

# **Regional climate models**

Lecture given at the Climate modelling school at SMHI,  
Norrköping, 13 October 2010

**Erik Kjellström**

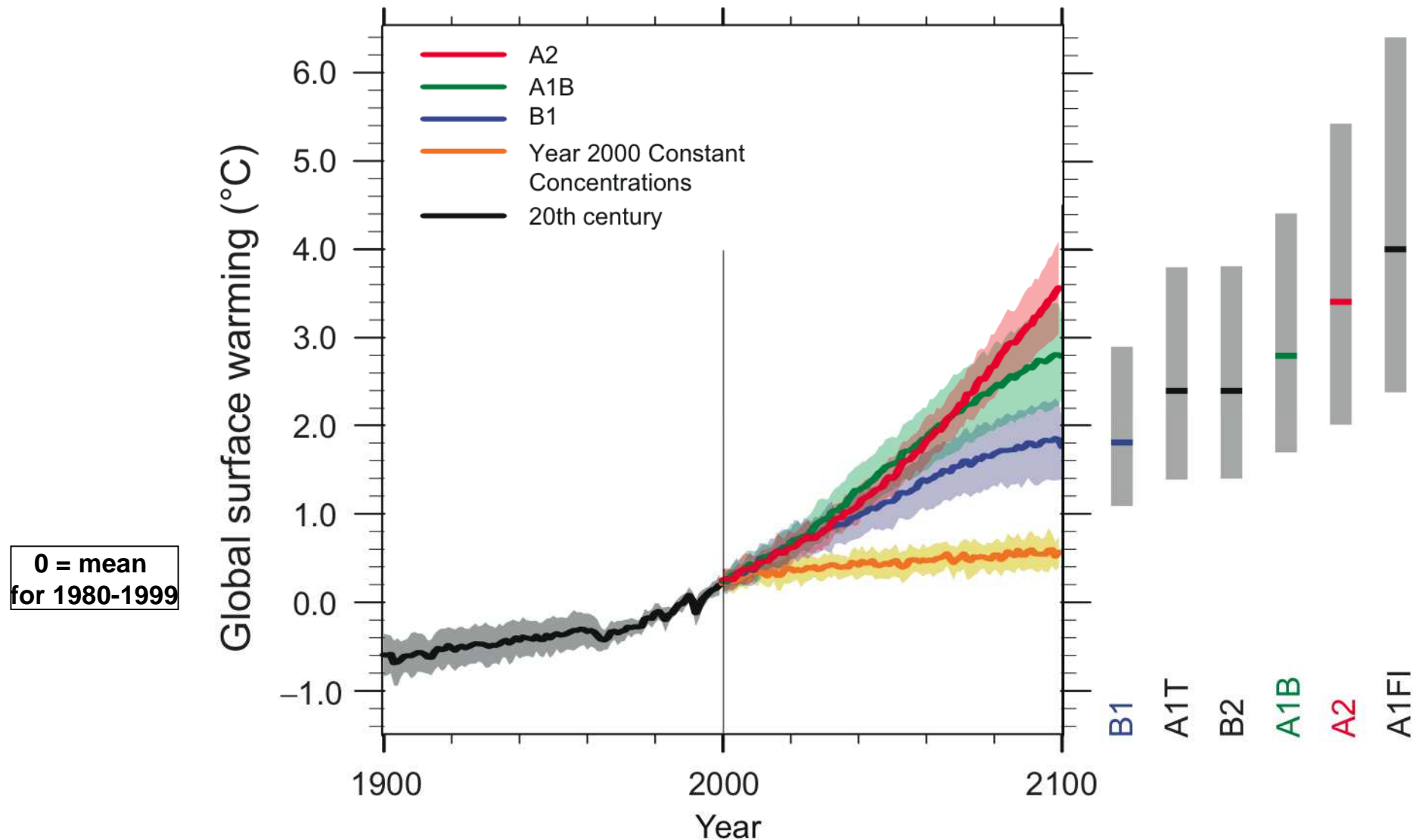
Rosby Centre

Swedish Meteorological and Hydrological Institute

- 
- Global and regional climate change in the 21<sup>st</sup> C
  - Need for regional climate models (RCMs)
  - RCMs and how they simulate the recent past climate
  - Use of RCMs for simulation of future (and past) climates
  - Some considerations

# Global mean near surface warming (°C)

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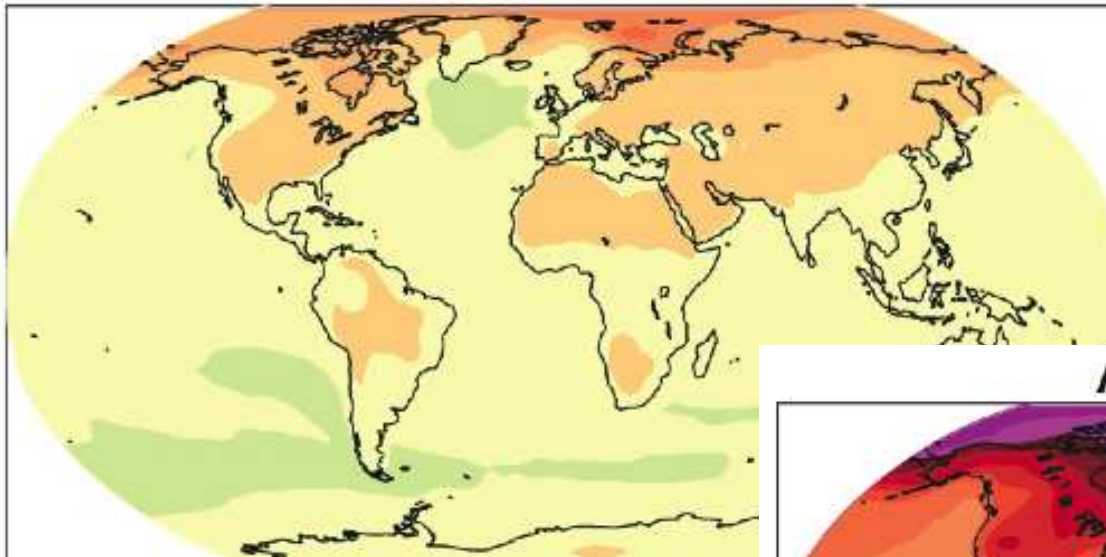
Source: IPCC (WGI) 2007

