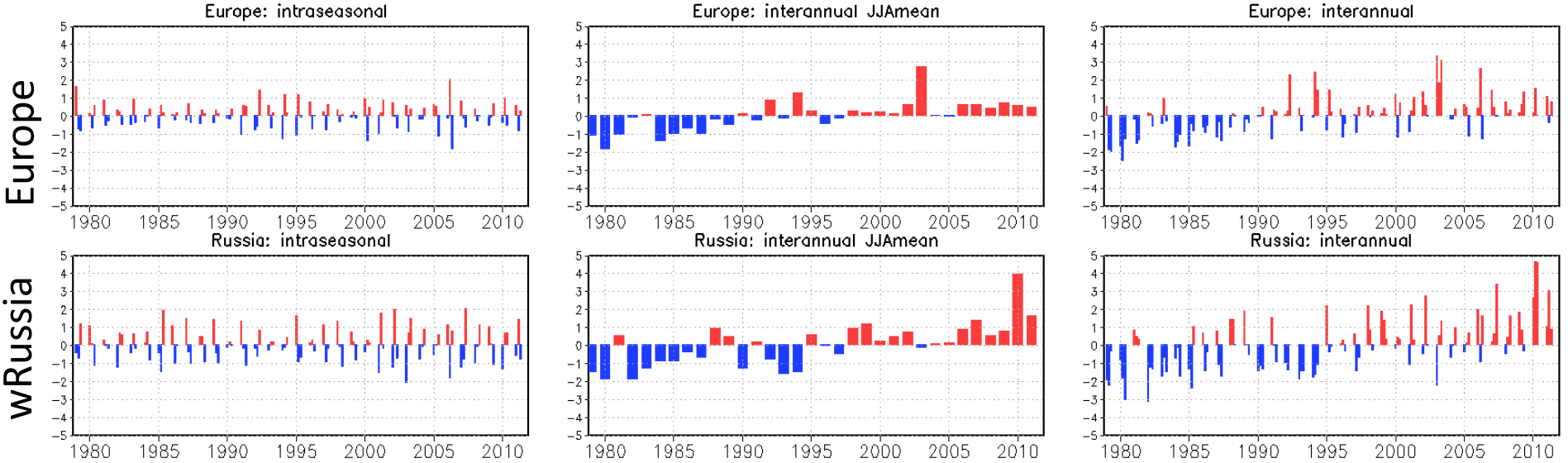


JJA Total Interannual

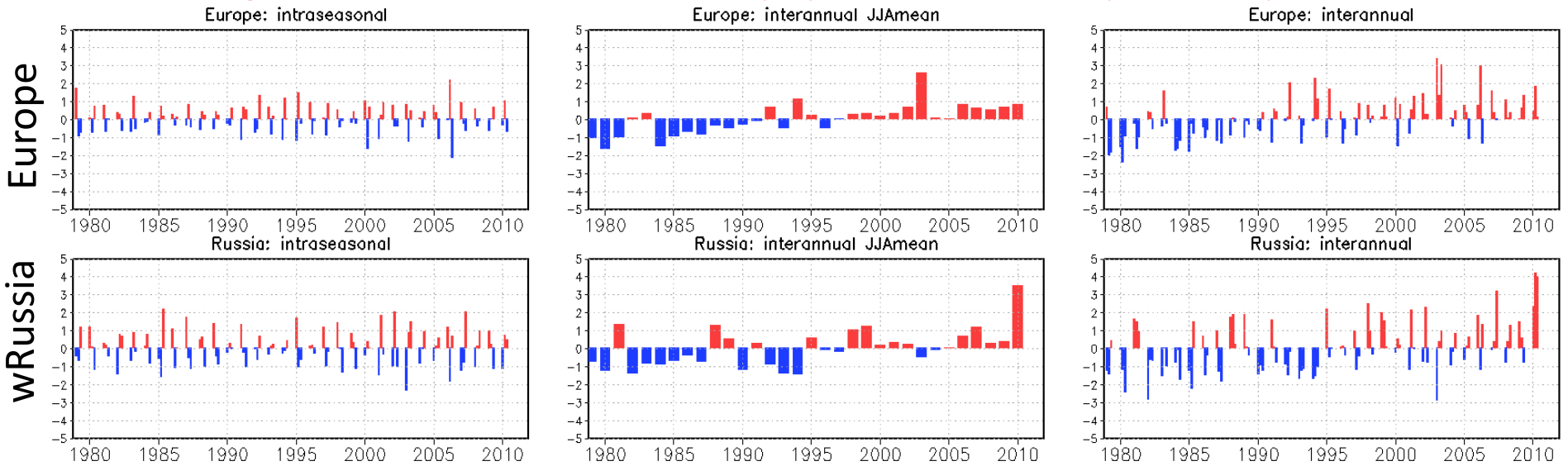


Near surface: intraseasonal and seasonal components are comparable, extreme heat waves reflected in seasonal components, with some intraseasonal modulation, apparent trend in seasonal means. **2003 over Europe,and 2010 over Russia stand out**

JJA Tsfc based on **MERRA** (1979-2011



JJA Tsfc based on **CRUTEM4** (1979-2010)



Why the alternating east/west oriented anomalies in Tfcs?

Nature of subseasonal (monthly) Tsfc variability?

Nature of seasonal mean Tsfc variability?

Causes of apparent trend in seasonal means of Tsfc ?

Why are 2003 and 2010 so extreme?

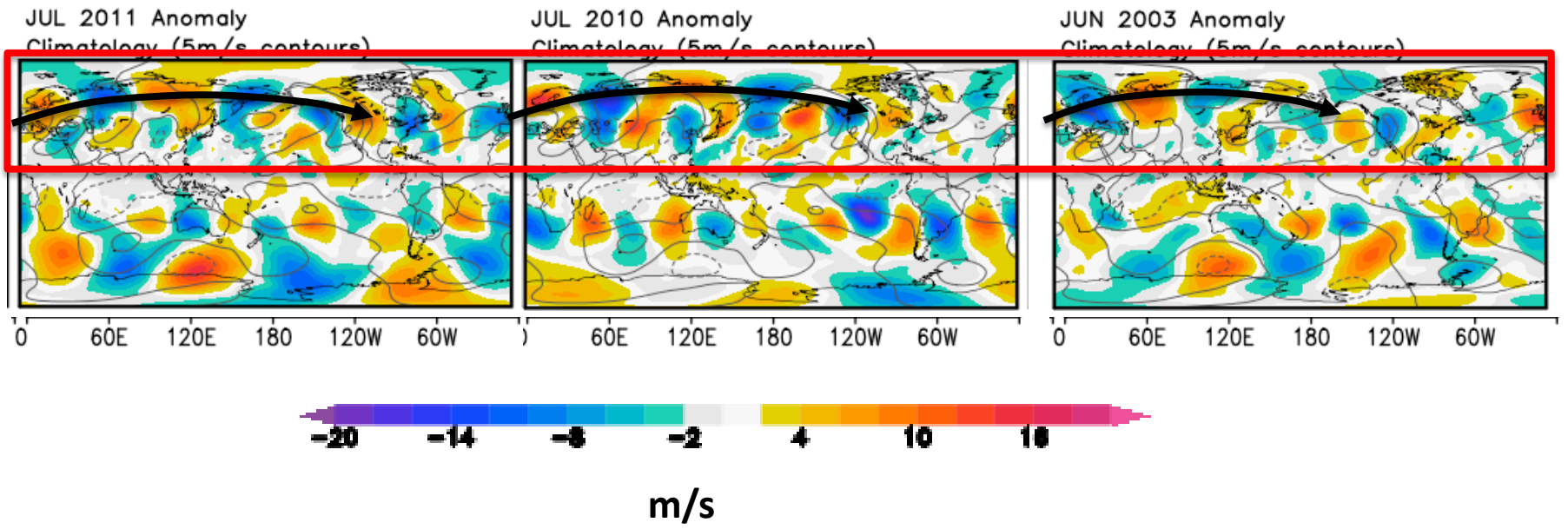
MERRA
Atlas

V250mb Anomalies (m/s)

July 2011

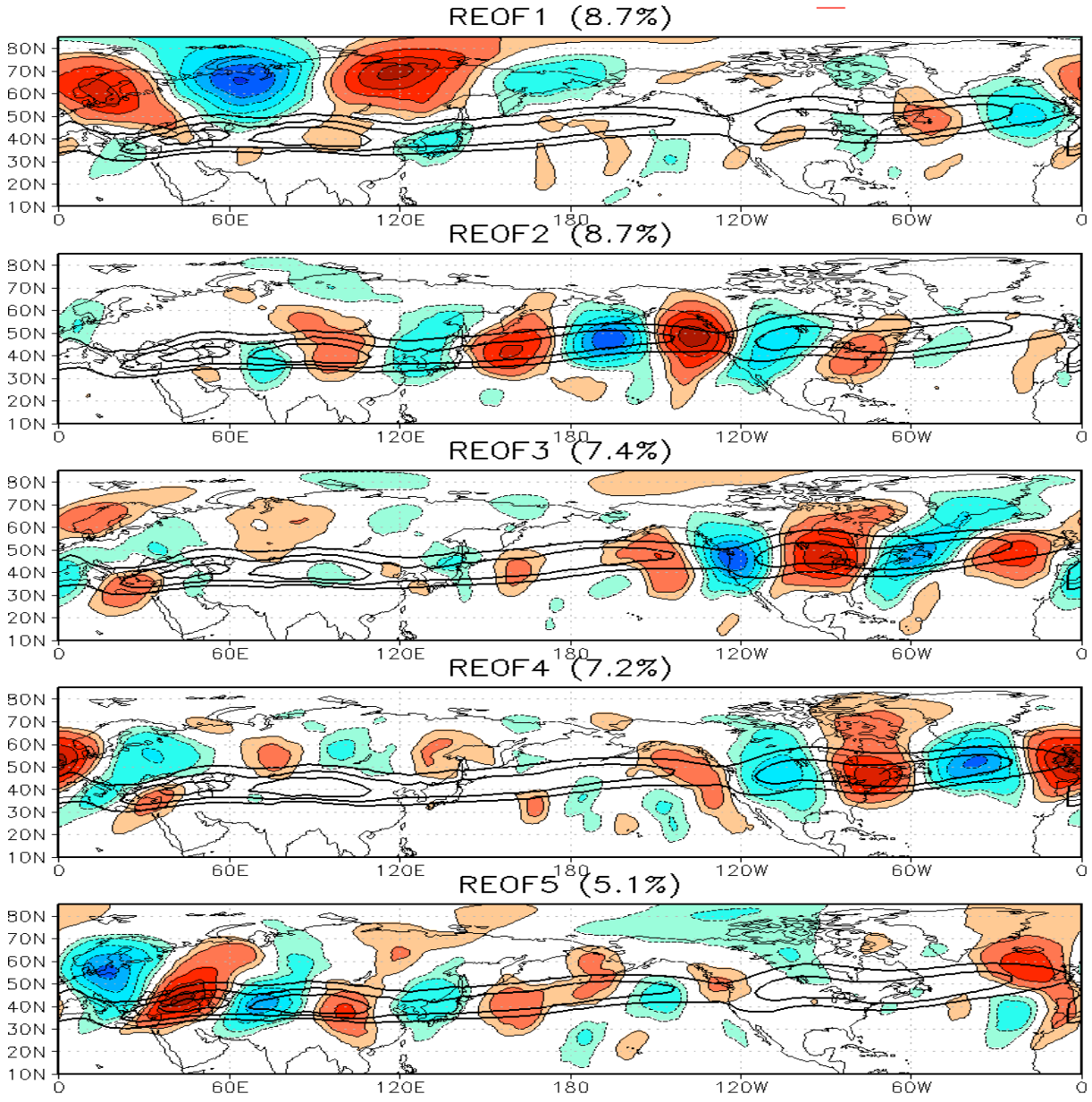
July 2010

June 2003



All three years show prominent upper tropospheric stationary Rossby waves extending across northern Eurasia

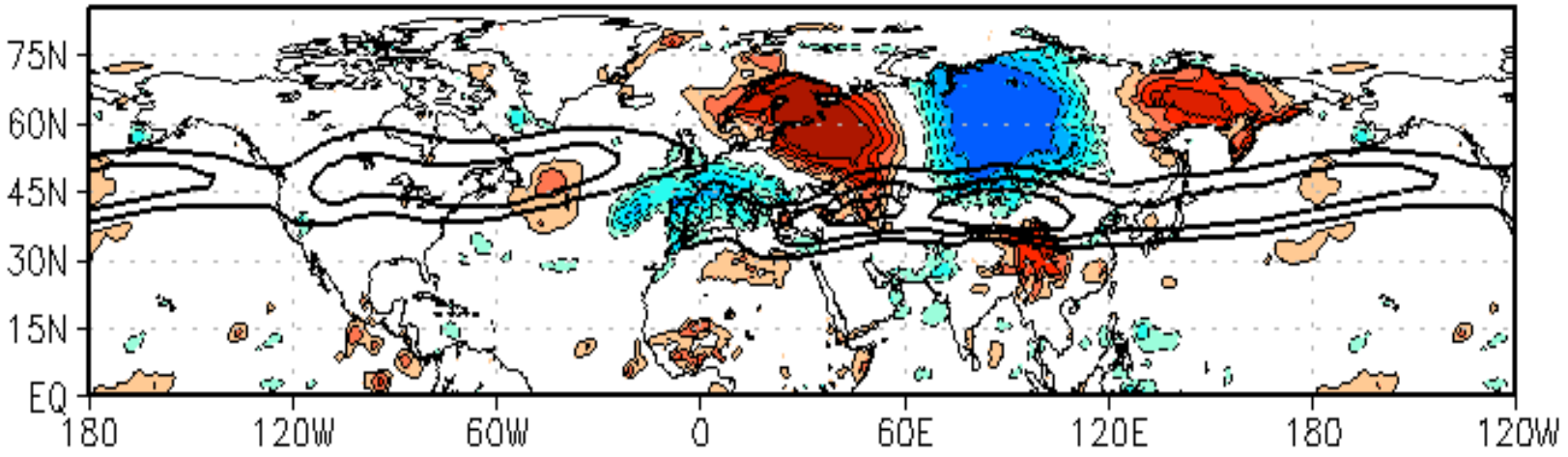
Leading Rotated EOFs of Intraseasonal (Monthly JJA) V250mb