# Future global warming

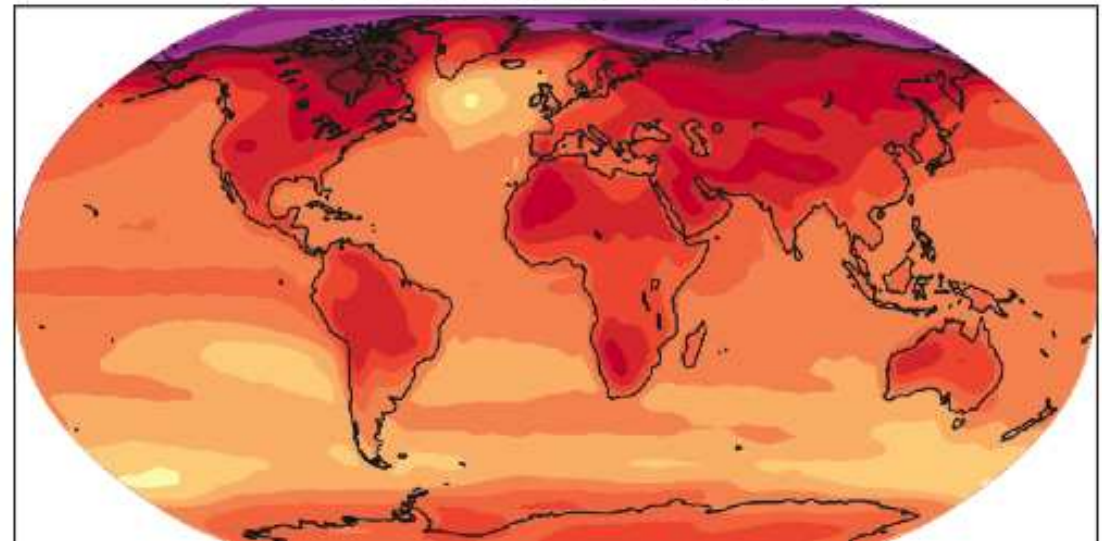
**SMHI**

A1B: 2020-2029

Source: IPCC (WGI) 2007



A1B: 2090-2099



Temperature change (°C)  
compared to 1980-1999

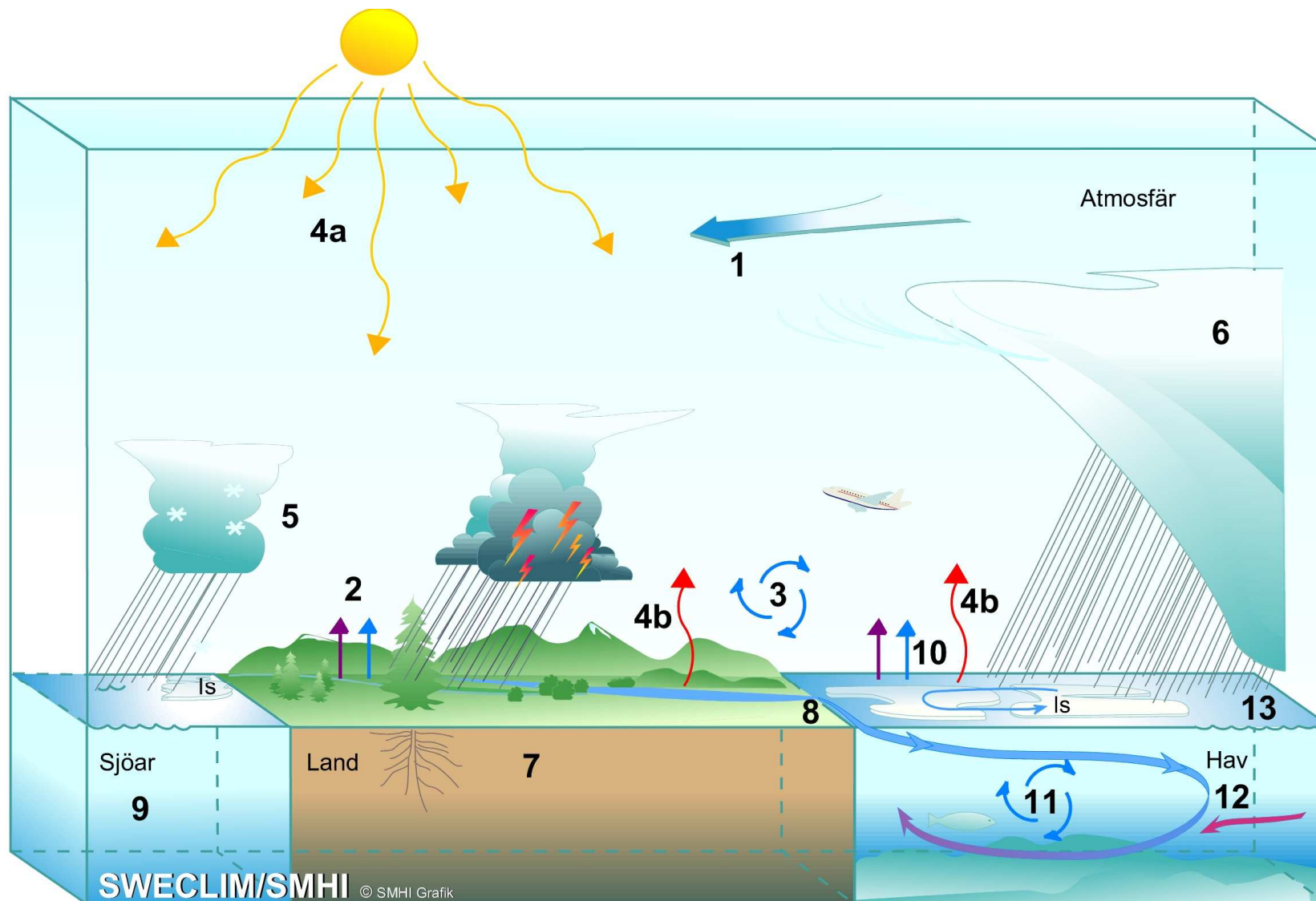




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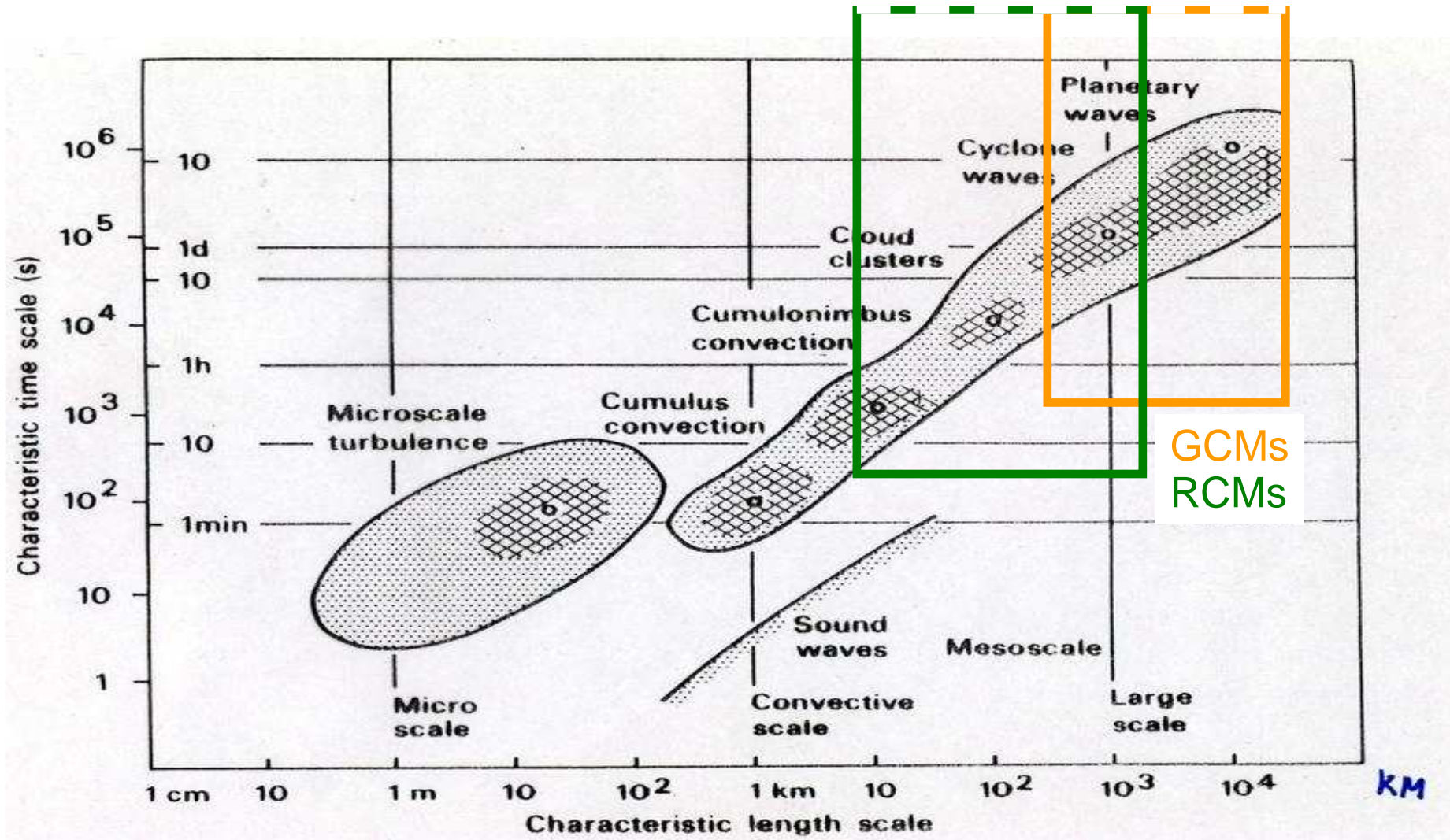
# The climate system

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# Time and length scales

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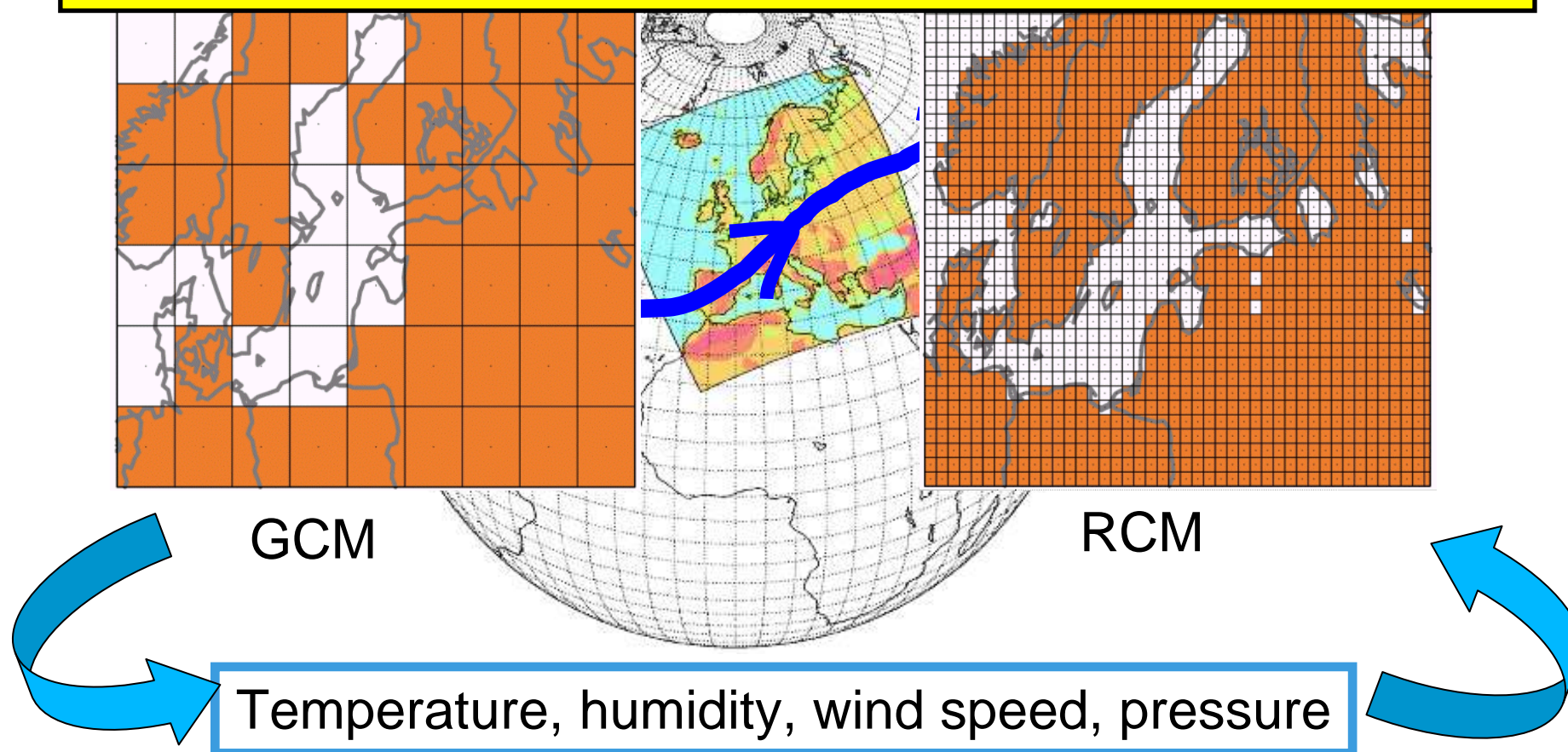
In addition: cloud physical processes, droplets, aerosols, radiative processes at length scales down to  $10^{-9}$  m



# Regional climate modeling

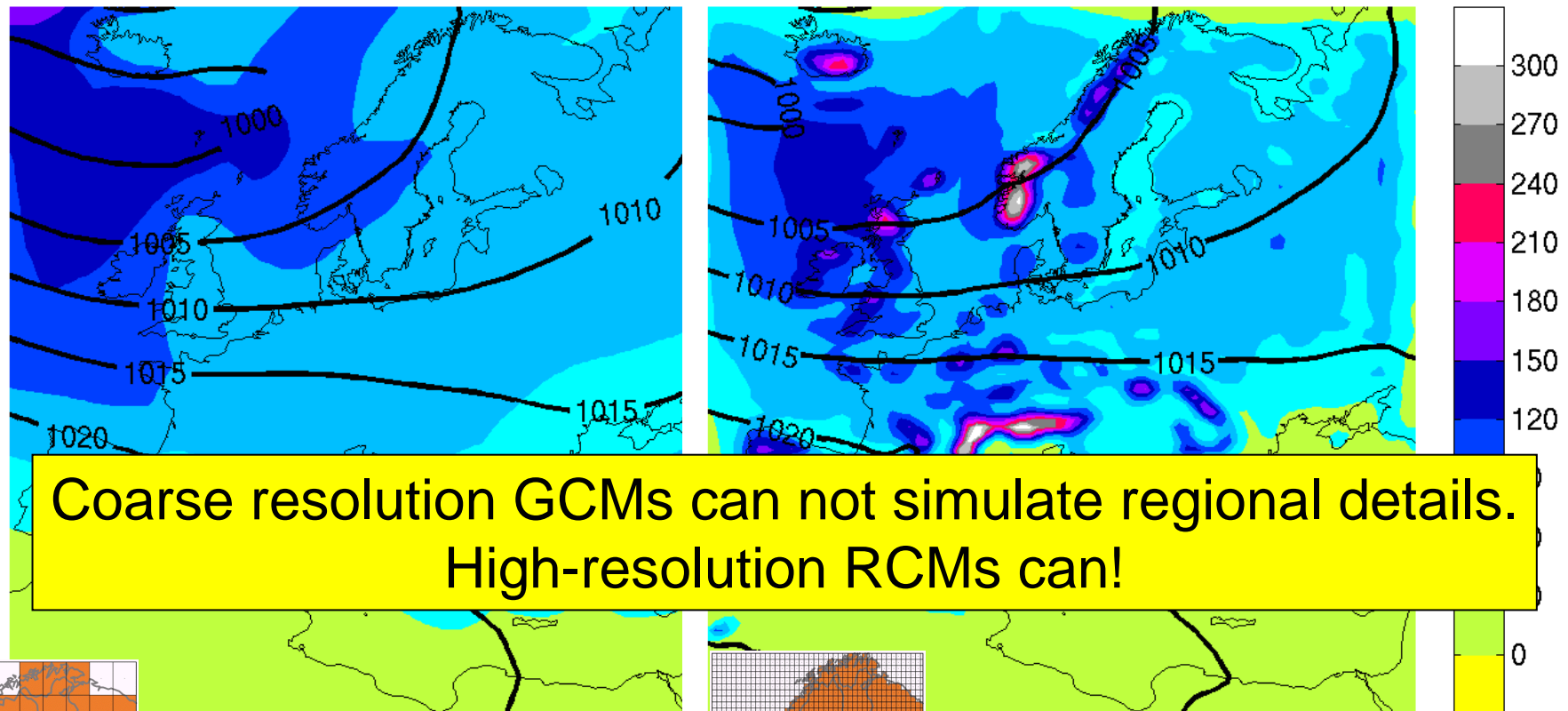
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Primary benefit is the increased resolution that leads to a more detailed regional forcing and a greater number of processes that are explicitly resolved by the model

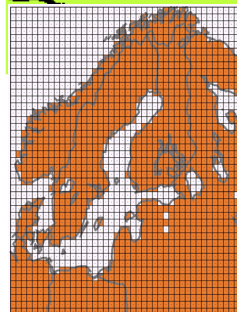


# Rationale for downscaling

MSLP and precipitation (DJF) for the period 1961-1990



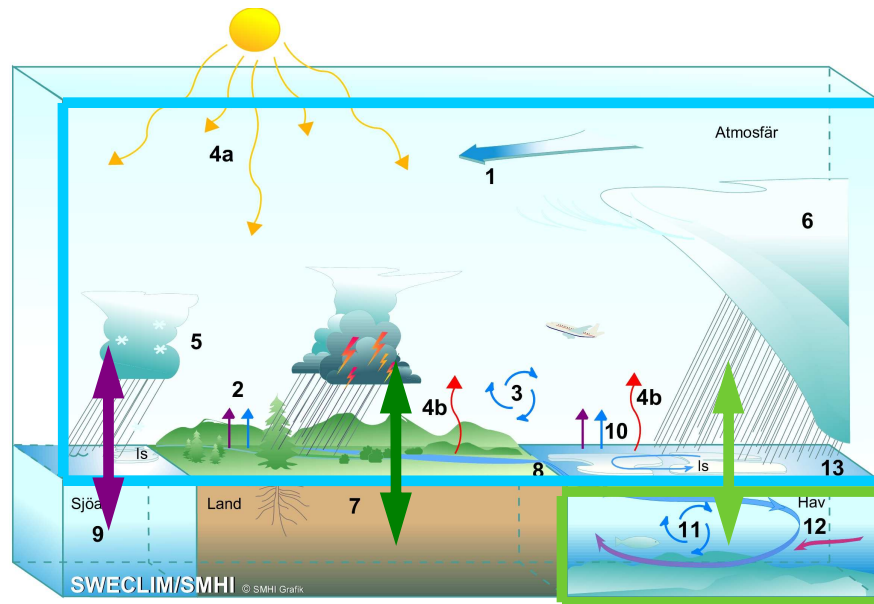
Global climate model (CCSM3)



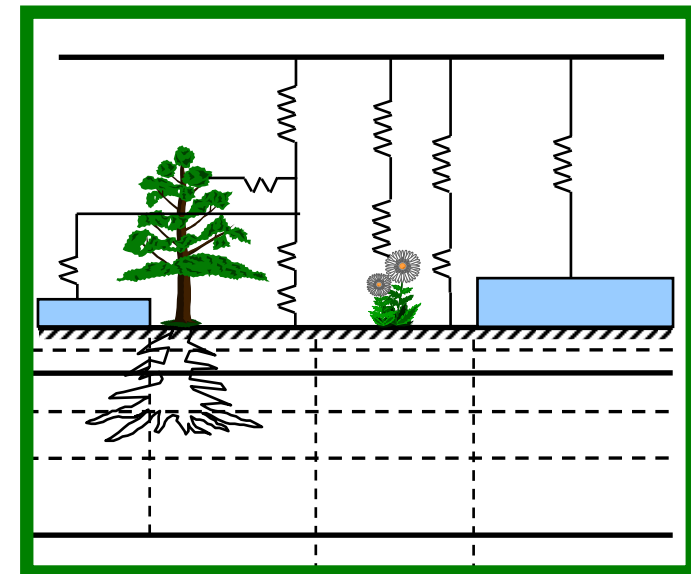
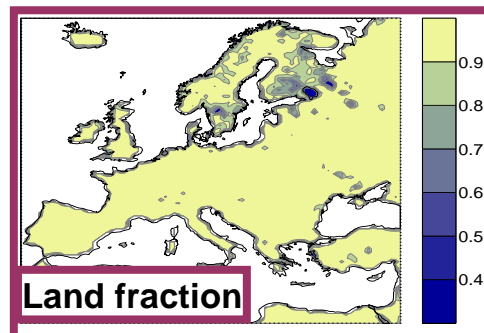
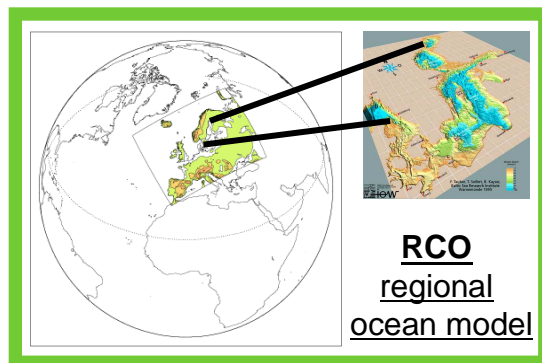
Regional climate model (RCA3)  
(lateral boundary conditions from CCSM3)

- 
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# The Rossby Centre regional climate model **SMHI**



- RCA3.0: Atmosphere, land surface, lakes
- Resolution: ca (6.25), 12.5, 25, 50 km
- Time step: 15(25km)-30(50km) min.
- Domains: Europe, Arctic, S. Africa, North and South America



The Rossby Centre Regional Climate Model RCA3: Model description and performance.  
Samuelsson et al., Tellus, published online. DOI: 10.1111/j.1600-0870.2010.00478.x

## Two basic types of regional modelling

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- A "perfect-boundary" simulation, for
  - **model development & evaluation**
  - **regional reanalysis (*cf.* detection, impact studies)**
- A GCM-driven simulation, for
  - **climate scenarios**
  - **extended climate variability studies**
  - **past climates**



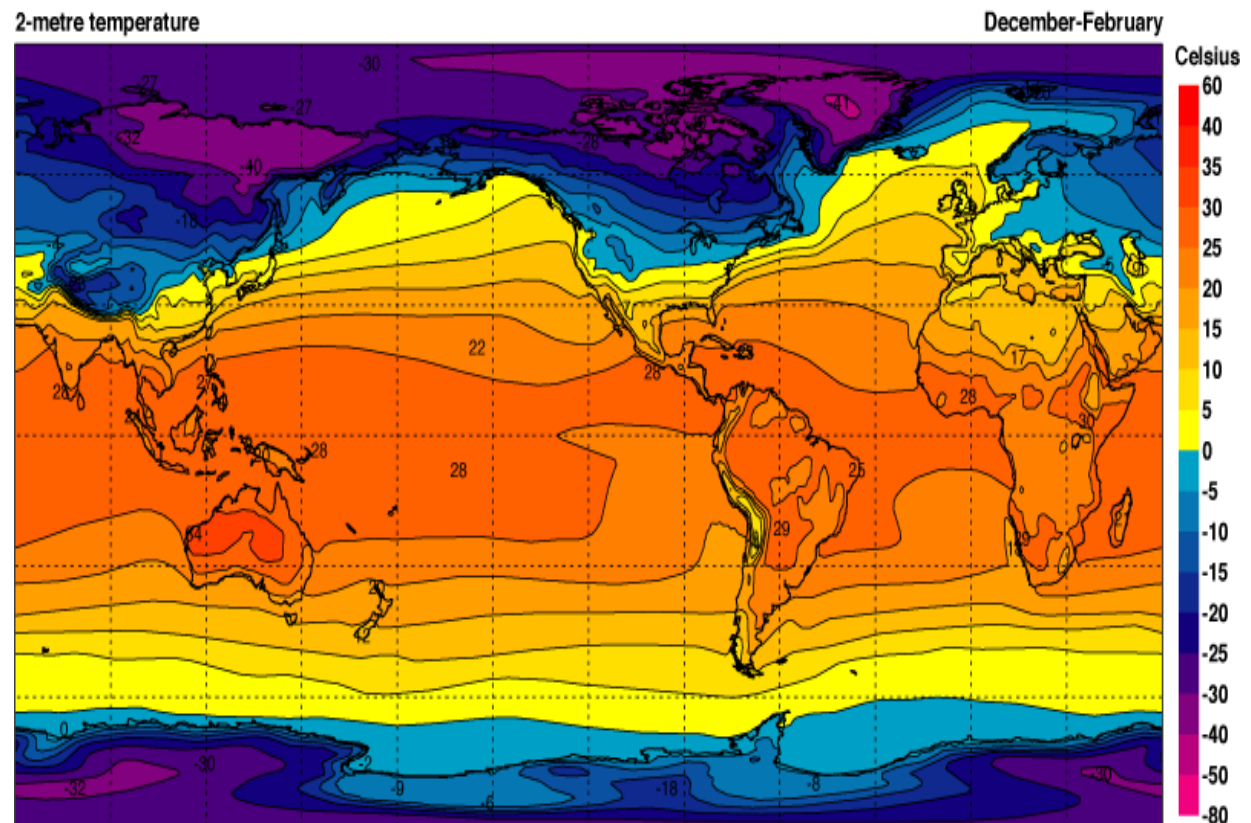
# What are so called "Perfect-boundary conditions"?

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- The best representation of the actual evolution of the 3D-state of the atmosphere for long time periods back in time (back to ~ 1950-60) are the so reanalysis products (available from ECMWF, NCEP, JMA):

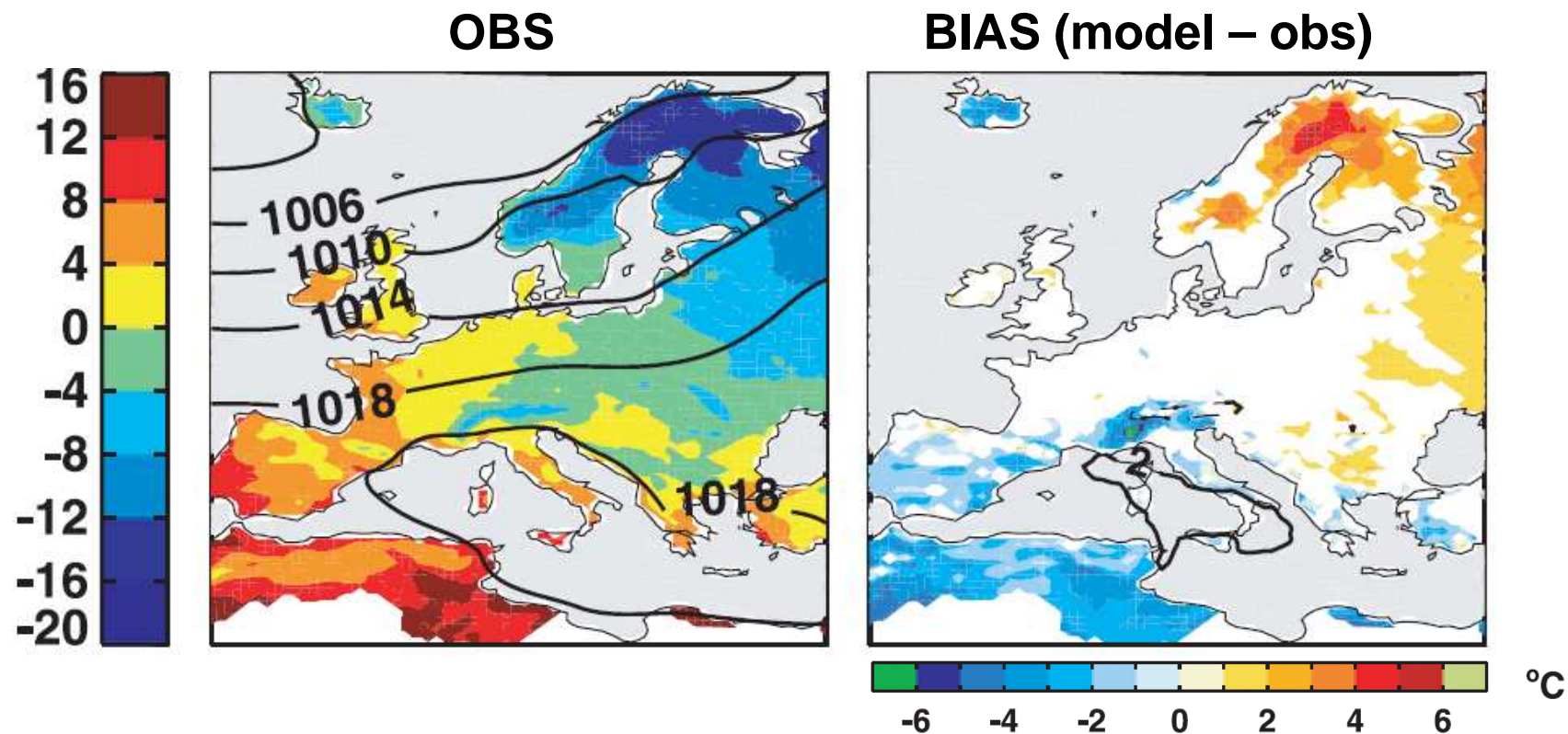
Build on observations as assimilated with a forecast model.