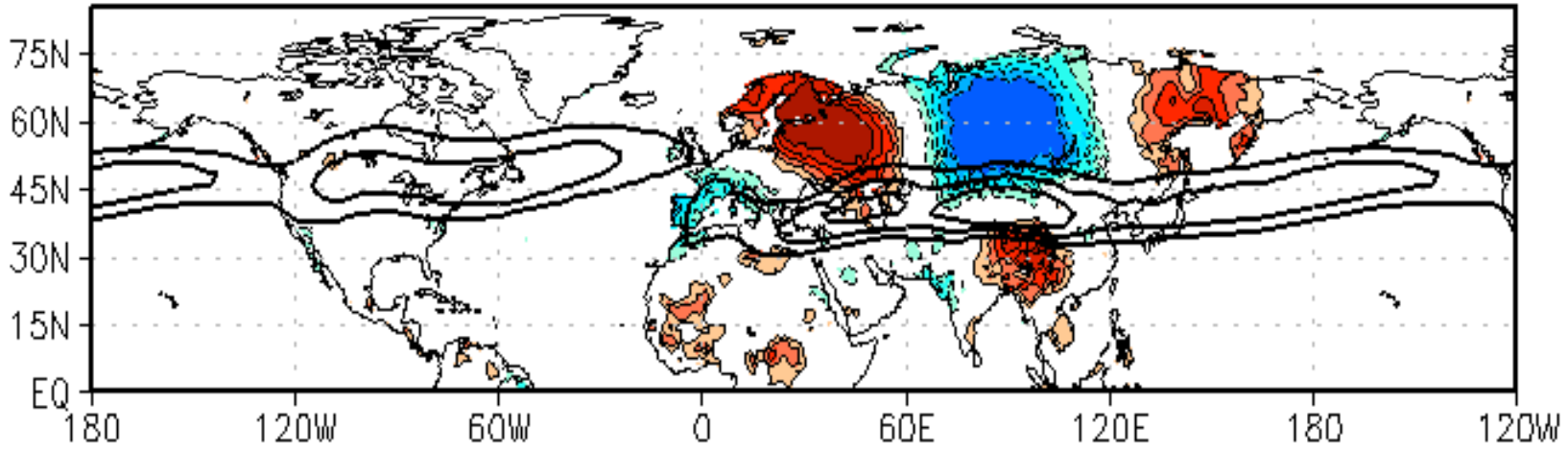
Based on MERRA: 1979- 2010

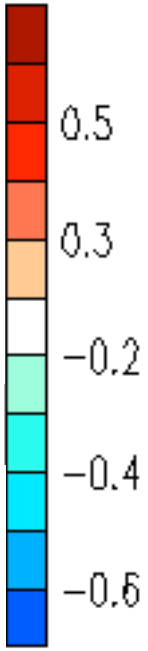
Correlation Between V250 REOF 1 and T2m

MERRA T2m



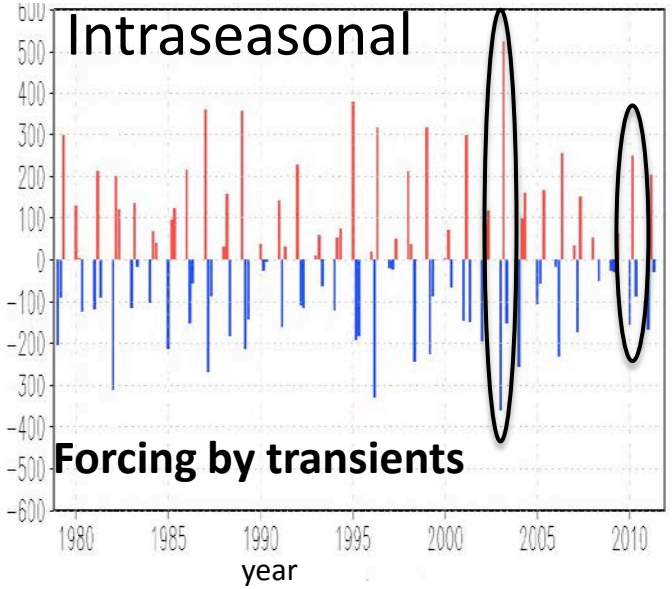
HADCRU Gridded Station Data T2m

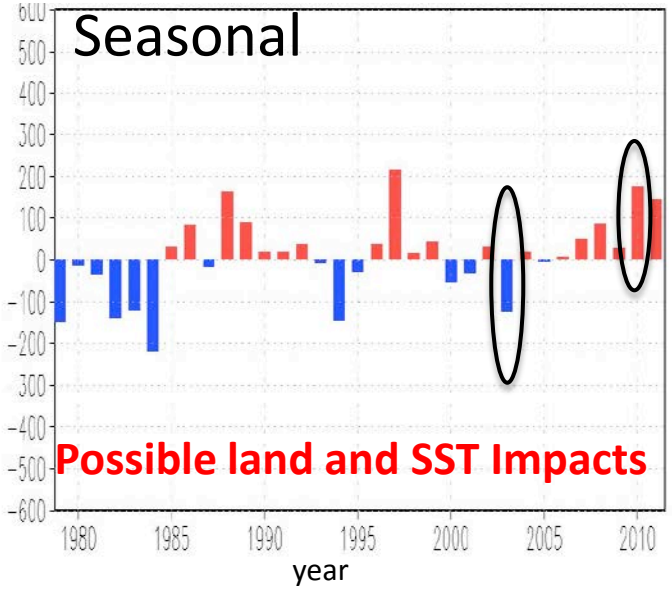




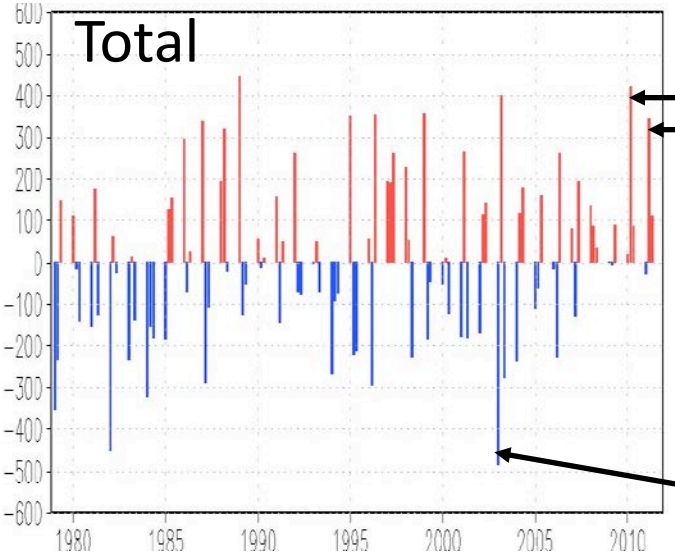
Based on Monthly (subseasonal) data JJA (1979-2008)

v250mb REOF 1 (PC, JJA 1979-2011)





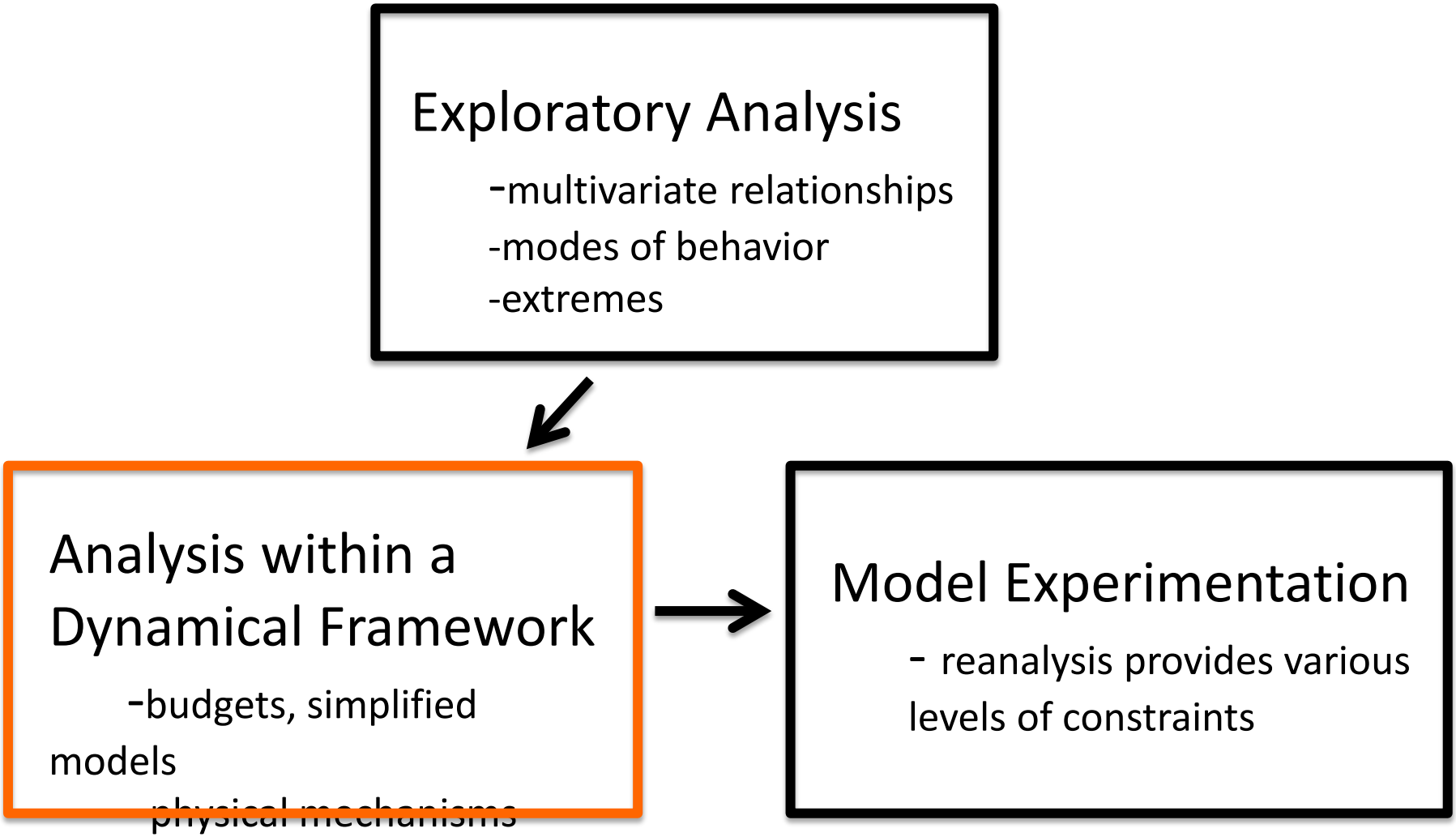
At upper levels: intraseasonal component is large, trends less apparent, peaks in heat waves linked to intraseasonal variability