Example:  
2m-temperature from  
ERA40 (ECMWF)  
1979-2001



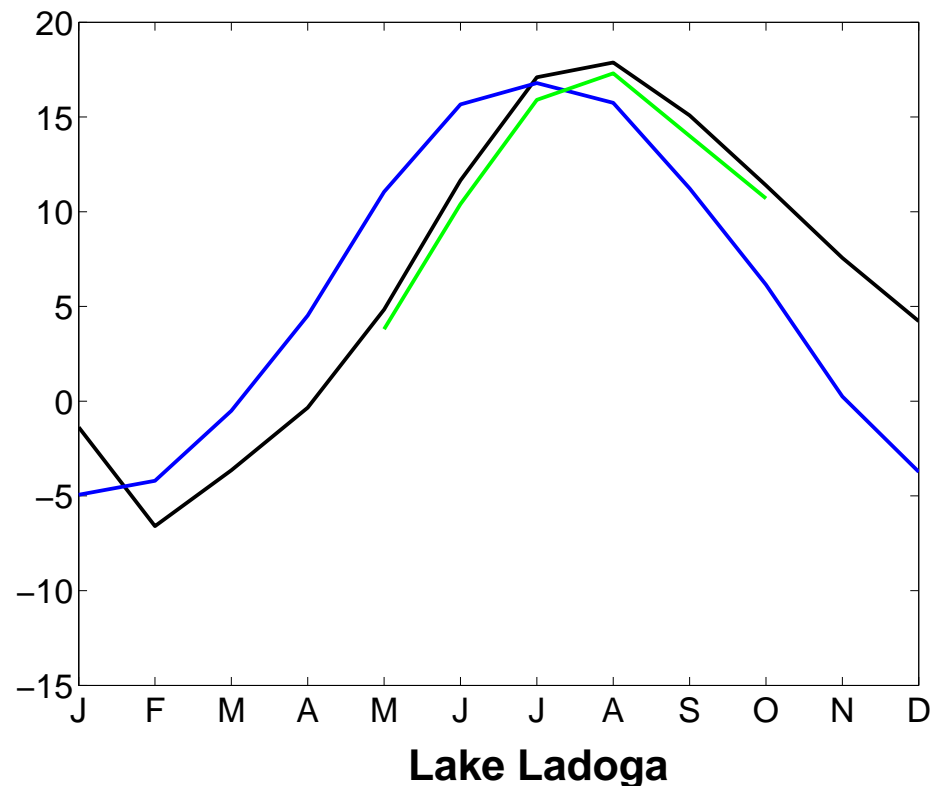
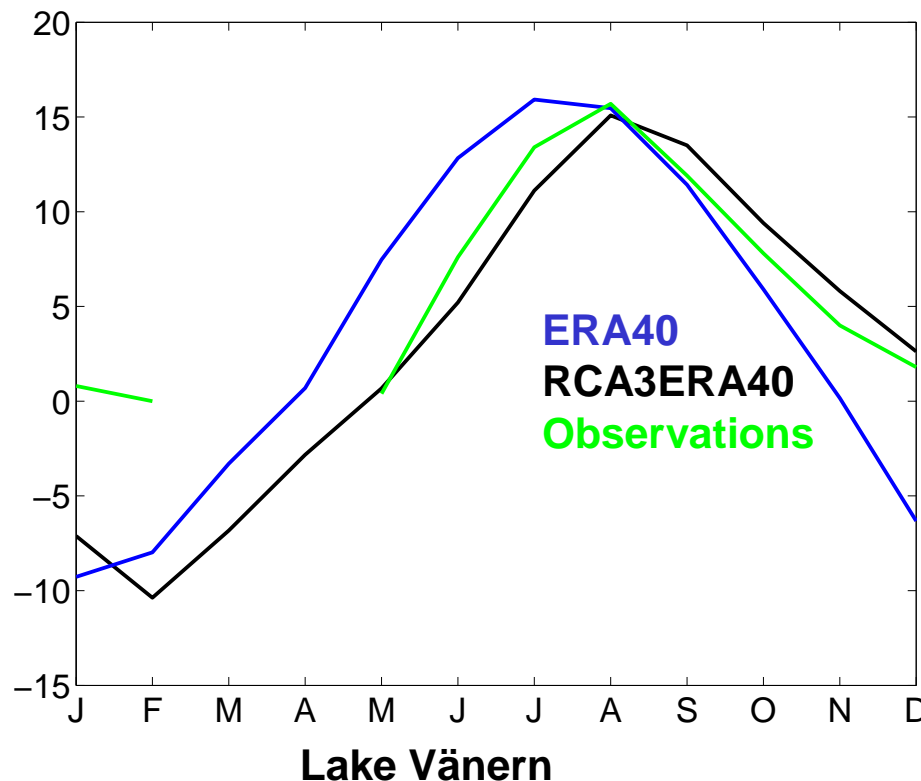
# How good is RCA3?

Temperature and MSLP in winter (DJF) 1961-1990



# More detailed processes/models

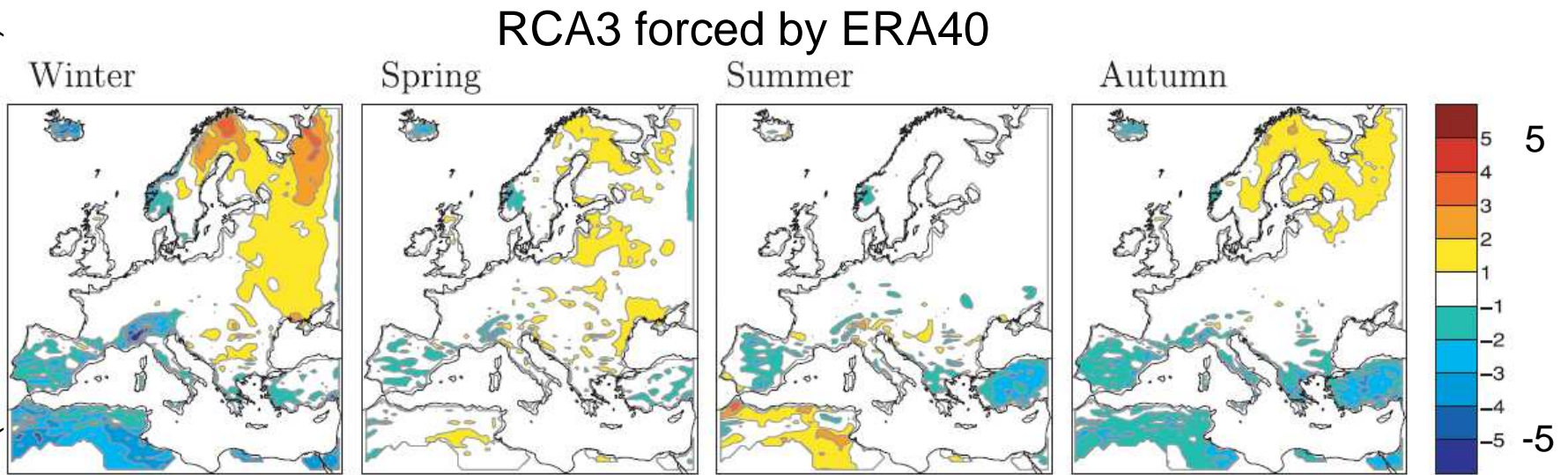
- *The Rossby Centre regional climate model (RCA3) contains a lake model (FLAKE). Improves the seasonal cycle of surface temperature*



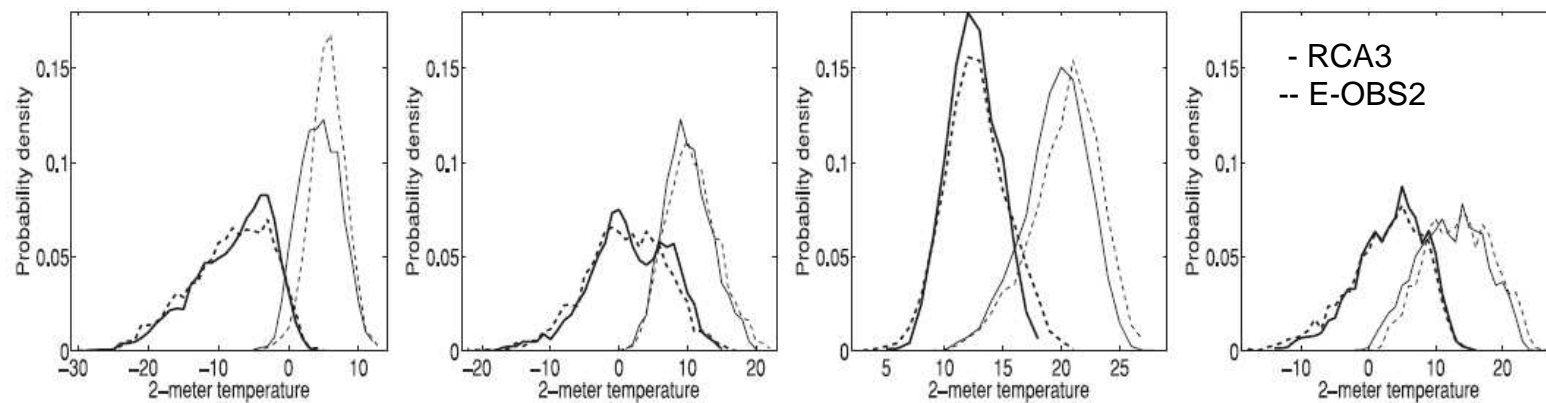
# Near-surface temperature in RCA3

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Bias in seasona mean  $T_{2m}(opl)$   
vs.  $(CRU+E-OBS2+Wilmott)/3$