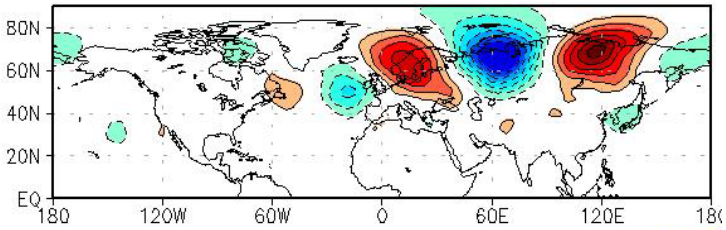
2010, 2011
July, Russian Heat Waves

2003 June European Heat Wave

Steps to Attribution



REOF 1



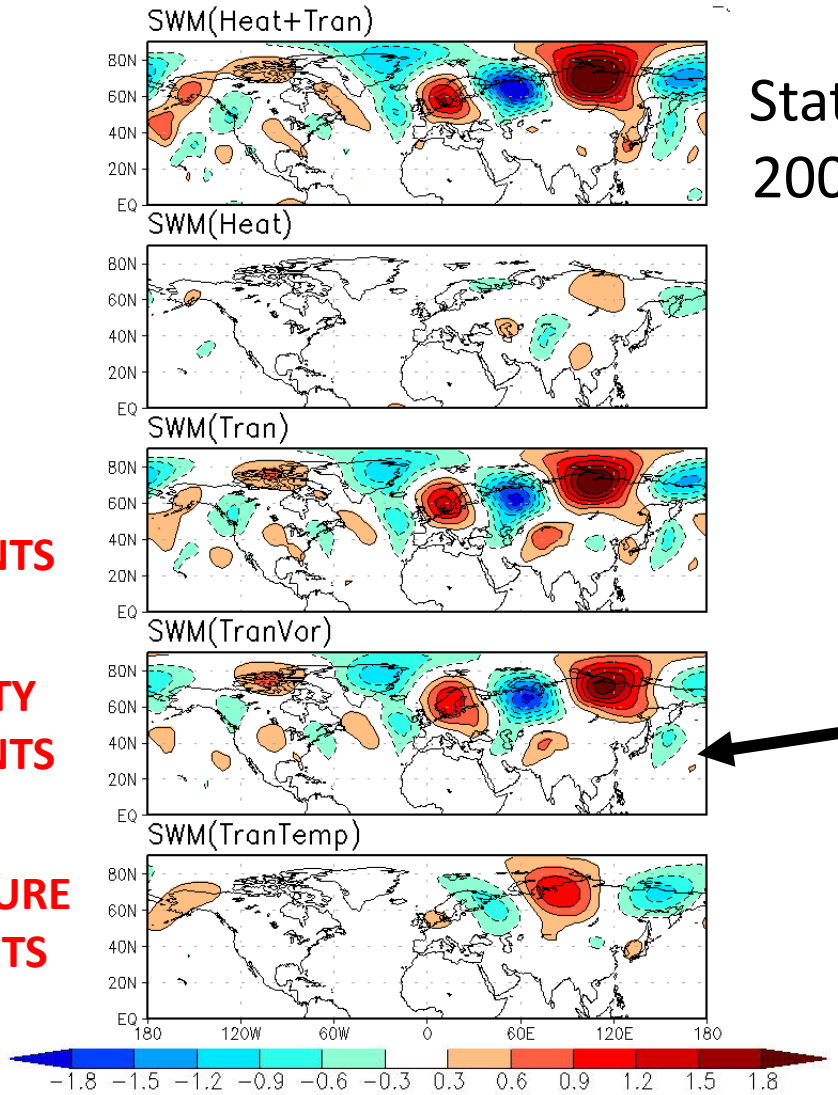
TOTAL FORCING

HEATING

Total TRANSIENTS

VORTICITY TRANSIENTS

TEMPERATURE TRANSIENTS



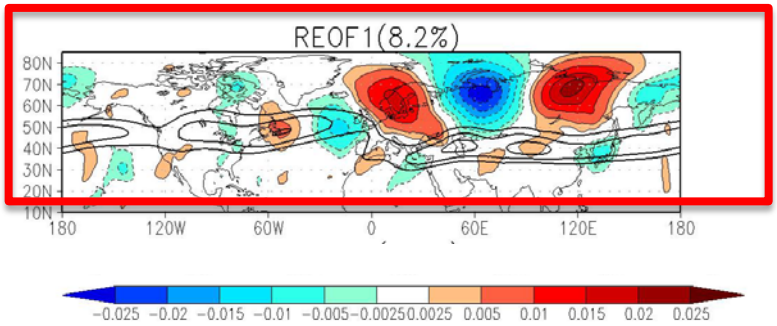
Stationary Wave Model (Ting et al. 2001) Forced By MERRA Estimates of Various Forcing Terms Associated with REOF 1

At subseasonal time scales vorticity transients are the main forcing

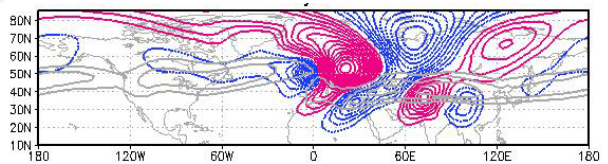
Schubert et. al. 2009

Leading Rotated EOFs
Monthly JJA V250mb

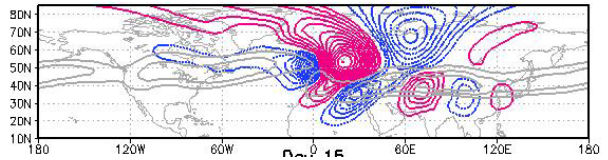
REOF 1



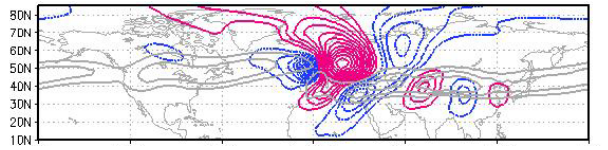
SWM response of the eddy v-wind at σ=0.257 to an idealized vorticity source at 0E, 50N



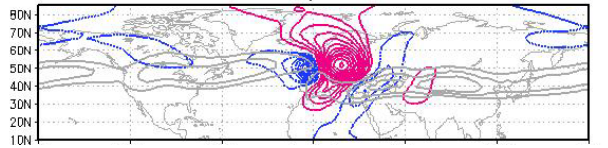
Day 20



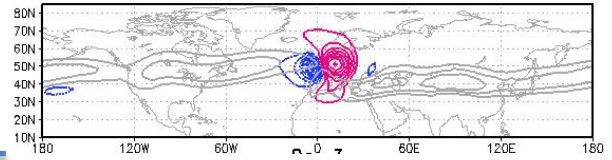
Day 10



Day 5



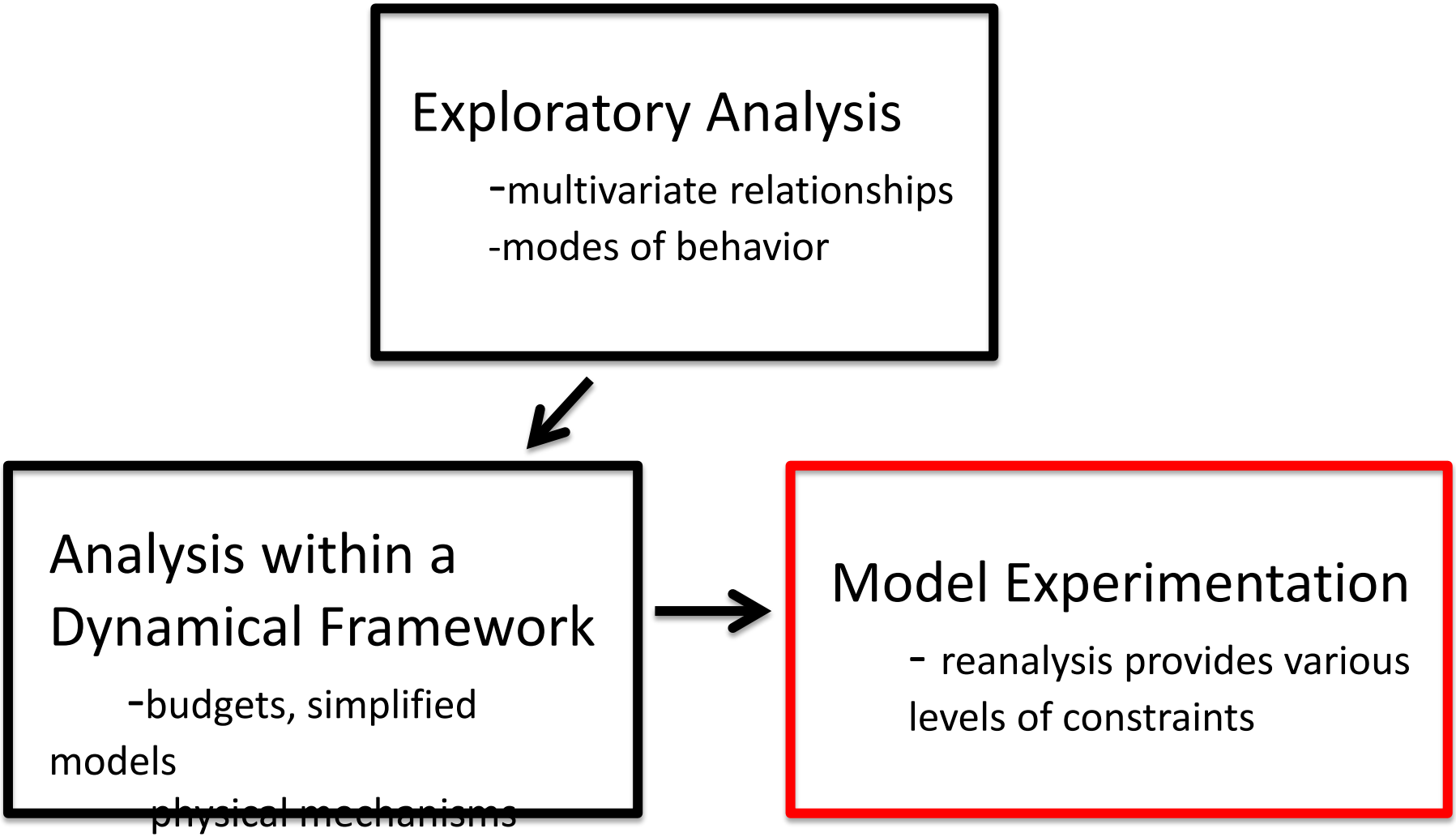
Day 3



Day 1

MERRA Base State: JJA 1979-2010

Steps to Attribution

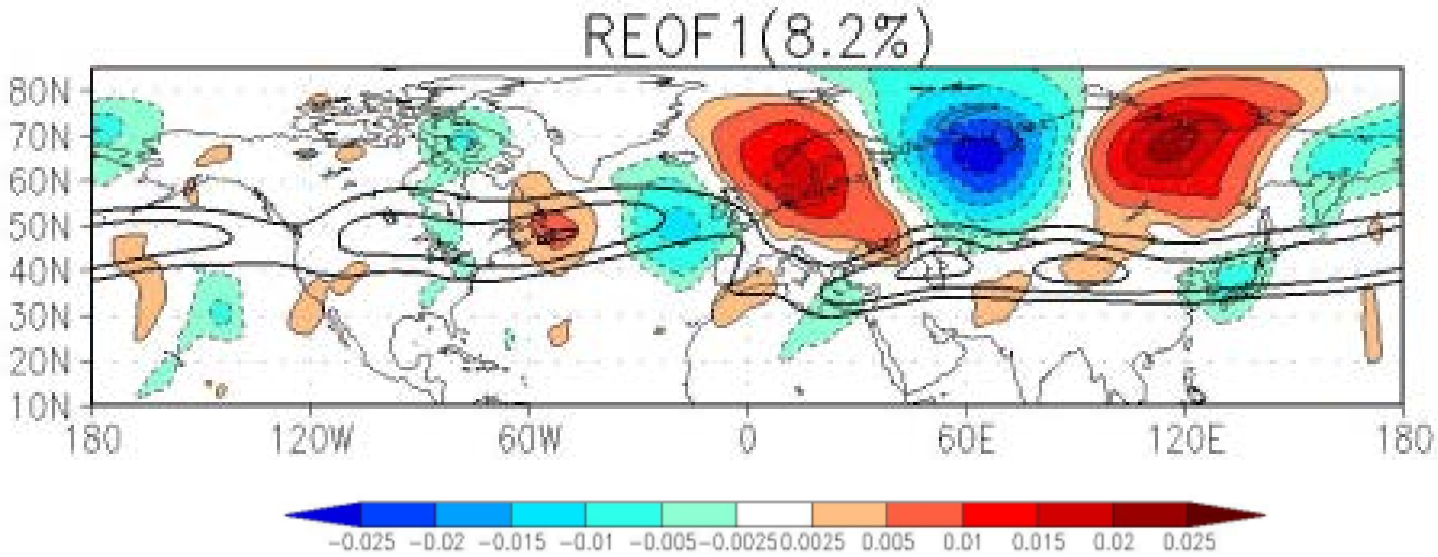


GEOS-5 AMIP Simulations (1870-present)

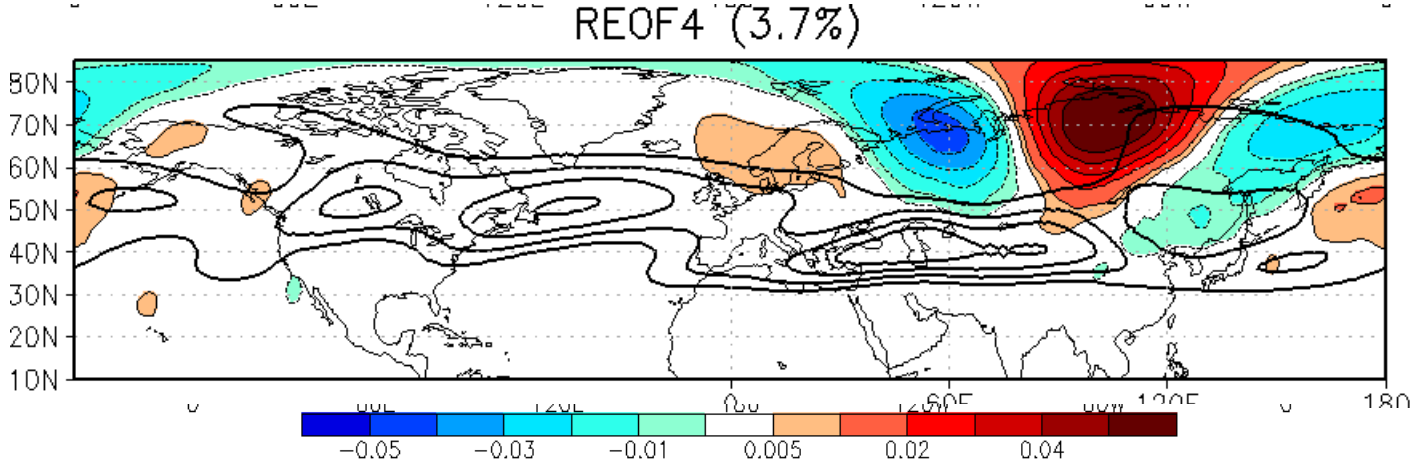
- 1 degree horizontal resolution
- 10 members with interactive aerosols
- 2 members with prescribed aerosol climatology
- IPCC CMIP-5 forcings

- Does the model reproduce REOF 1 (Eurasian Stationary Rossby Wave)?
- Does the model reproduce the subseasonal and seasonal variability, and trends in Tsfc?

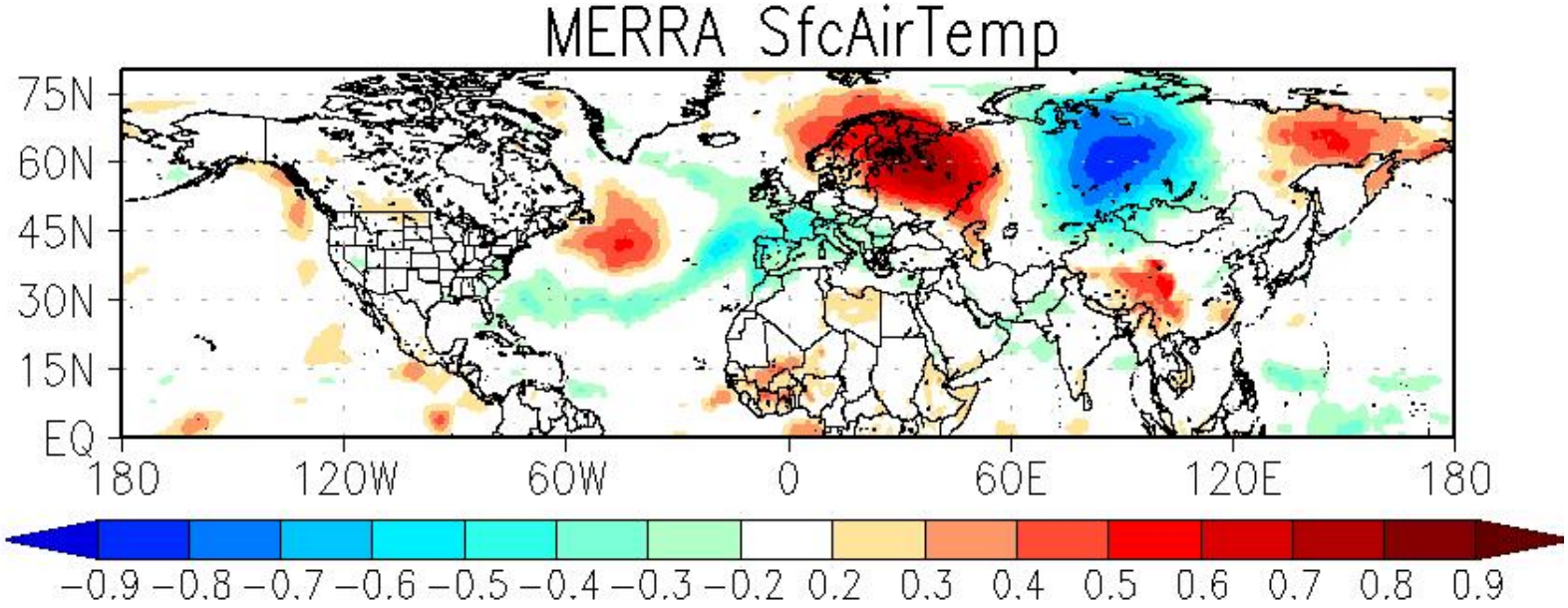
MERRA(1979-2010): REOF1_intraseasonal_v250mb



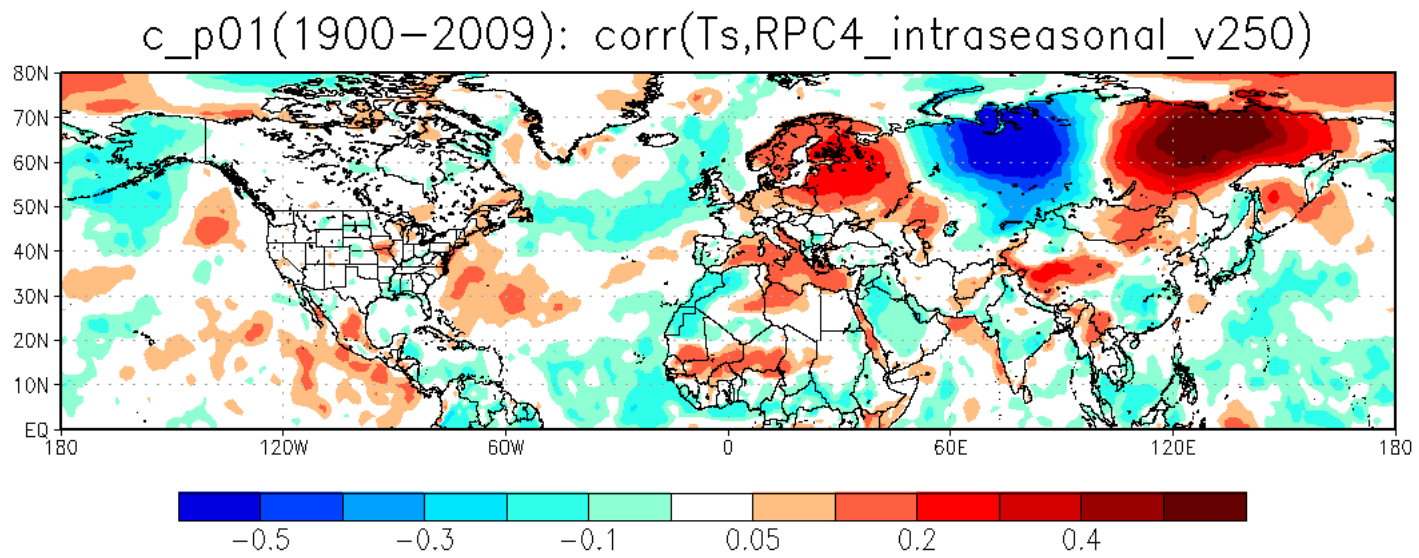
C_p01(1900-2009): REOF4_intraseasonal_v250mb



MERRA(J-J-A1979-2010): Corr(intraseasonal_Ts; RPC1_intraseasonal_v250)

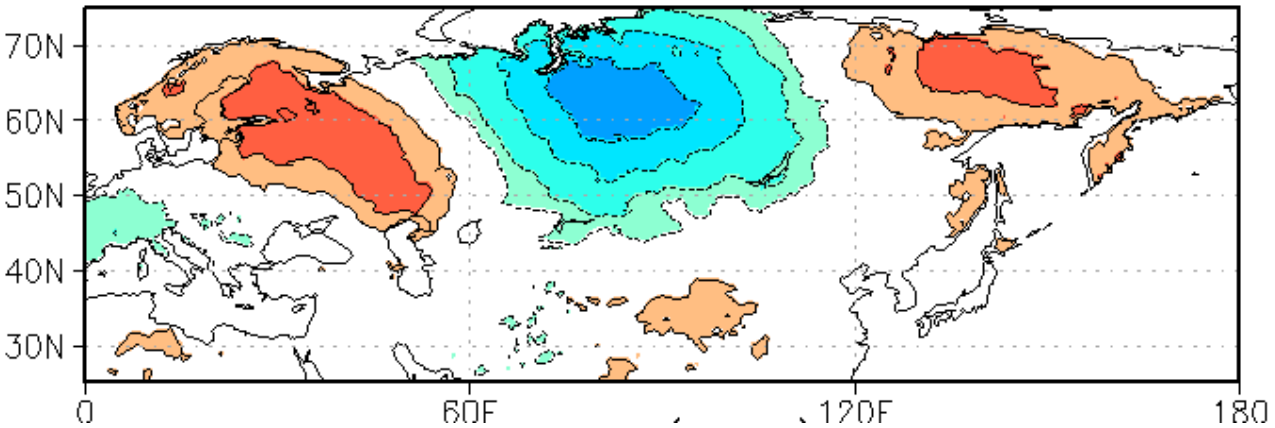


C_p01(J-J-A1900-2009): Corr(intraseasonal_Ts; RPC4_intraseasonal_v250)

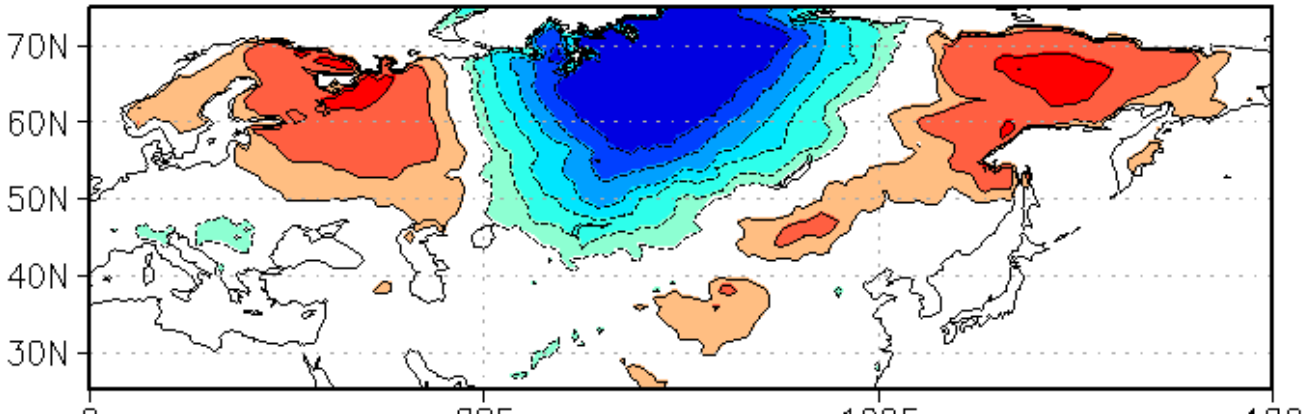


Leading REOF of Ts_land (JJA intraseasonal)

MERRA: REOF1 (17%)- 1979-2011



Model ENS C6: REOF1 (13%) – 1871-2011



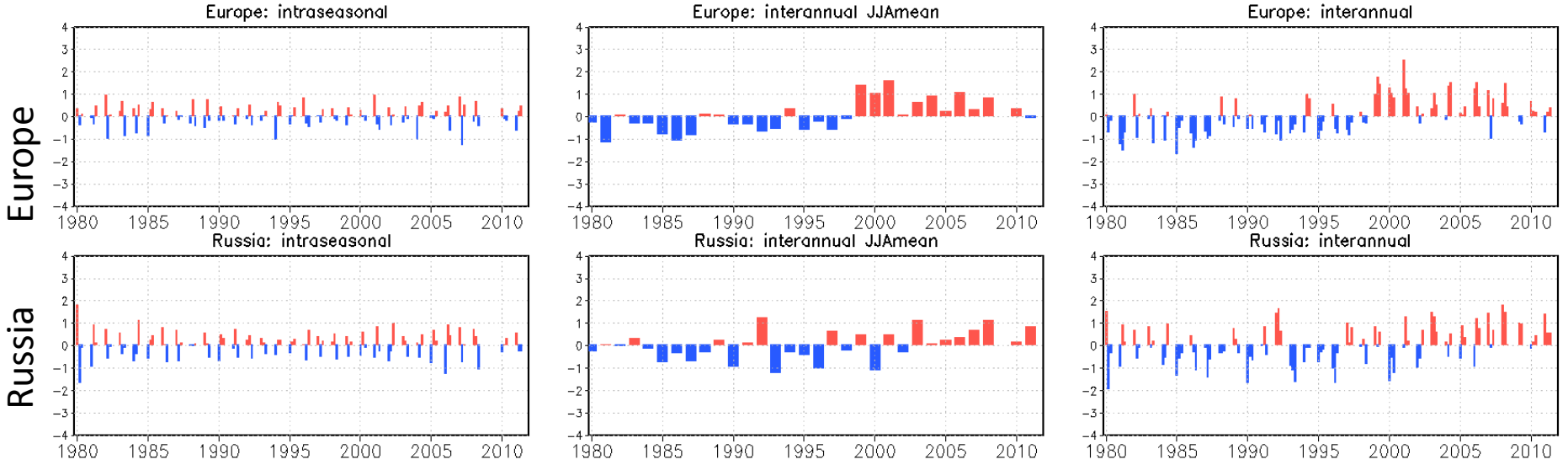
Let's look at the T2m time series from some of the AMIP ensemble members:

- note scale goes from -4 to + 4 °C
  (versus -5 to + 5 for MERRA)

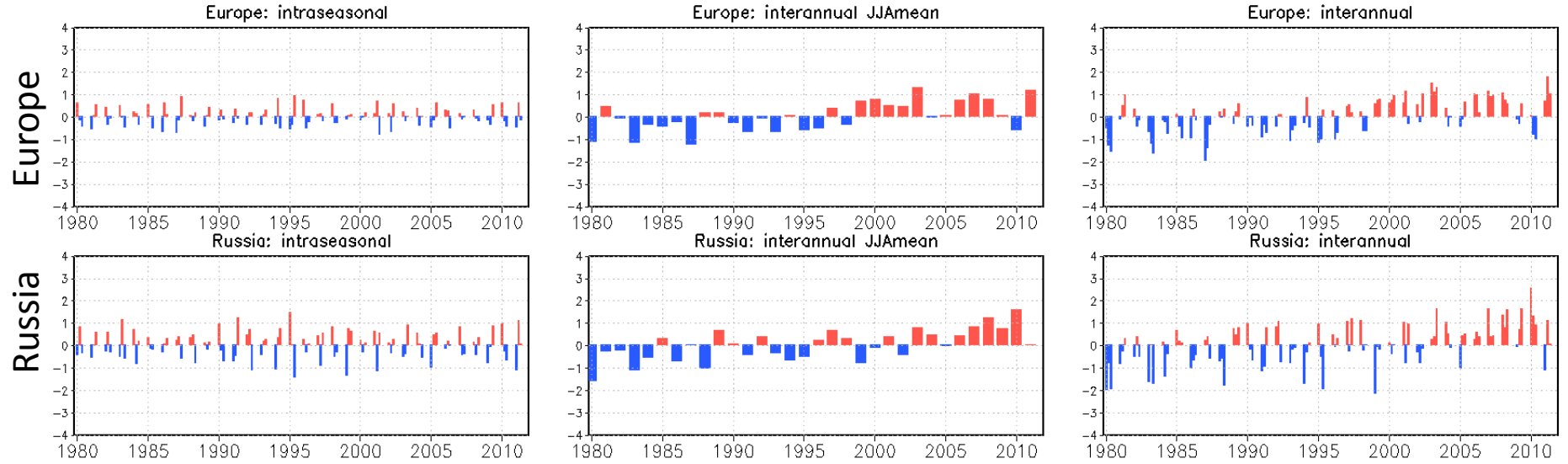
- we have also slightly redefined the western Russia region (based on correlations with REOF 1), though not much sensitivity

T2m (°C)

AMIP Ensemble member C1



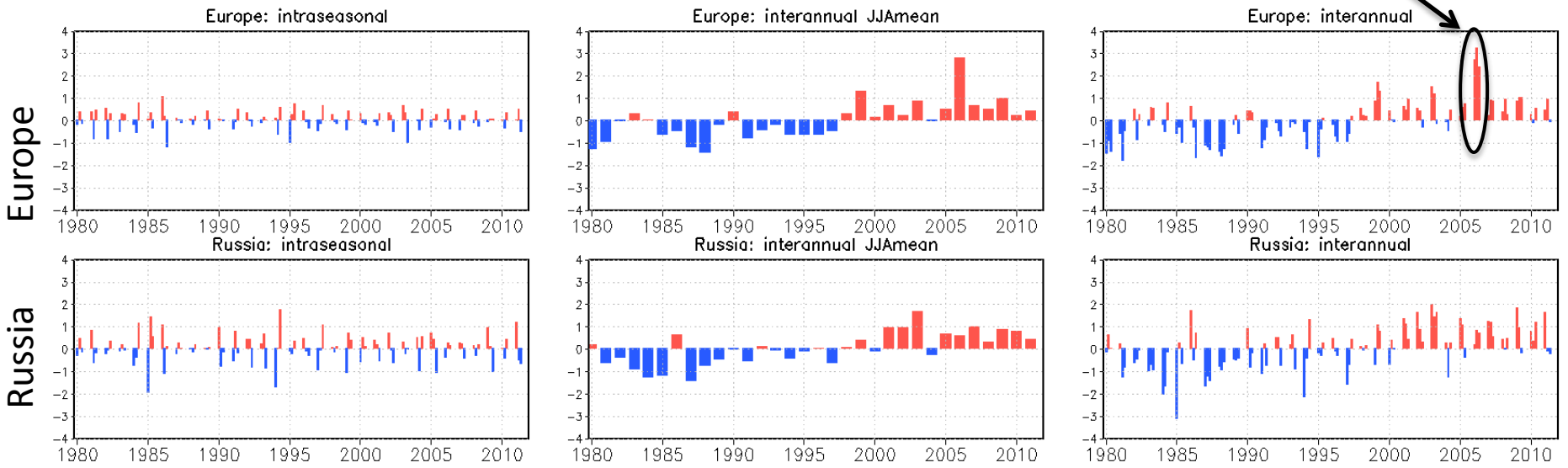
AMIP Ensemble member P1



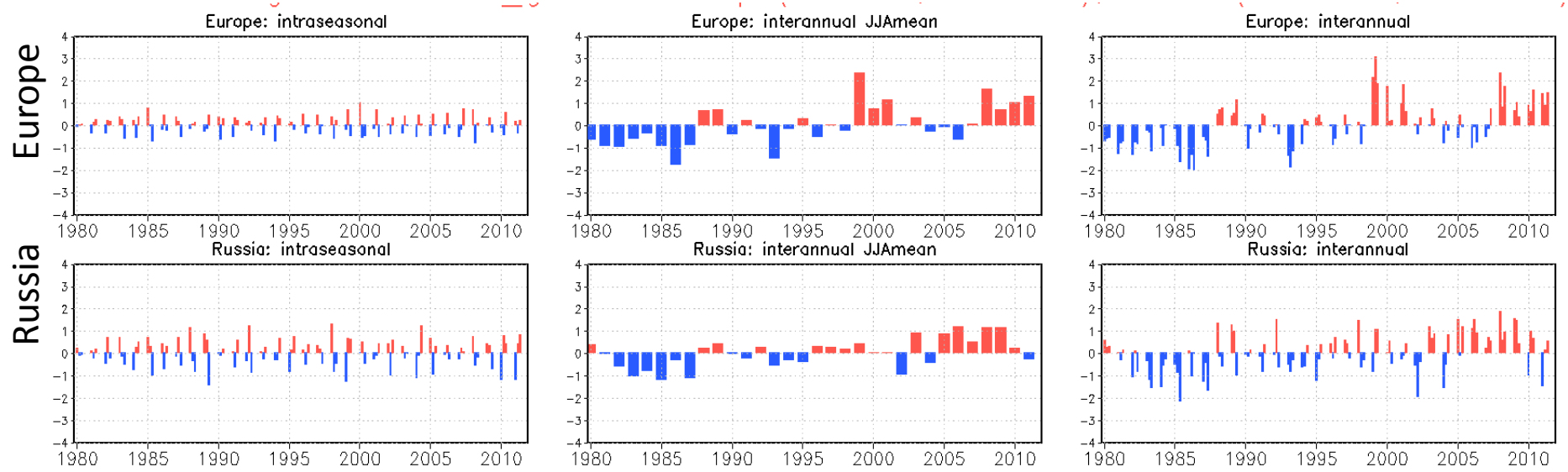
T2m (°C)

AMIP Ensemble member C8

Major simulated 2006 European Heat Wave

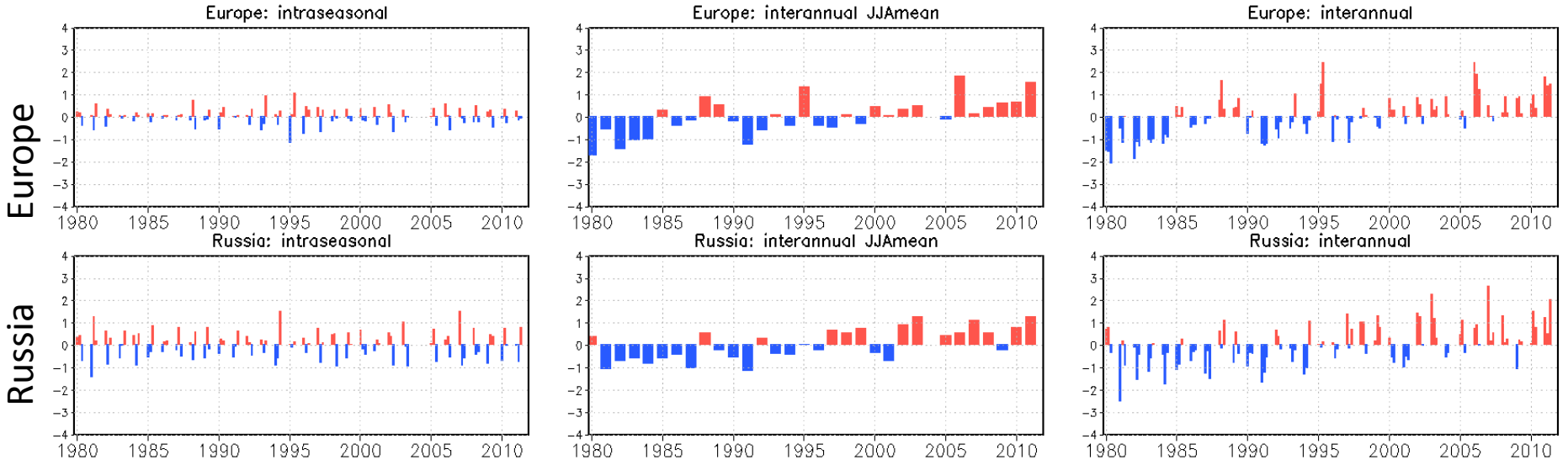


AMIP Ensemble member C9



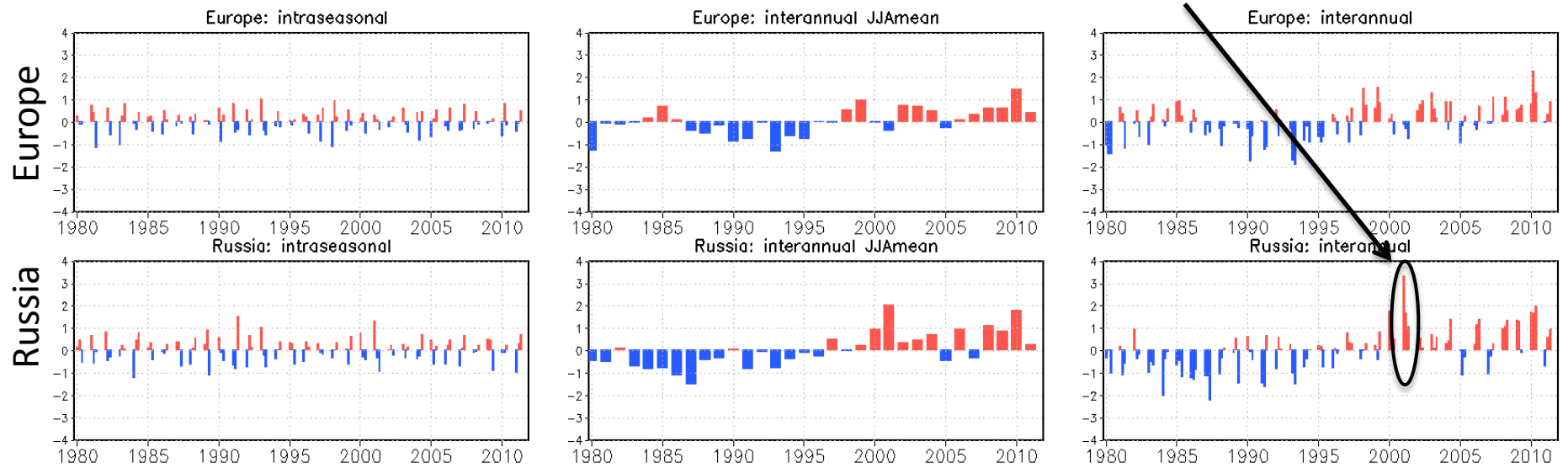
T2m (°C)