PDFs of daily mean  $T_{2m}(opl)$

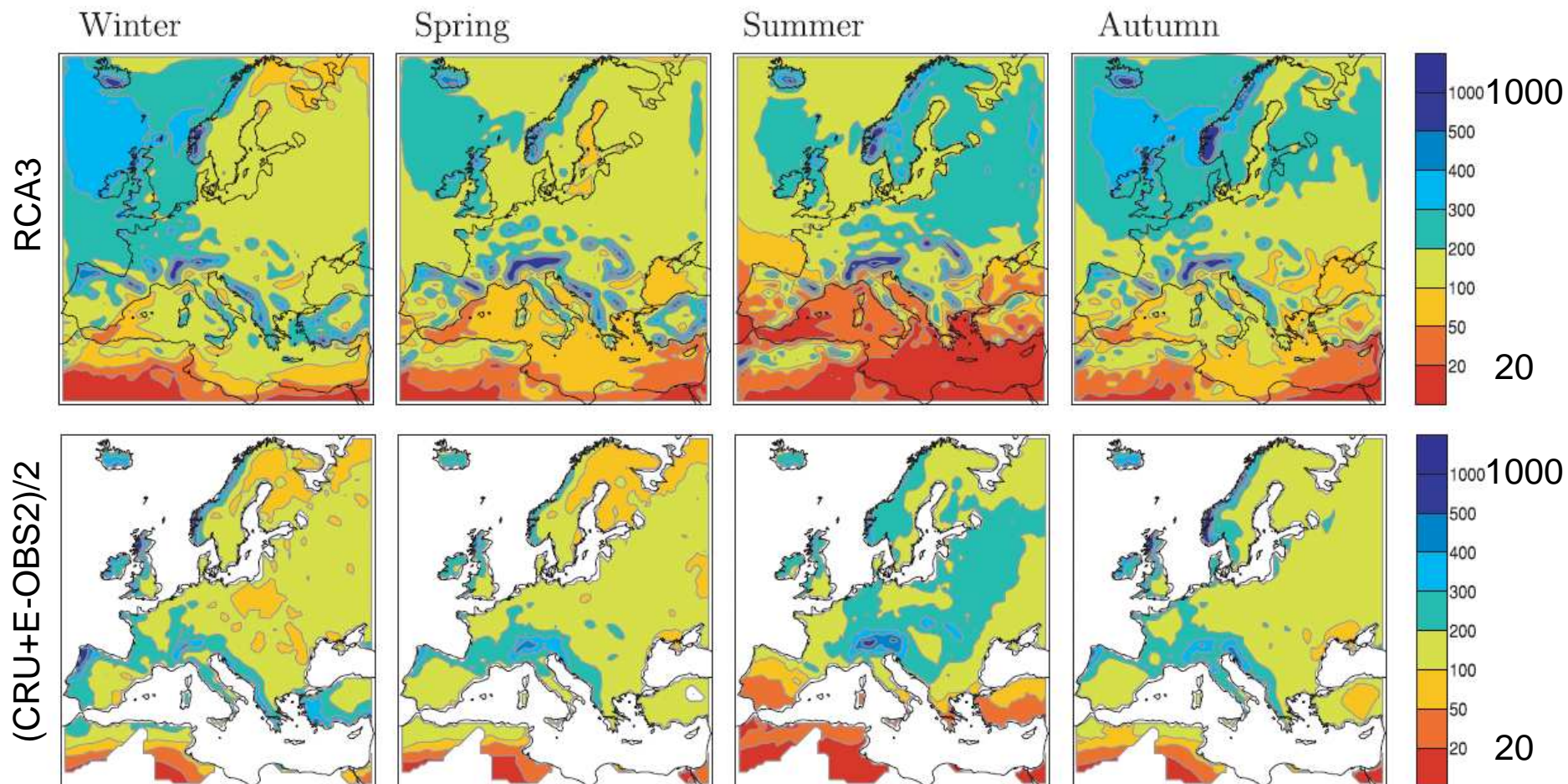




# Precipitation in RCA3

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RCA3 forced by ERA40

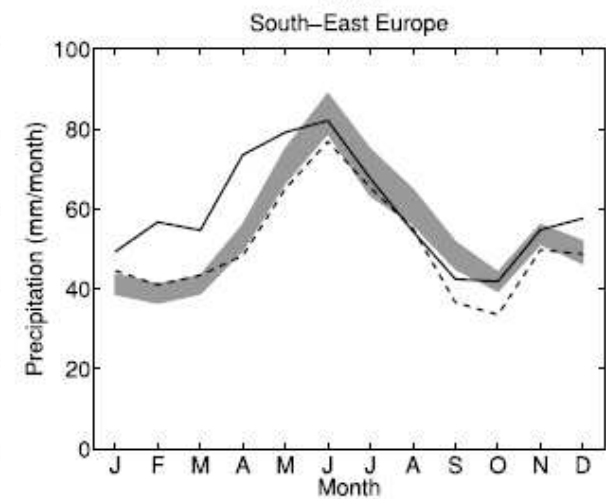
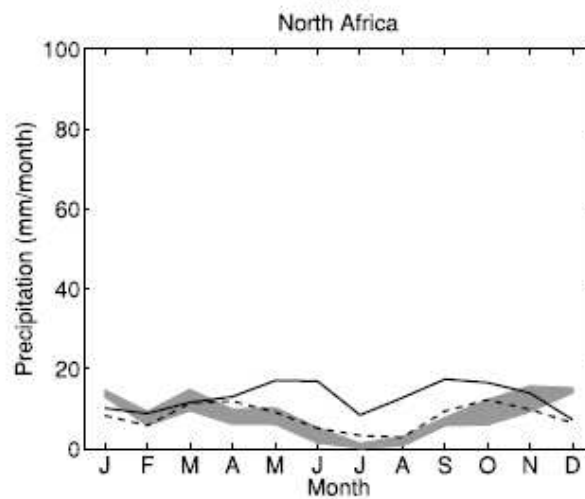
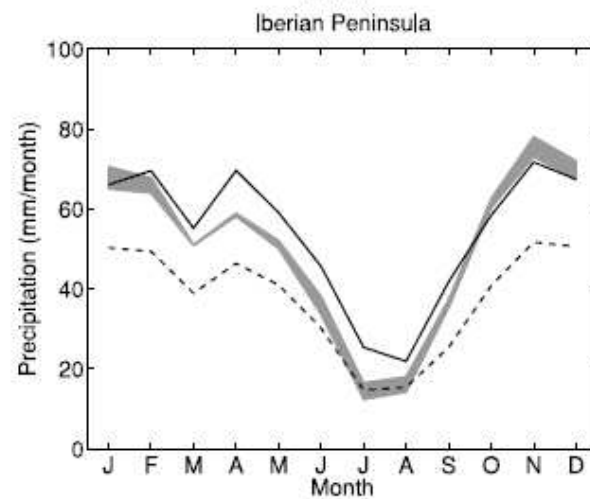
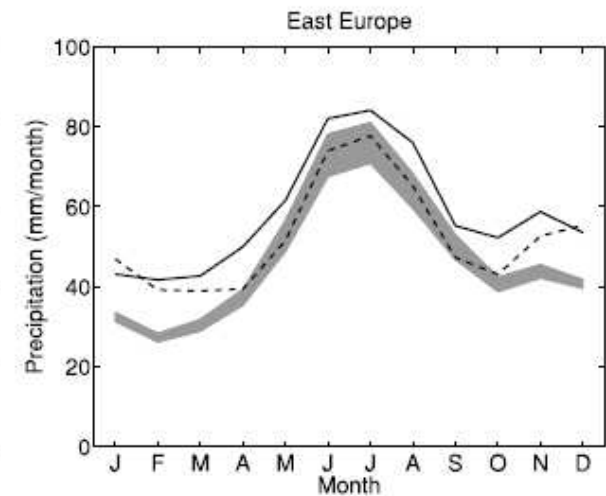
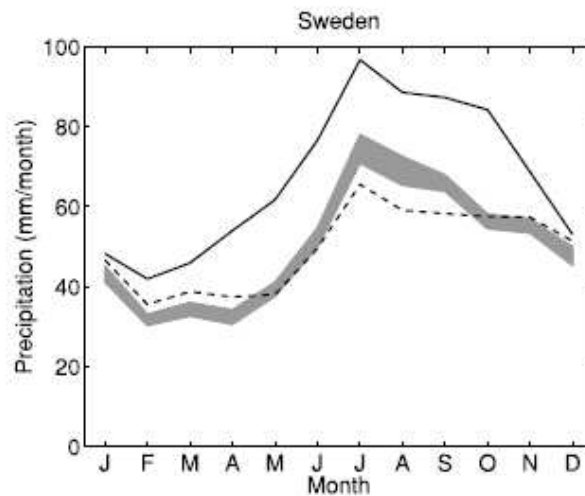
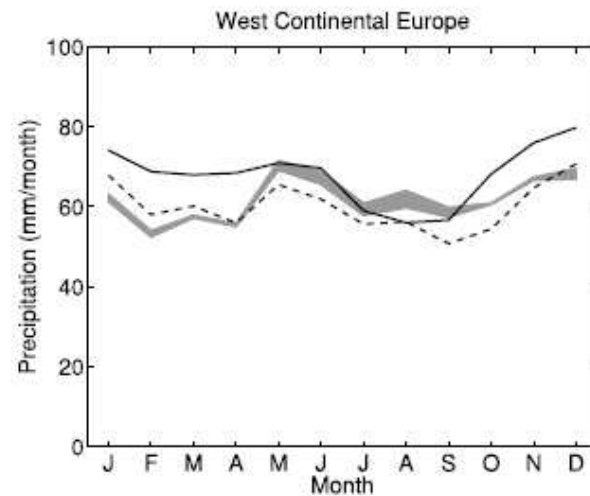


# Precipitation in RCA3

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RCA3 forced by ERA40

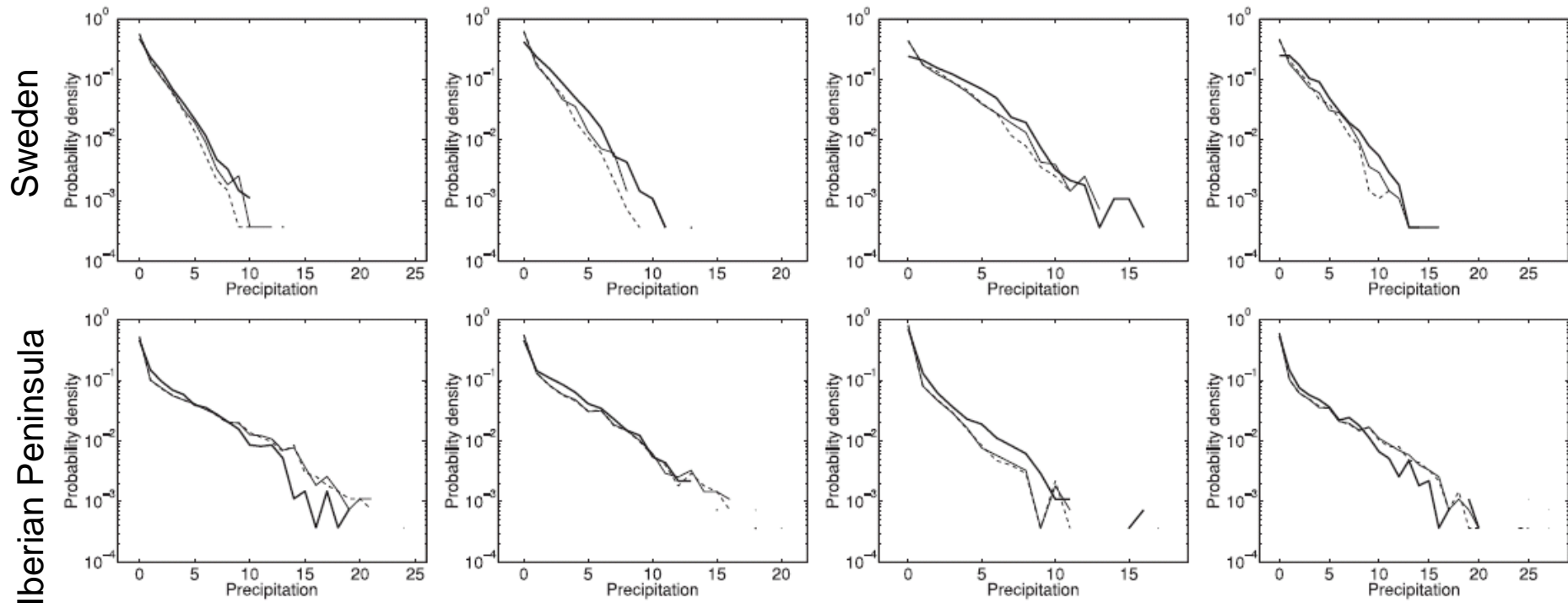
- RCA3  
-- ERA40  
shaded (CRU+E-OBS2)/2



# Precipitation in RCA3

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RCA3 forced by ERA40



PDFs of daily precipitation

- RCA3  
-- E-OBS1  
- E-OBS2

# How good are RCMs at reproducing the recent past climate in Europe?

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- The large-scale circulation given by the boundary conditions is realistically downscaled in RCMs
- Daily mean temperatures generally within  $\pm 1-2^{\circ}\text{C}$  from observations on a seasonal mean basis
- The seasonal cycle of precipitation is generally well captured although biases in individual models can be of the order of  $\pm 100\%$  for some regions/seasons
- Larger errors in extremes
- Too many days with weak to moderate precipitation in northern Europe and too few dry days
- Most attention has been on evaluating temperature and precipitation
- Given good boundary conditions RCMs has the potential of producing a realistic climate



- 
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## Two basic types of regional modelling

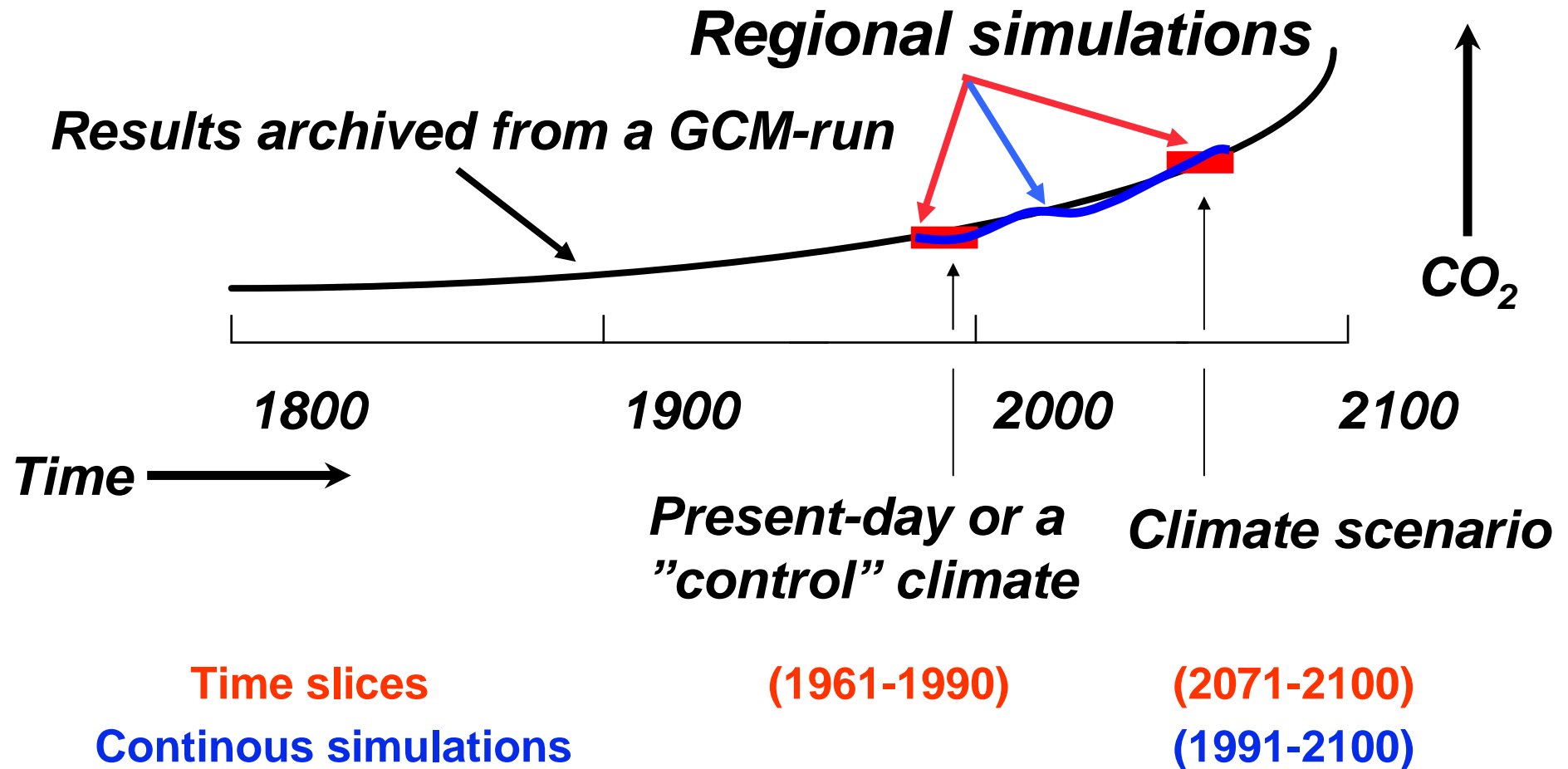
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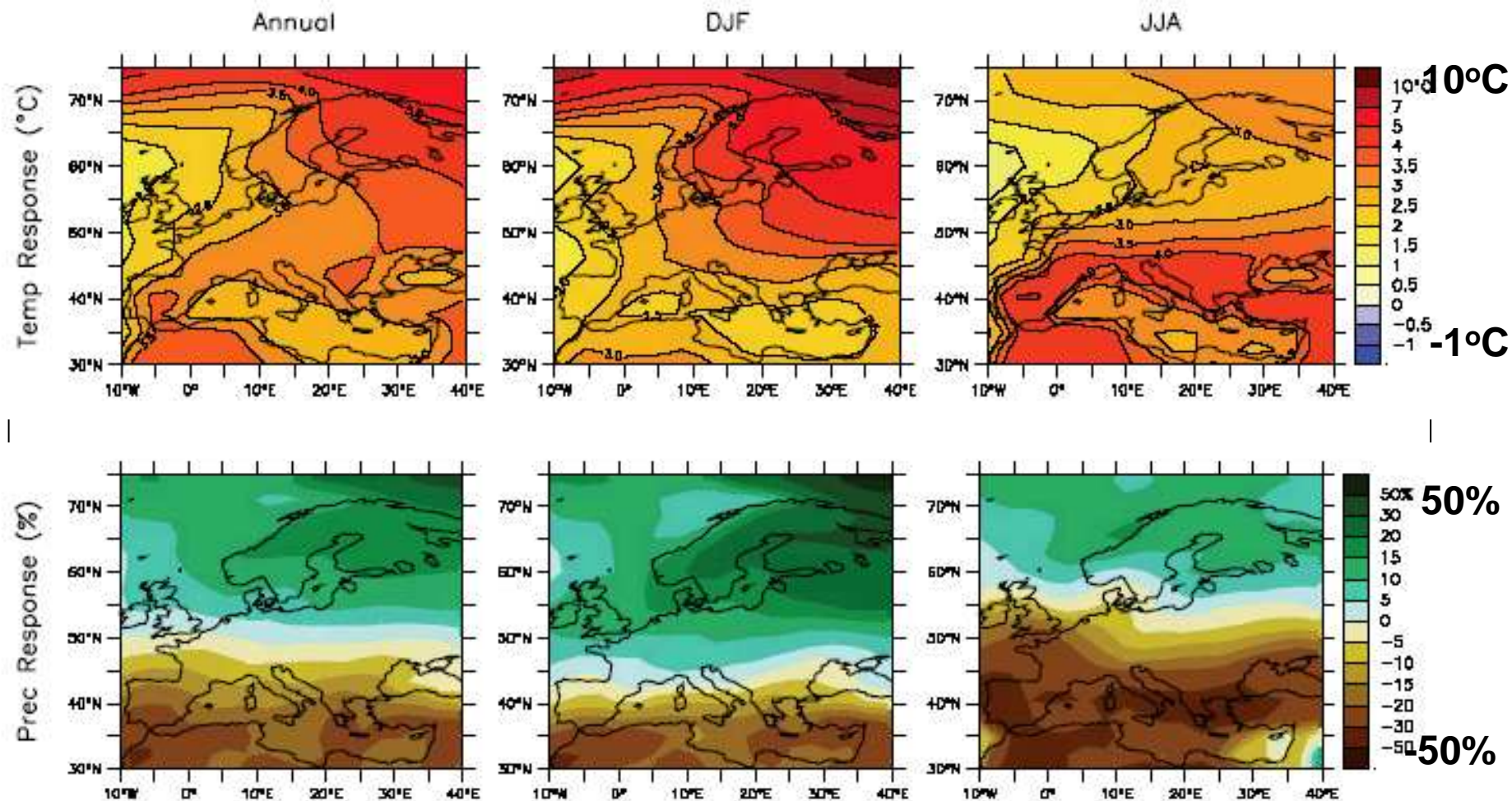
# How to simulate transient climate change in a RCM?

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# Future climate change in Europe

Climate change (2080-2099 vs 1980-1999), A1B emissions scenario, average of 21 GCMs

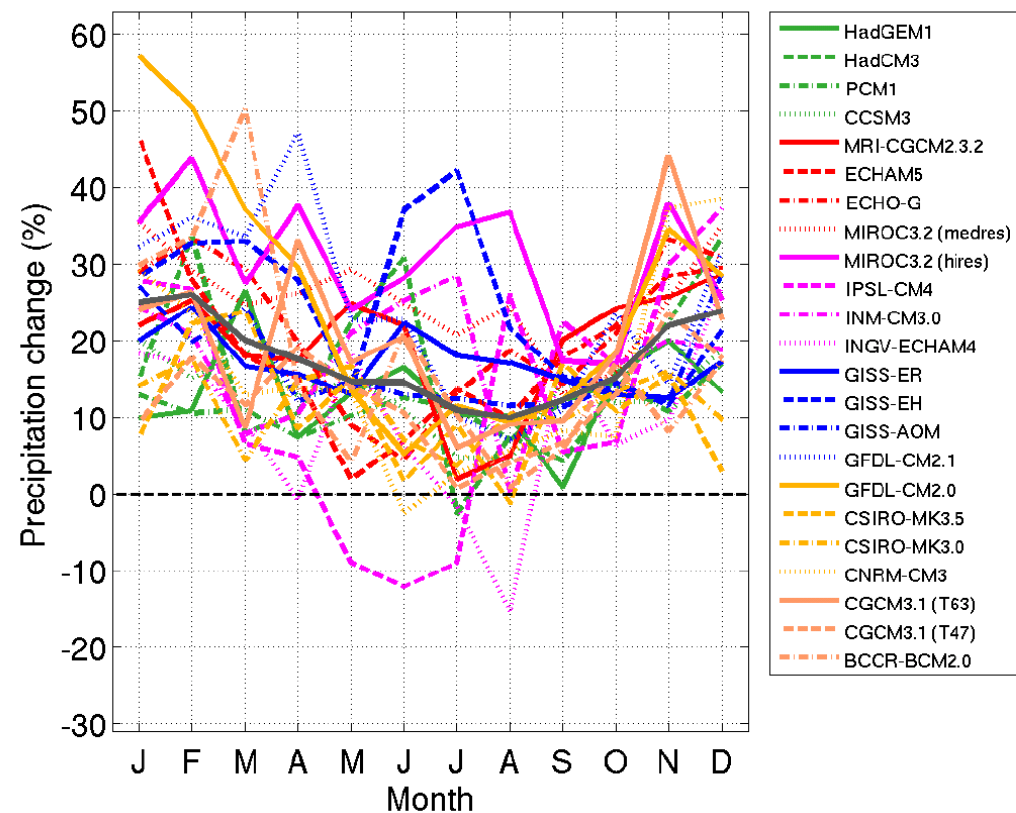
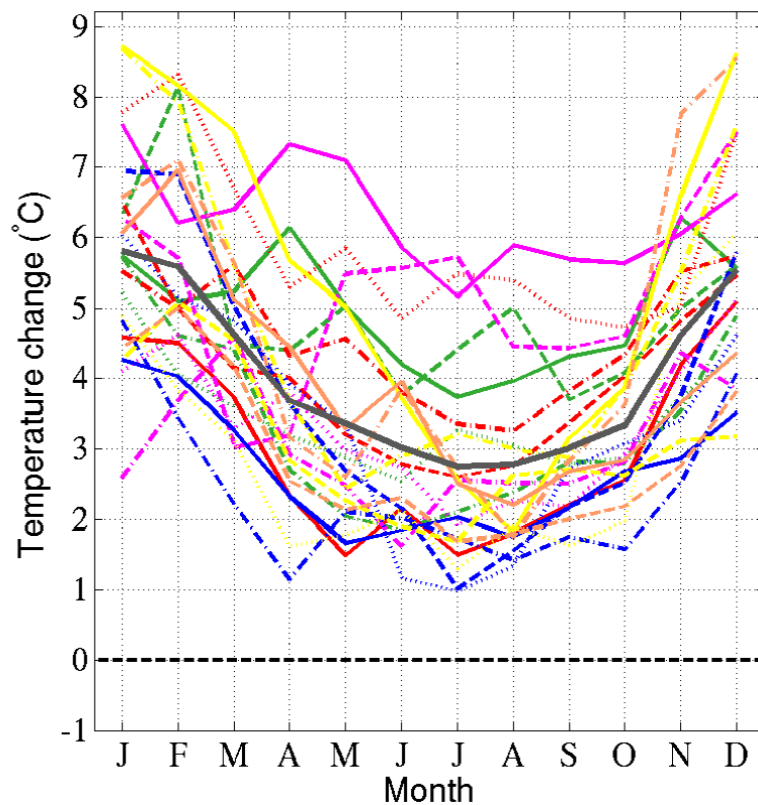
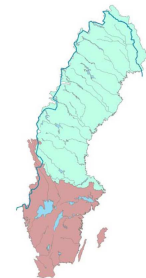


Christensen, et al. 2007: Regional Climate Projections. In: *Climate Change 2007: IPCC AR4 WGI*

# Need for more than one scenario!

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## Climate change in Northern Sweden: Comparing 2071-2100 vs 1961-1990 (SRES A1B)



# Climate change experiments at the Rossby Centre



- 16 simulations with RCA3.0 set up on the ENSEMBLES domain. All simulations are at 0.44° (~50 km) horizontal resolution
  - ✓ 16 transient climate change experiments for (1951) 1961-2099 (2100) with forcing according to 20C3M (1961-2000) and SRES-scenarios (2001-2100)
  - ✓ 1 reference (1961-2002) experiment with boundary data from ERA40
- Radiative forcing in RCA3 is implemented in terms of equivalent CO<sub>2</sub> concentrations
- Reference period (1961-1990) evaluated against E-OBS (ENSEMBLES gridded observational climatology), ERA40 and CRU TS2.1
- Seasonal mean MSLP, T<sub>2m</sub>, precipitation and 10 m wind speed

Kjellström, E., Nikulin, G., Hansson, U., Strandberg, G. and Ullerstig, A., 2010. 21st century changes in the European climate: uncertainties derived from an ensemble of regional climate model simulations. Tellus, published online. DOI: 10.1111/j.1600-0870.2010.00475.x

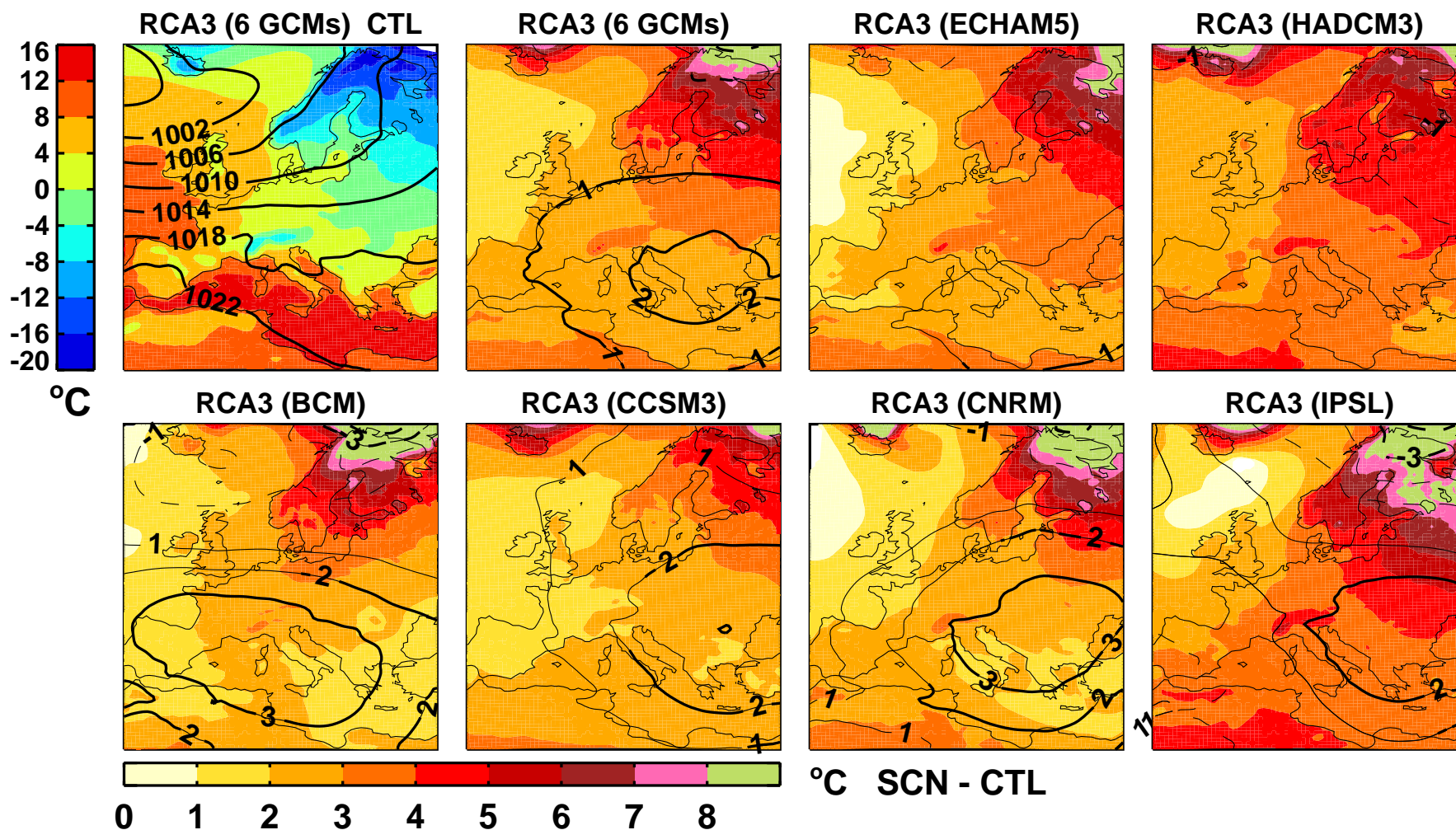
Nikulin, G., Kjellström, E., Hansson, U., Jones, C., Strandberg, G. and Ullerstig, A., 2010. Evaluation and Future Projections of Temperature, Precipitation and Wind Extremes over Europe in an Ensemble of Regional Climate Simulations. Tellus, published online. DOI: 10.1111/j.1600-0870.2010.00466.x