AMIP Ensemble member C5

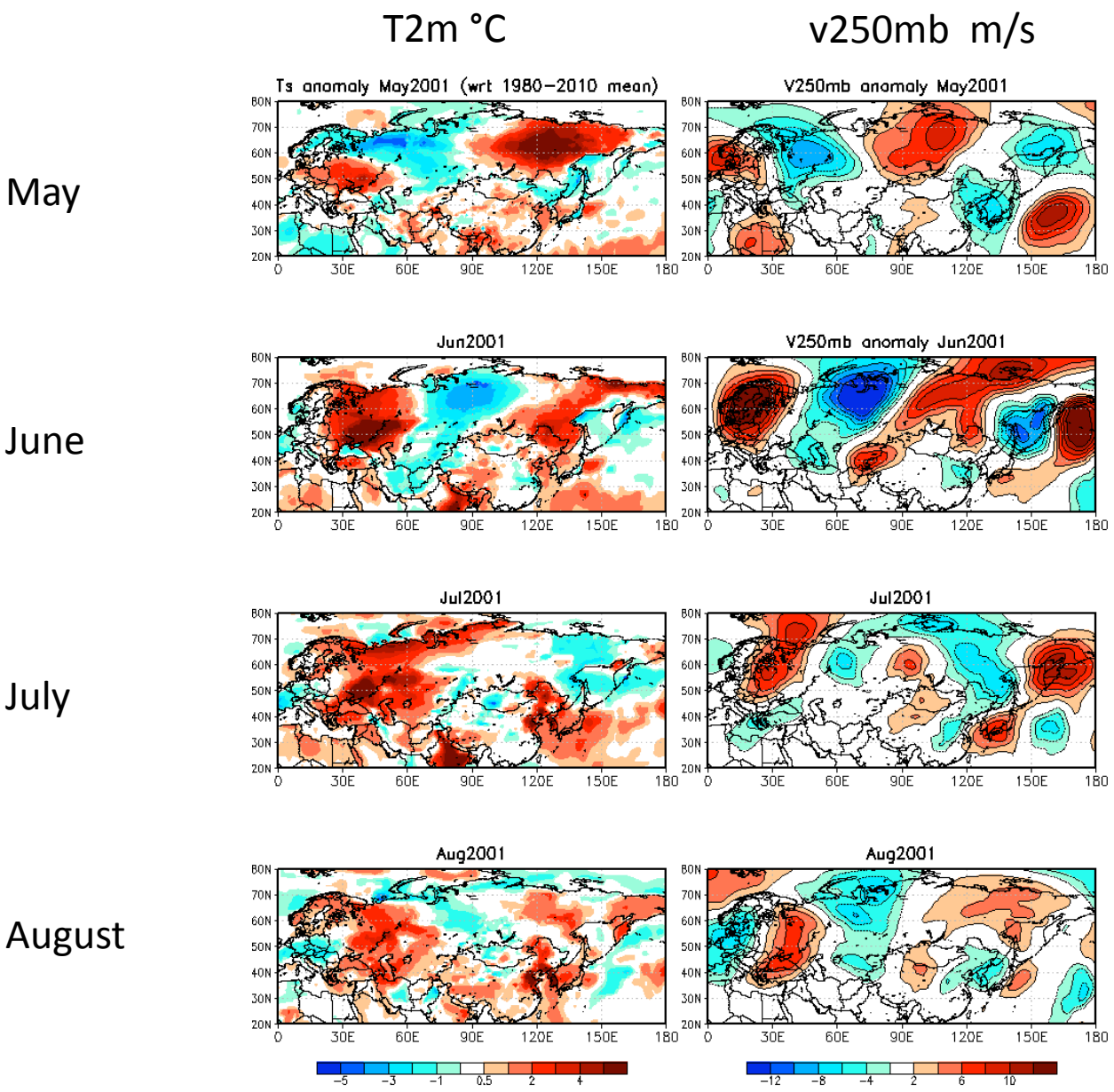


AMIP Ensemble member C6

Major simulated 2001 Russian Heat Wave

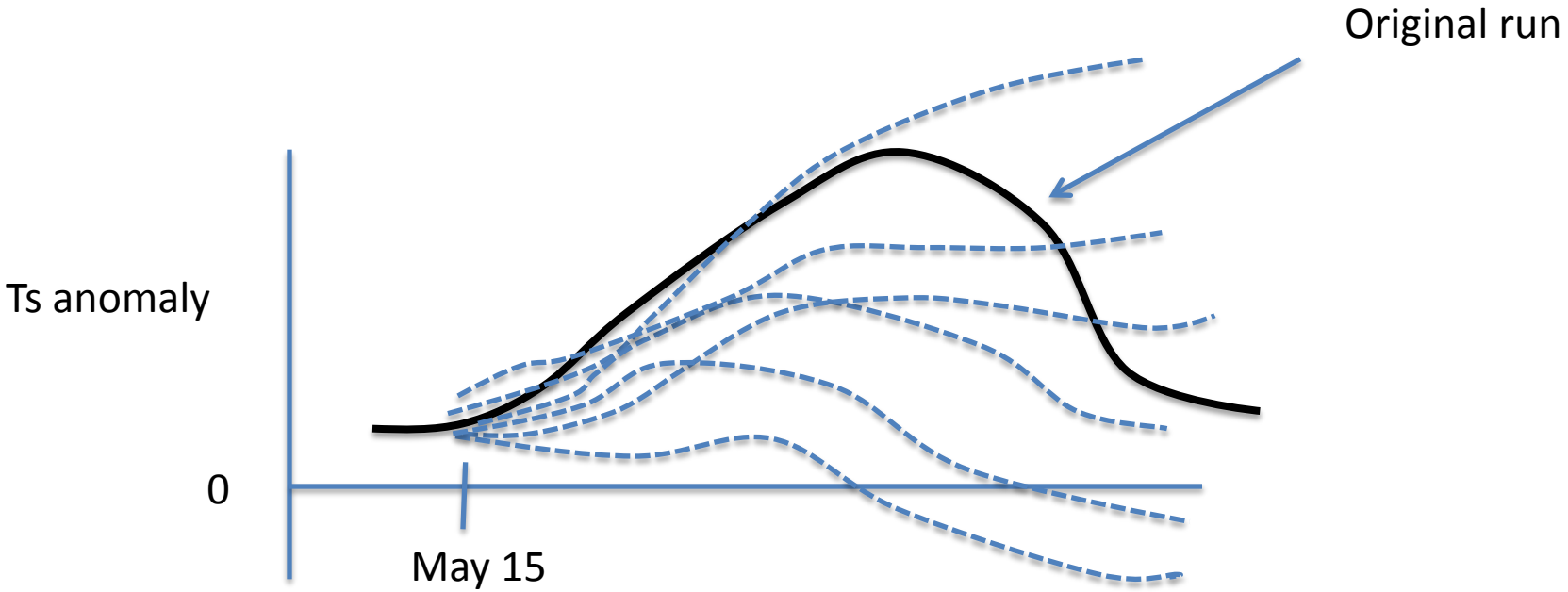


Simulated 2001 Russian Heat Wave



How Predictable is the Event?

- Examine sensitivity to initial conditions
- Restart runs on May 15th 2001 with small perturbations in the atmosphere
- 20 ensemble members



Simulated 2001 Russian Heat Wave (T2m °C)

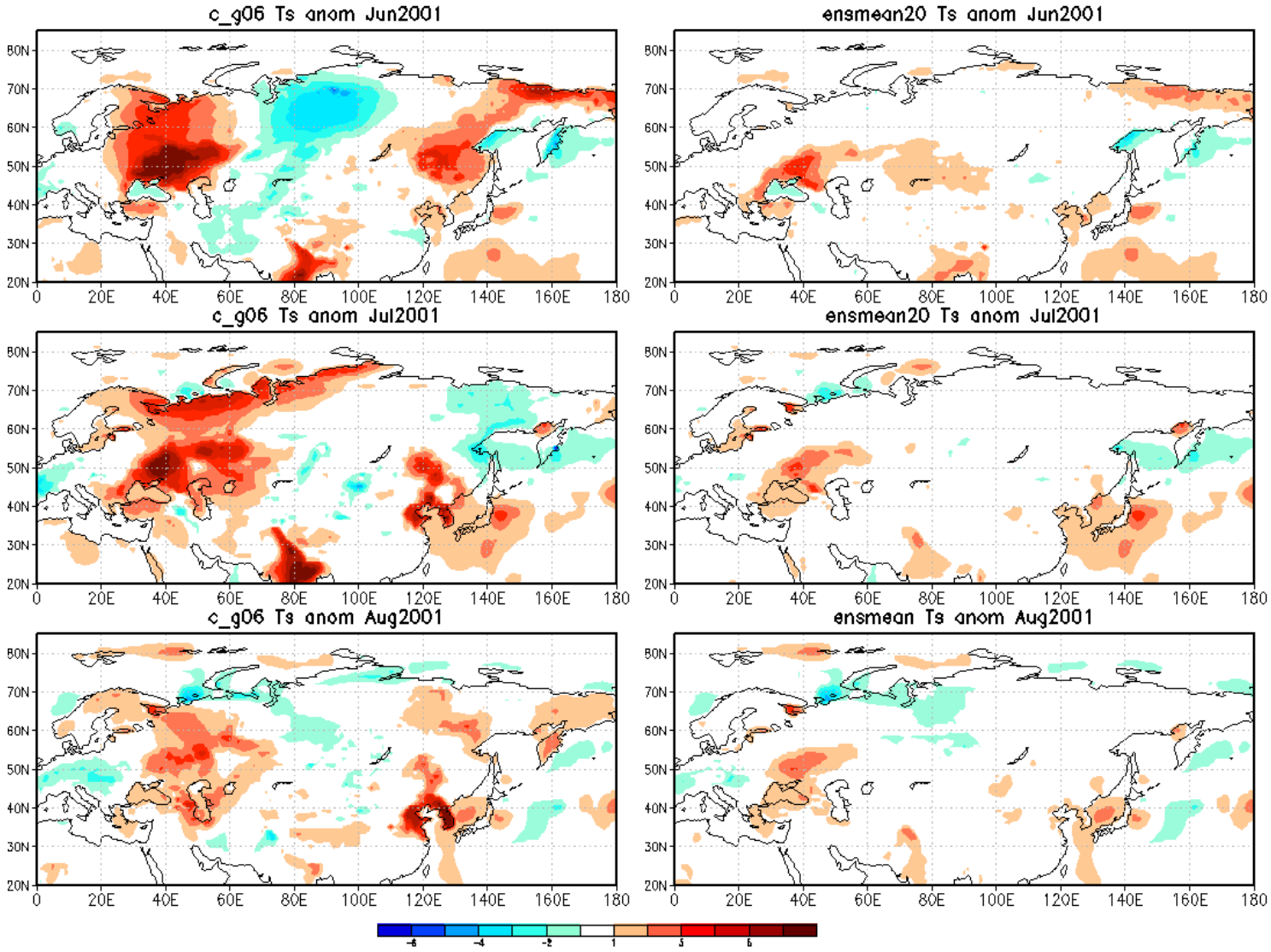
Original

Ensemble Mean (runs initialized May 15)

June

July

August

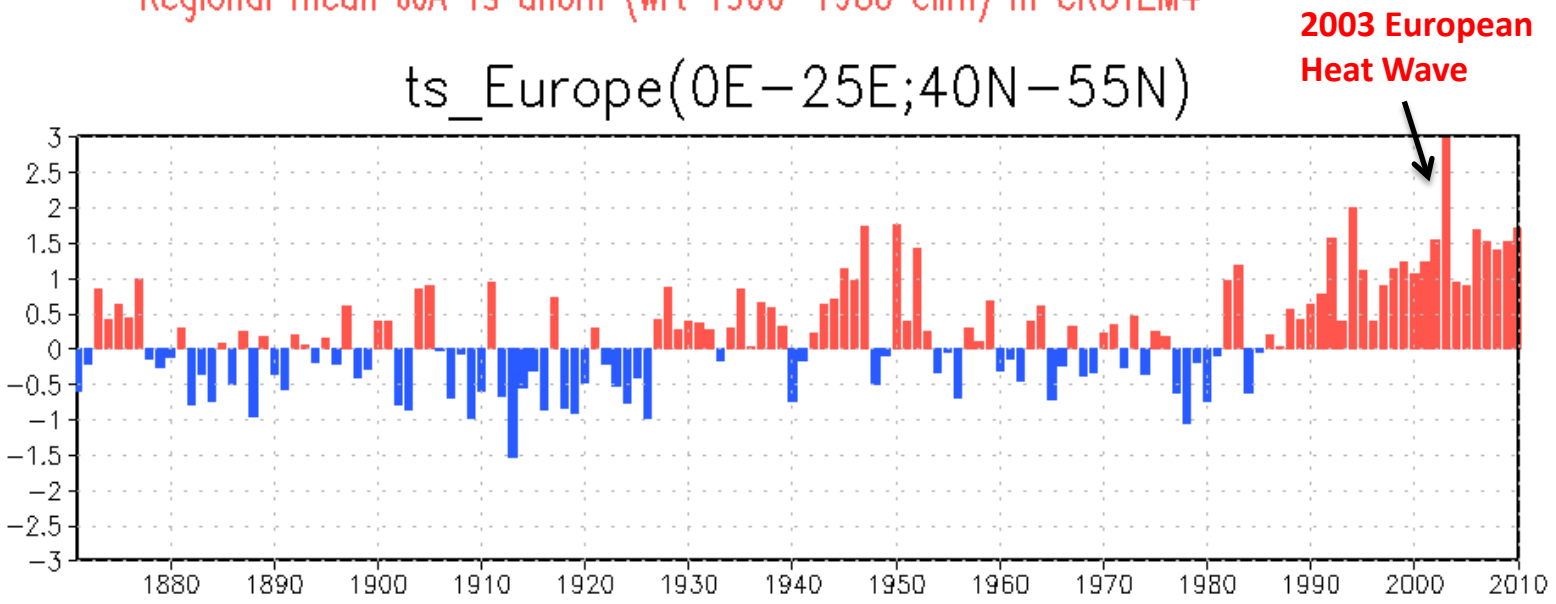


Longer Term Changes (1871-2010)

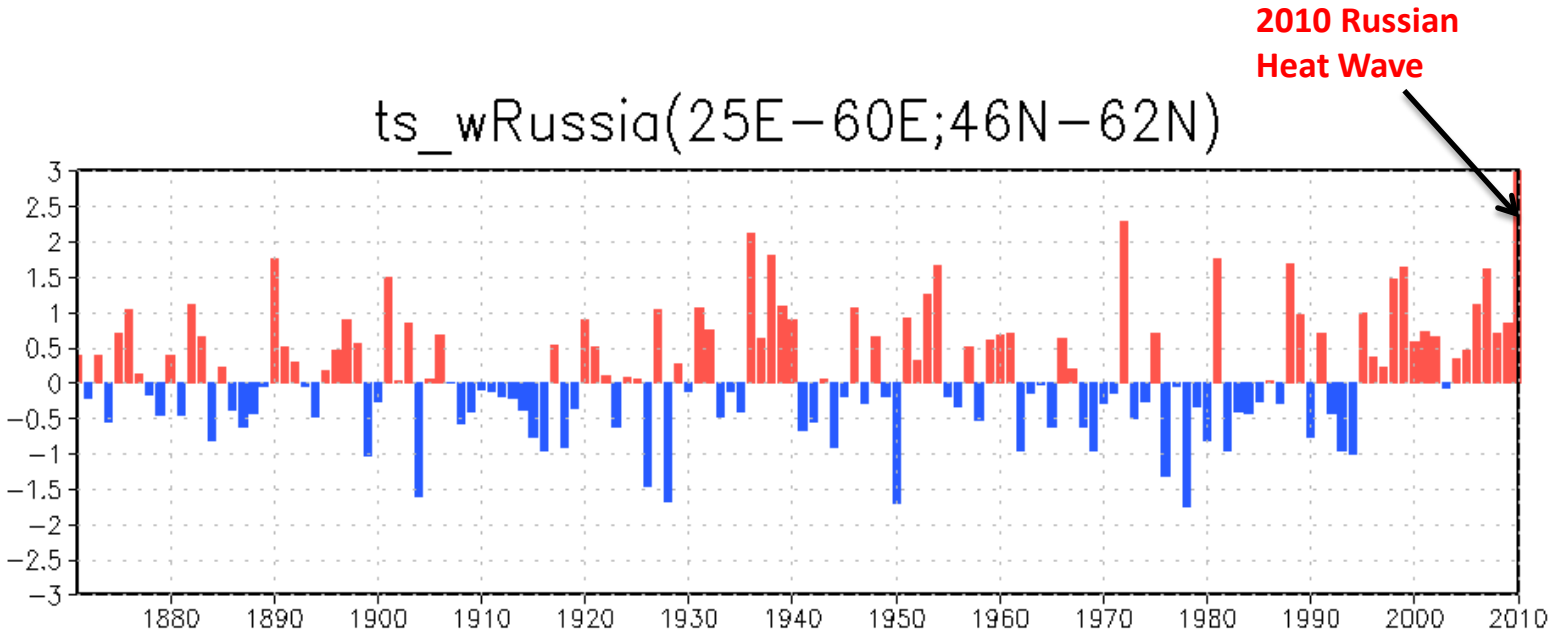
Observations
Ts (°C)

Regional mean JJA Ts anom (wrt 1900–1980 clim) in CRUTEM4

Europe



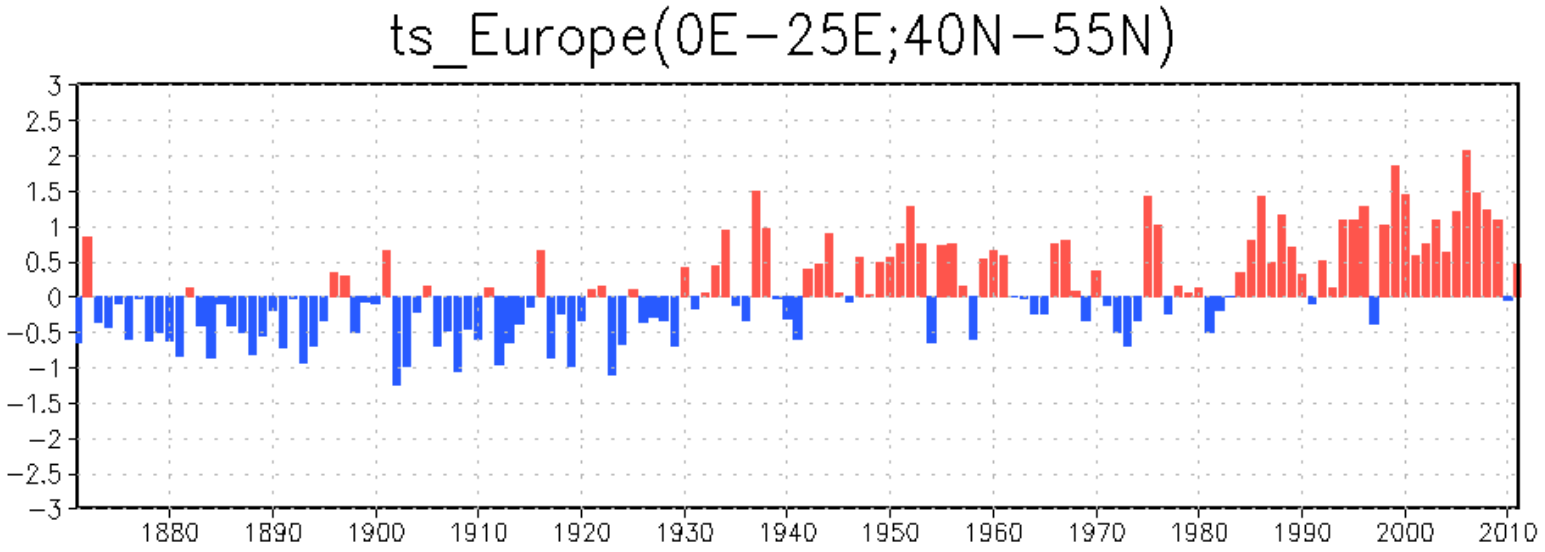
Russia



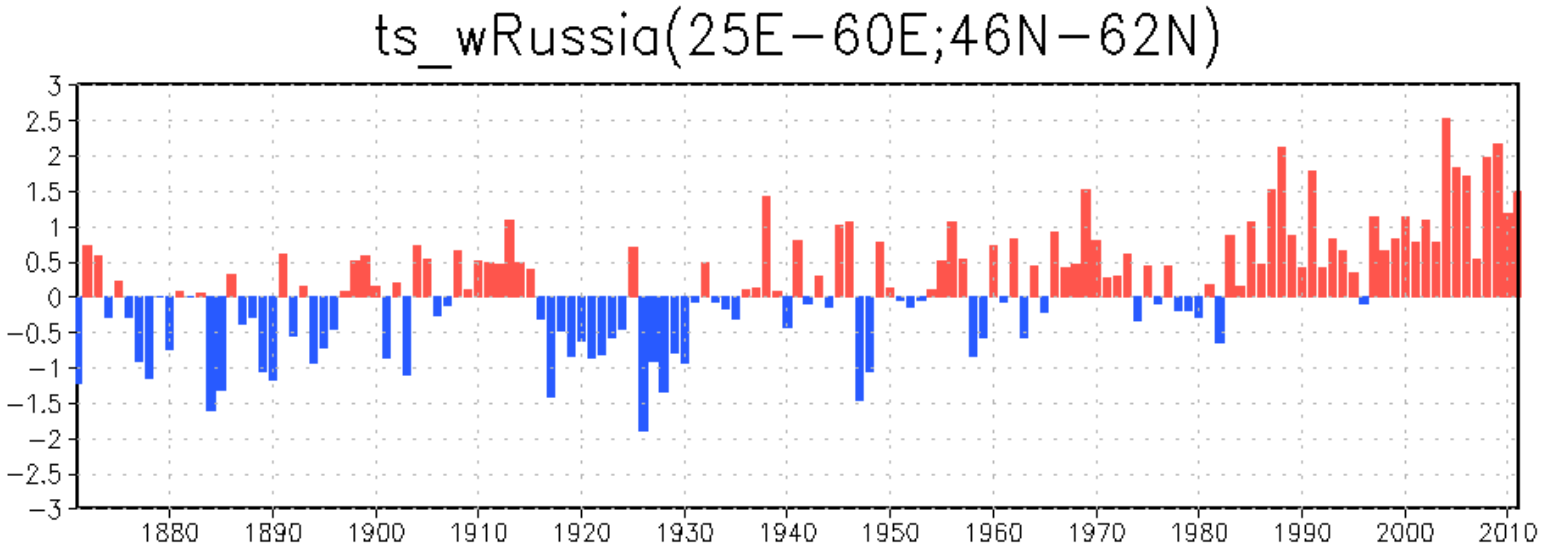
Model (Ens P2)
Ts (°C)

Regional mean JJA Ts anom (wrt 1900–1980 clim) in c_p02

Europe



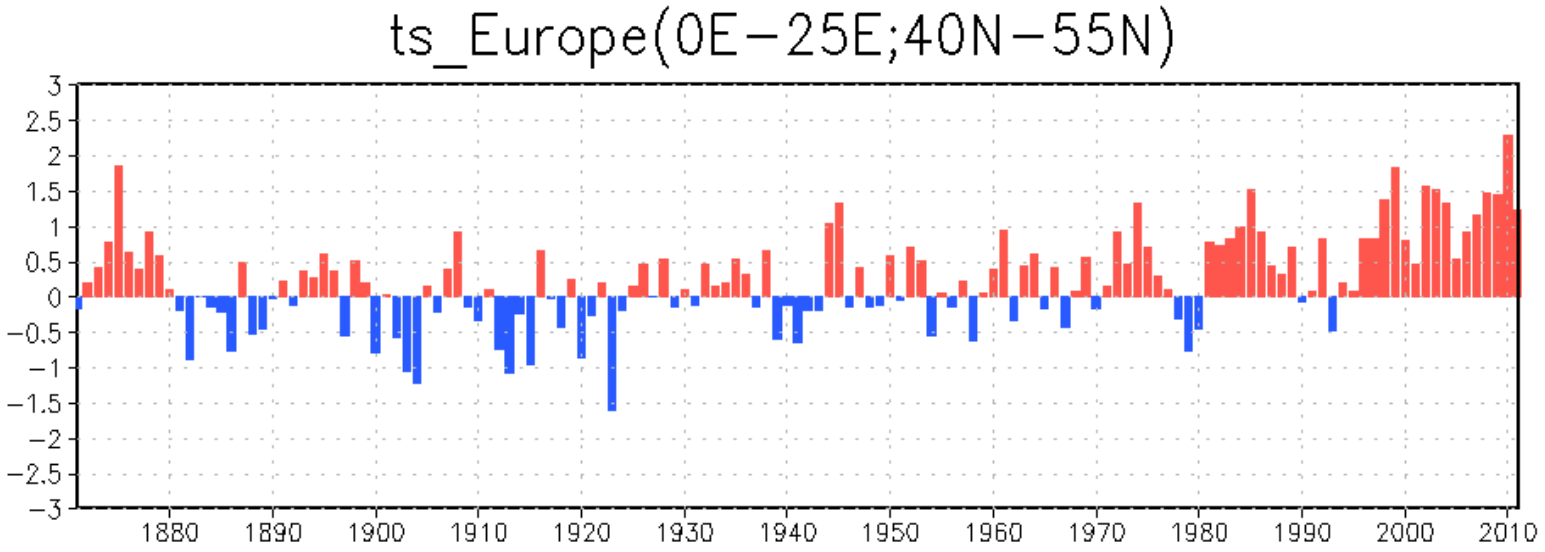
Russia



Model (Ens C6)
Ts (°C)

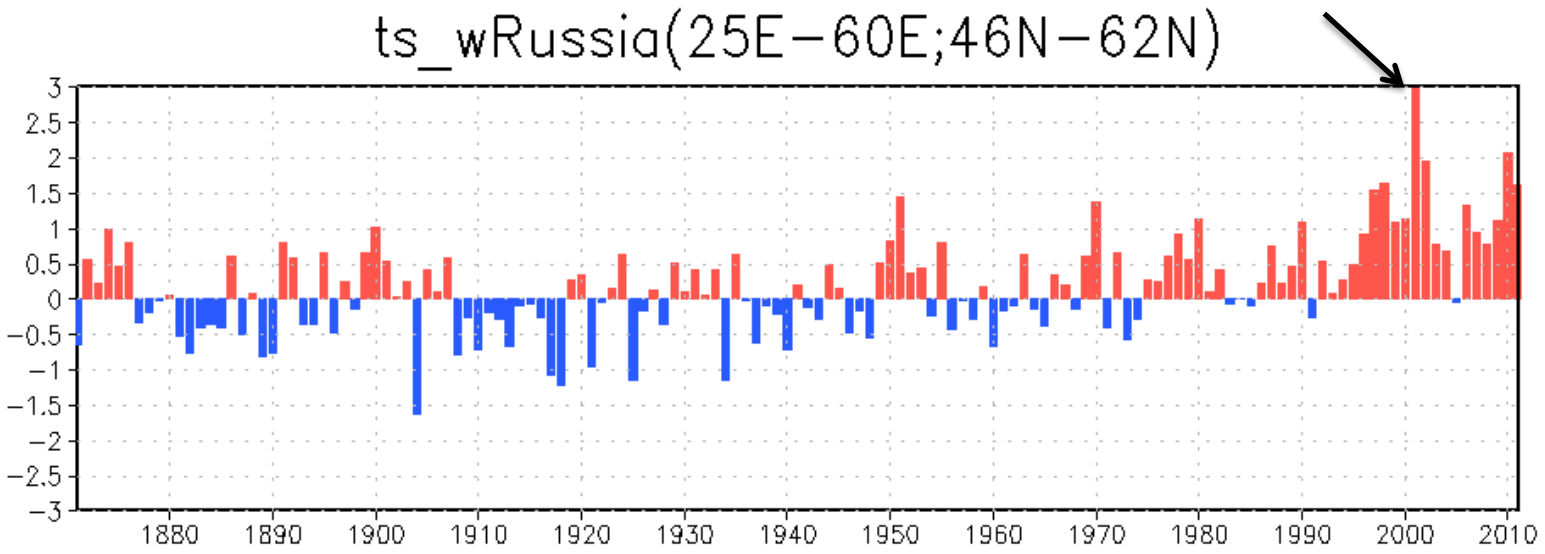
Regional mean JJA Ts anom (wrt 1900–1980 clim) in c_g06