# Changes in winter temperature

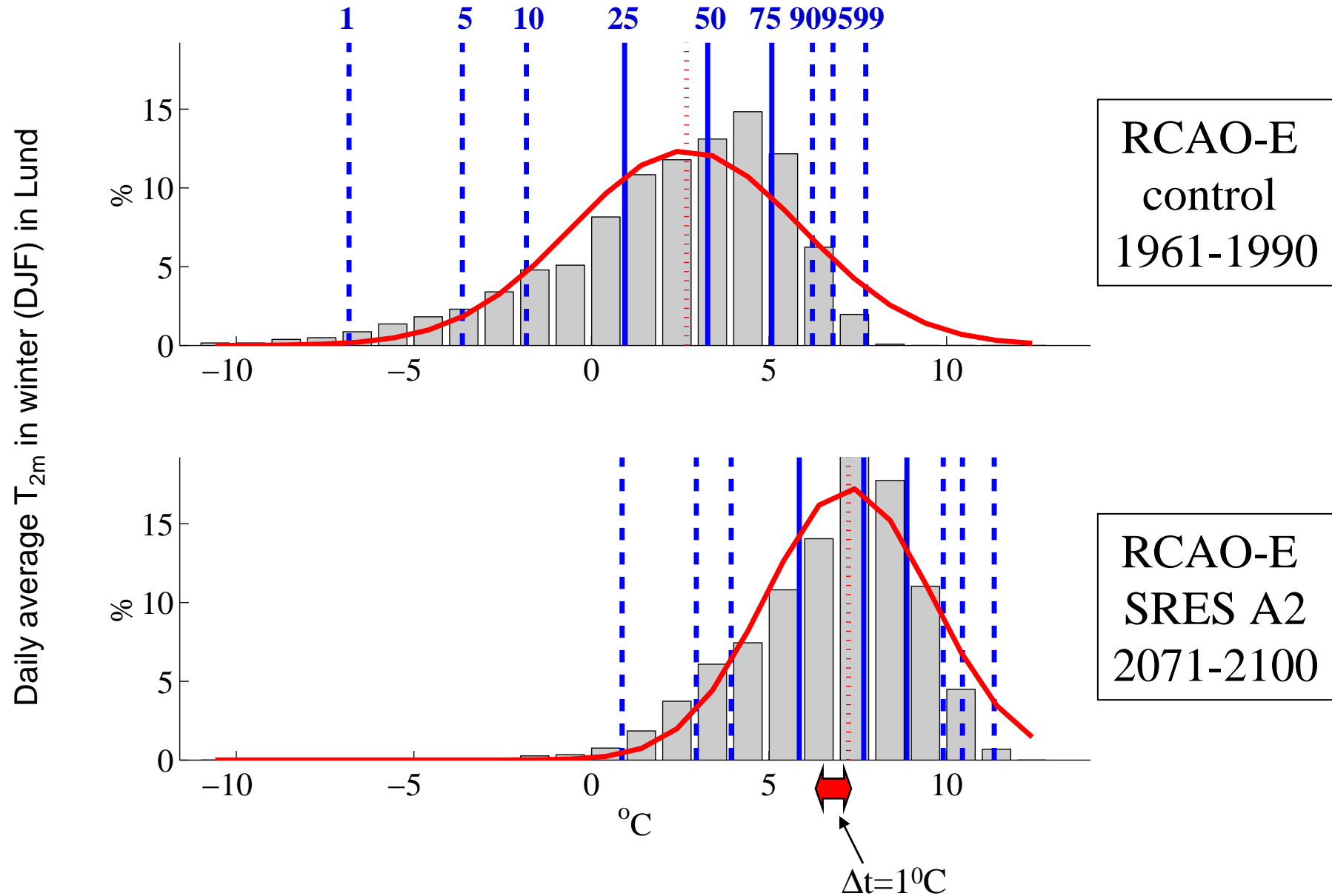
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2m temperature Winter (DJF) SCN: 2071-2100 CTL: 1961-1990



# Daily temperature statistics

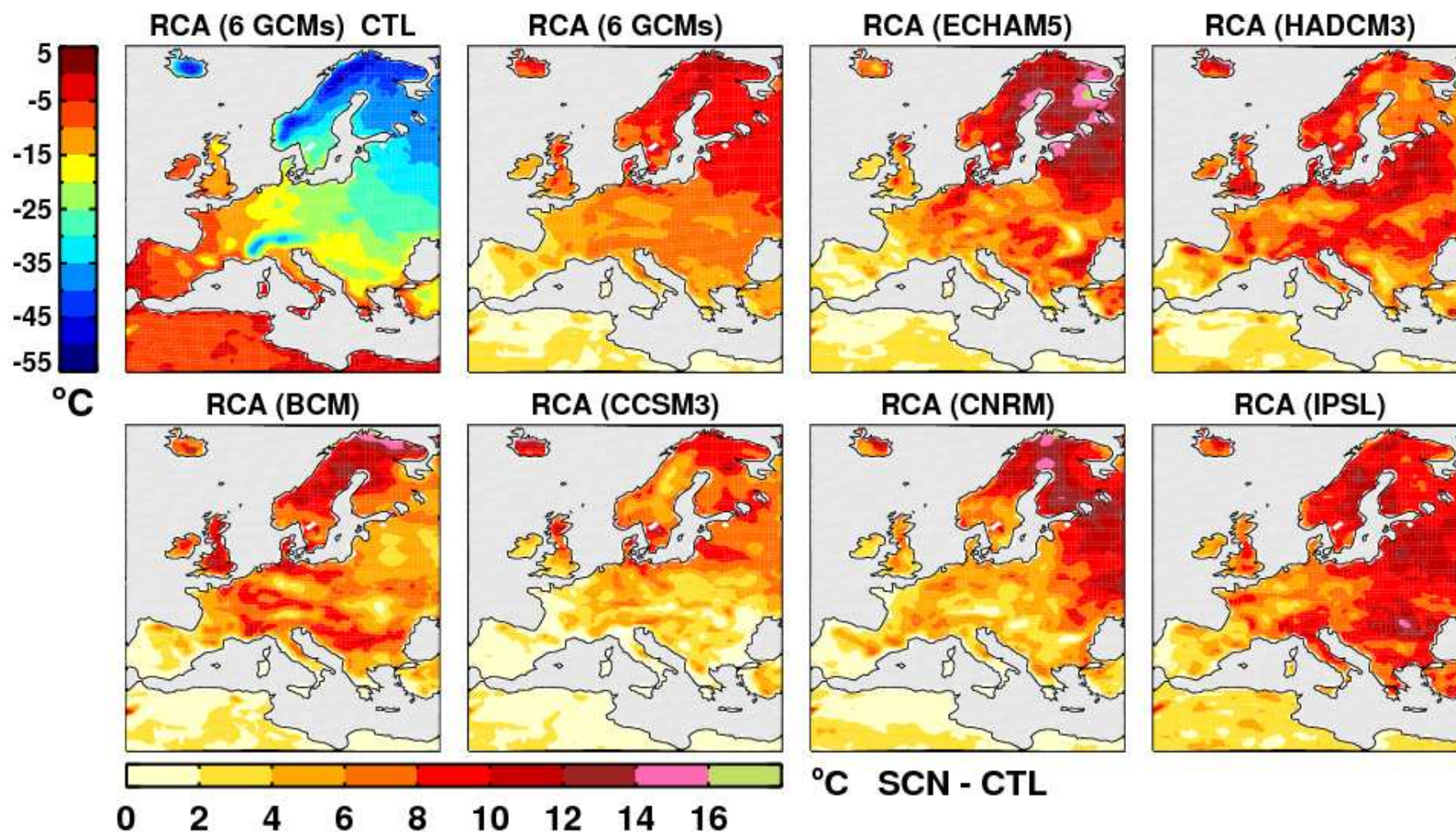
SMHI





# Changes in cold extremes

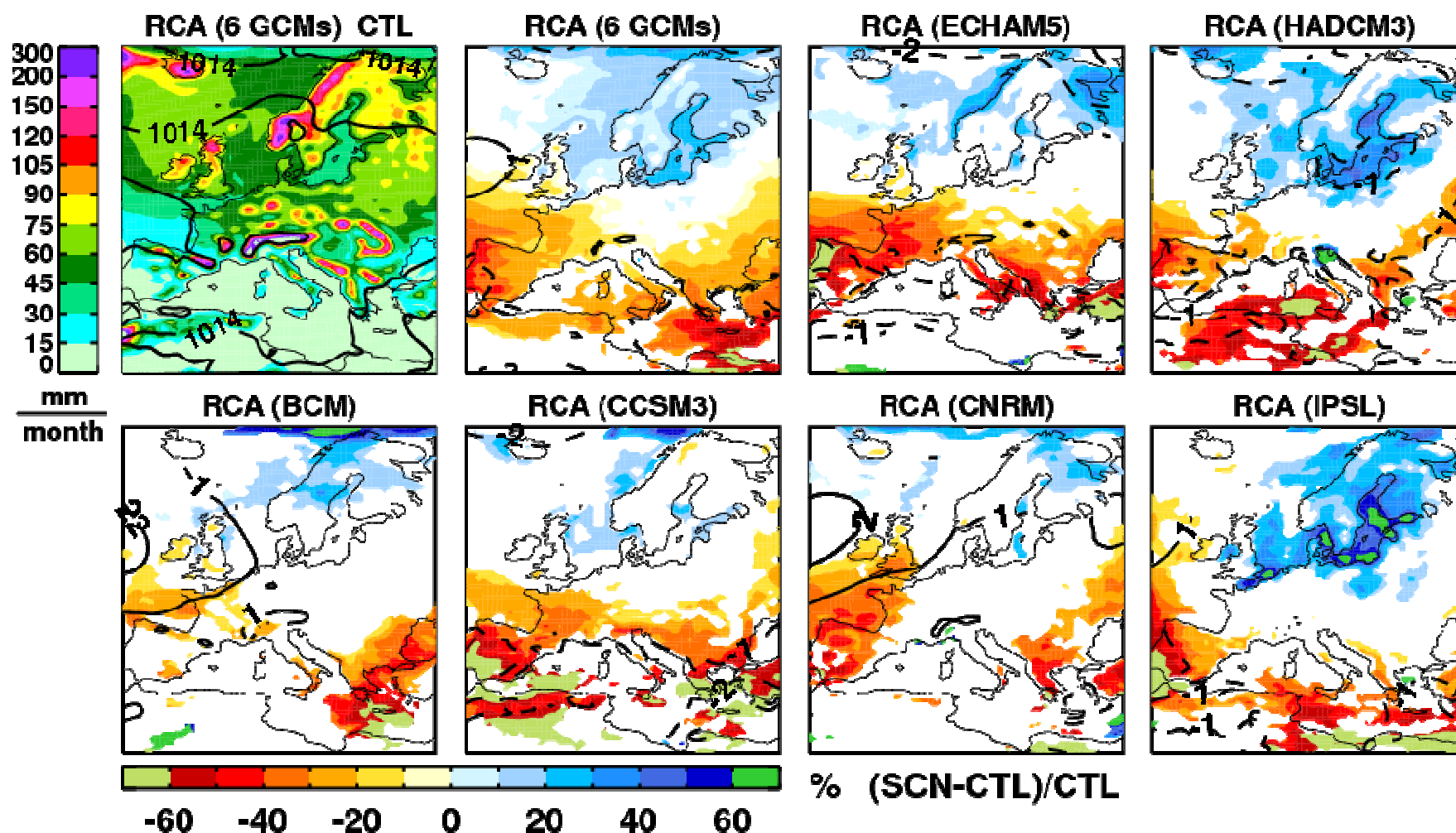
20-yr ret. values of T2min | SCN: 2071-2100 CTL: 1961-1990