Europe

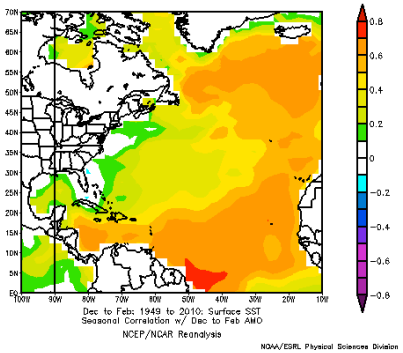


Simulated 2001
Russian Heat Wave

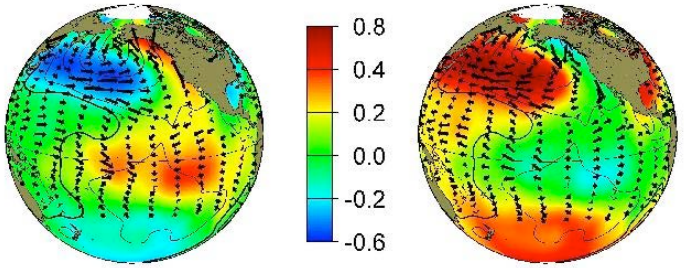
Russia



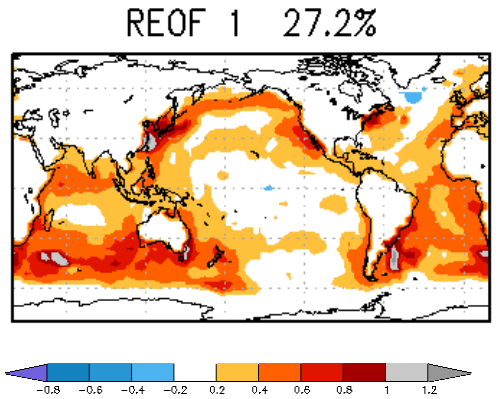
AMO



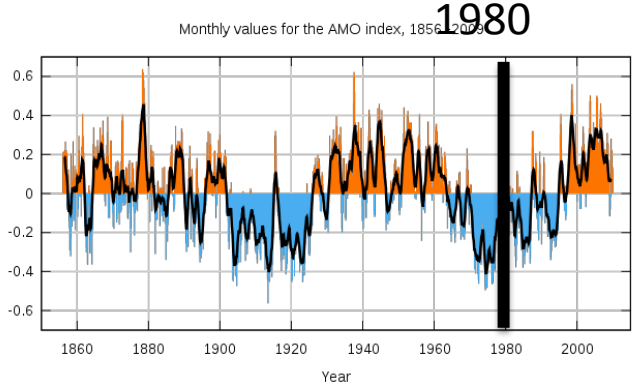
PDO



Trend

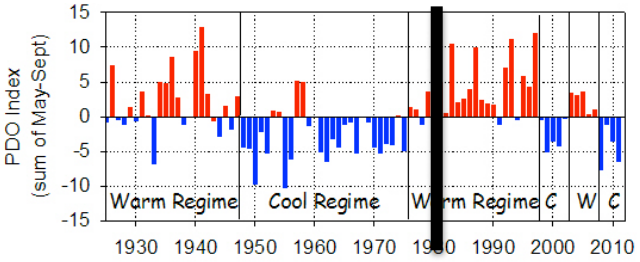


1980



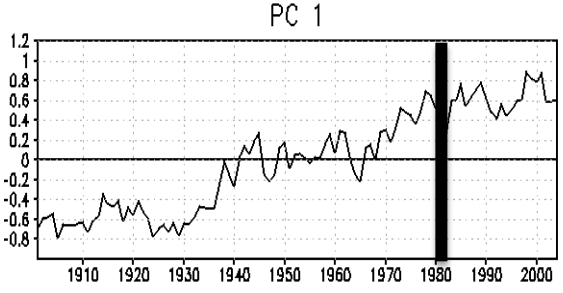
http://en.wikipedia.org/wiki/File:Amo_timeseries_1856-present.svg

1980



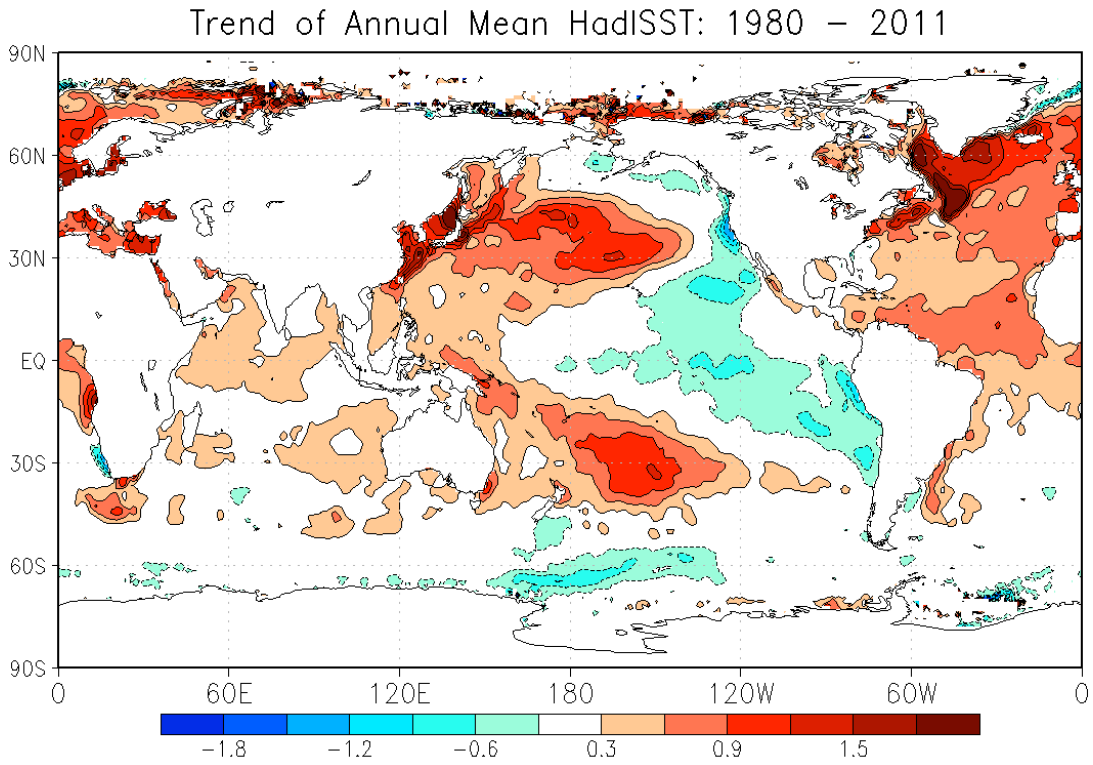
http://jisao.washington.edu/pdo/

1980



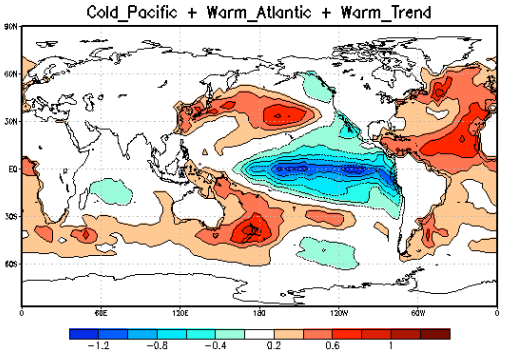
Schubert et al. 2009

Recent (1980-2011) SST "Trend" has signature of Negative PDO and Positive AMO



USCLIVAR
(Schubert et al. 2009)

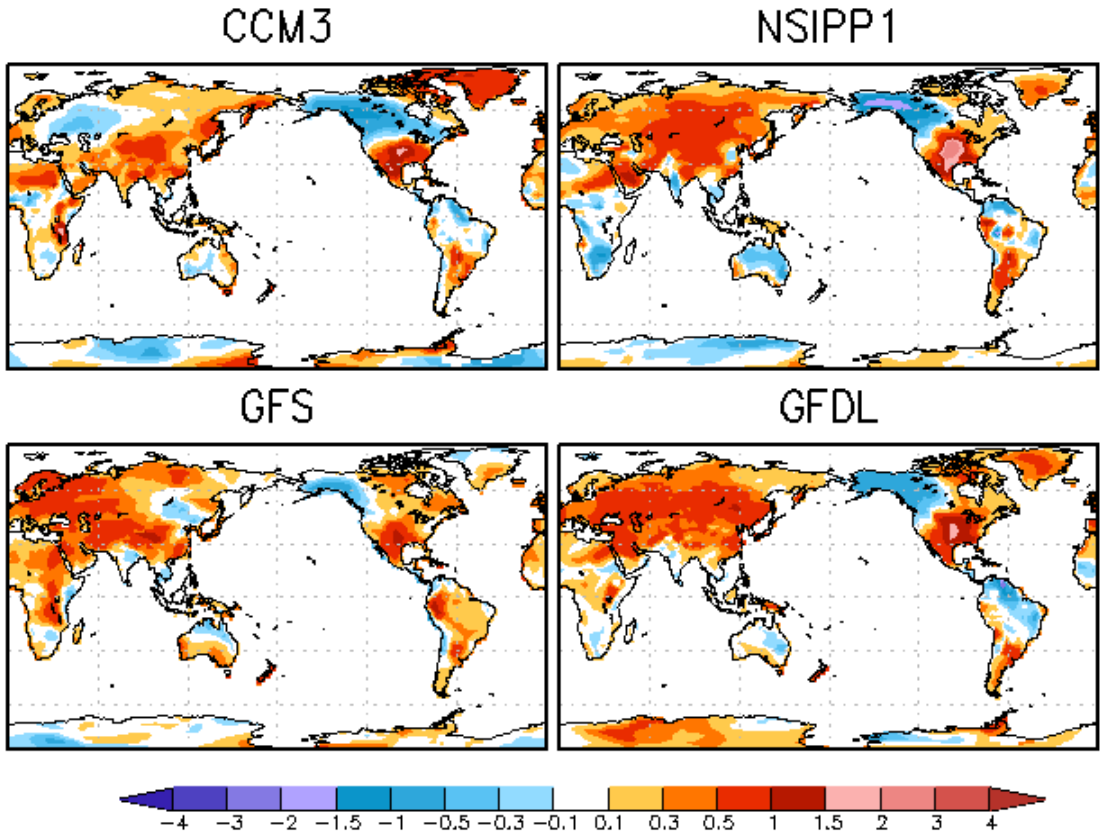
"Ideal" ocean for drought in US Great Plains



°C

But also tends to warm the Eurasian continent

Annual Mean Tsfc Response to SST anomalies consisting of
Cold Pacific+Warm Atlantic+Trend



T2m (°C)

Let's Return to the Questions

Why the alternating east/west oriented anomalies in Tfcs? – spatial structure associated with the development of a particular Eurasian stationary Rossby wave (Schubert et al. 2011 – MERRA special issue)

Nature of subseasonal (monthly) Tsfc variability?

- time scale linked to development and maintenance of the stationary Rossby wave forced by vorticity transients (Schubert et al. 2011 – MERRA special issue)

Work in Progress

Nature of interannual Tsfc variability? *– seasonal means in Tsfc appear to reflect a rectification of Rossby wave impacts by the **land***

Causes of apparent trend in seasonal means of Tsfc? In recent decades, *decadal SST variability (PDO and AMO) appears to be reinforcing long term trends over Eurasia (and US Great Plains)*

Why are 2003 and 2010 so extreme? *– similar (super) extreme events are simulated by the model – not yet clear why they occur, but land feedbacks likely play a key role*

Further work:

- What are the mechanisms that at times cause the Rossby wave to "lock in" for a month or longer? Soil moisture?

- Does the general warming of the continent impact the character of these extreme events and if so what are the mechanisms (e.g., via land feedbacks, changes in the upper level jet, etc)