# Changes in summer precipitation

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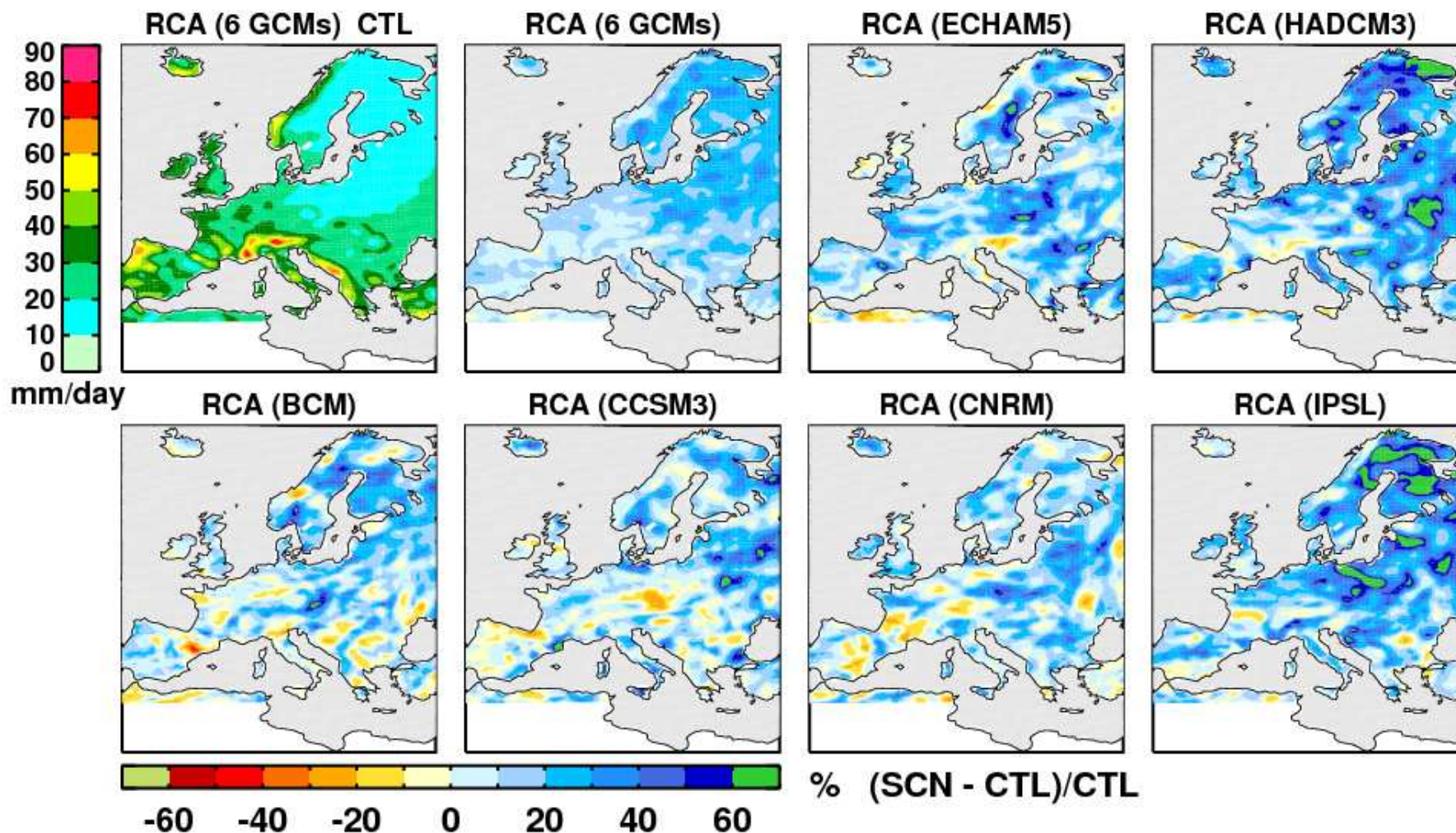
Precipitation Summer (JJA) SCN: 2071-2100 CTL: 1961-1990 (SLP: 1 hPa)





# Change in wet extremes

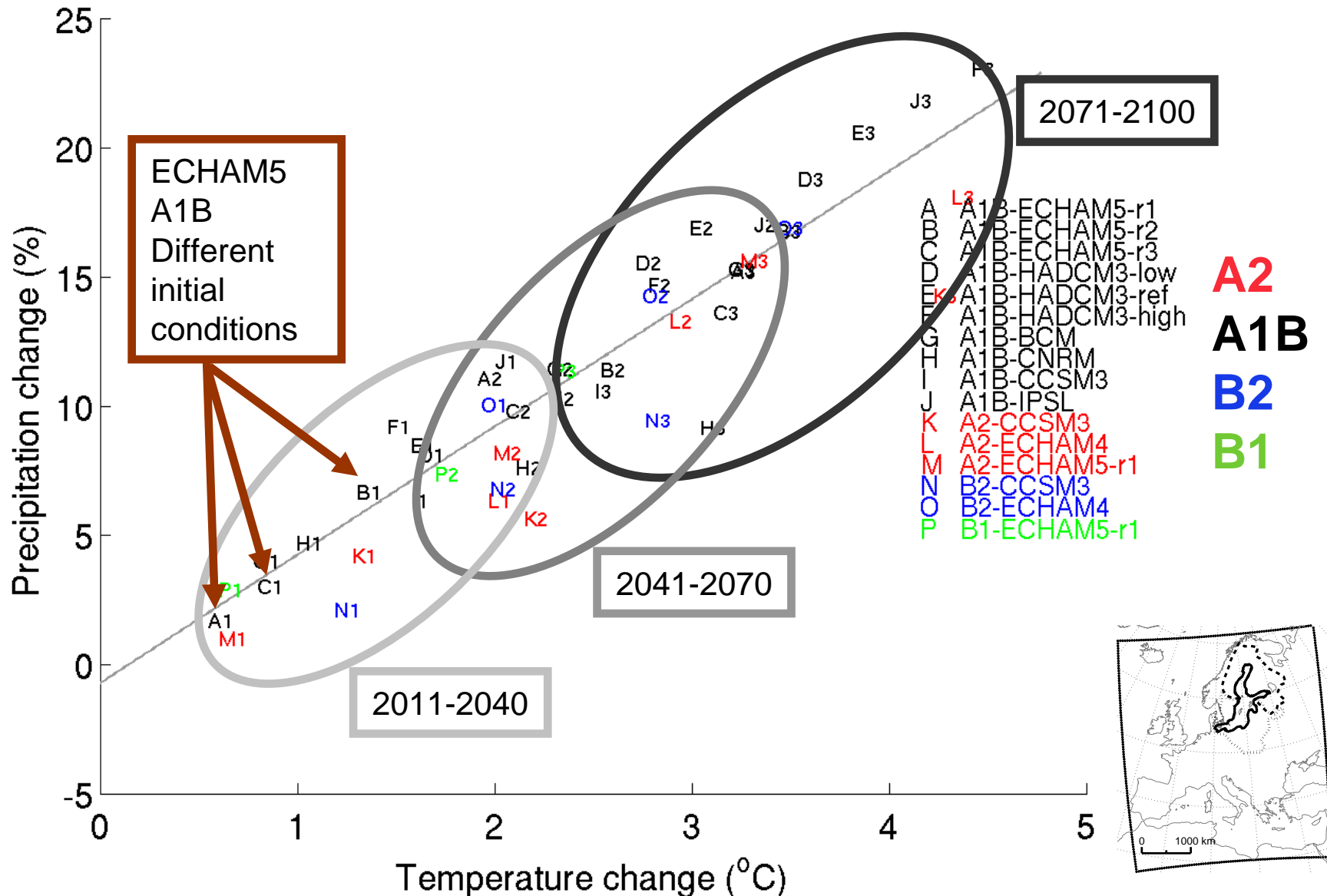
Change in 20-year return values of daily precipitation amounts for summer (JJA)



# Change compared to 1961-1990

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AREA=BALTEX land SEASON=ANN CC=0.92637 k=4.9541 l=-0.74939

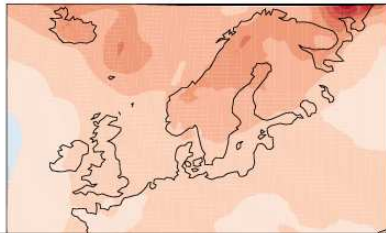


# Climate models represent natural variability

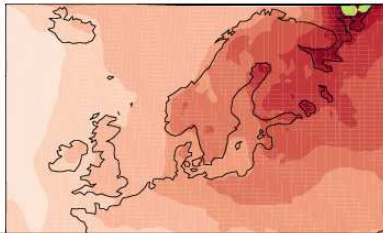
SMHI

2-meter temperature, WINTER (DJF) MEAN, CTL: 1961-1990 SCN: 2011-2040

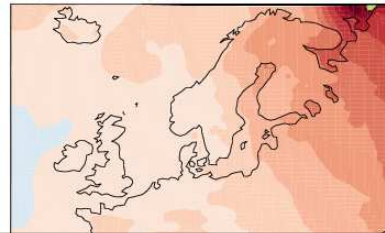
ECHAM5 A1B-1 (50km)



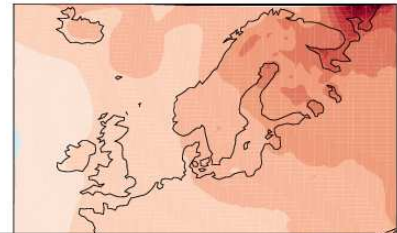
ECHAM5 A1B-2 (50km)



ECHAM5 A1B-3 (50km)

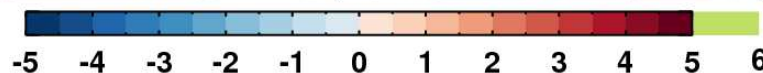
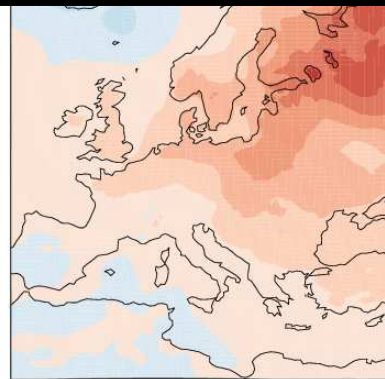
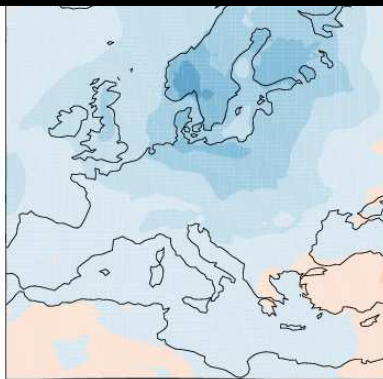
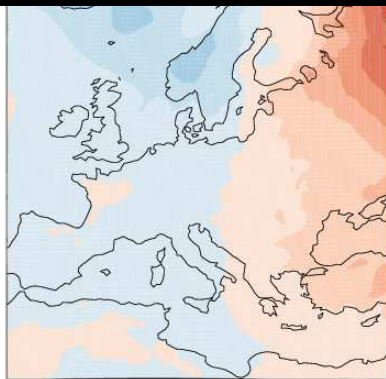


ENSEMBLE MEAN



Differences between members are of the same order as the CC signal!

*Note – changes in wintertime temperatures in NE Europe is one of the most pronounced CC signals.*



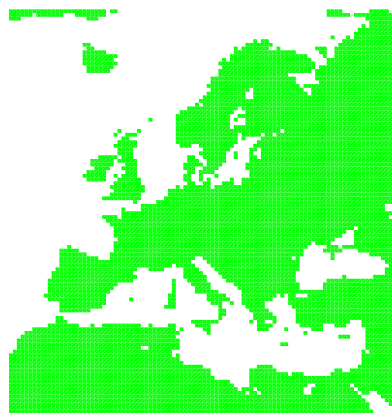
°C, Diff. among members

- Projected climate change in Europe is large
  - *Largest temperature increase in the north in winter and in the south in summer*
  - *Precipitation increase in northern Europe and decrease in the south*
  - *Changes in extremes are larger than corresponding changes in means*
  - *Extremes of tomorrow are different than those of today*
  
- Ensembles of RCM scenarios (like the Rossby Centre ensemble) allows us to better illustrate aspects of climate change and its dependence on
  - *Emission scenario – most important in the 2nd half of the 21st century*
  - *Model formulation – important both in the near and distant future*
  - *Natural variability – most important in the nearest decades*

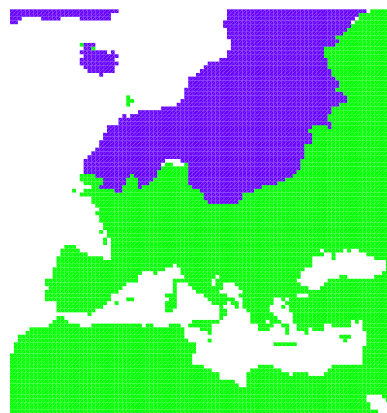


# RCMs can be used also for past climates

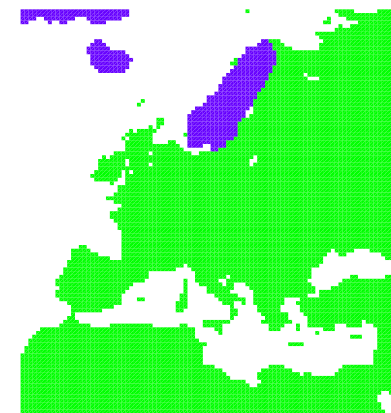
Warm



Glacial



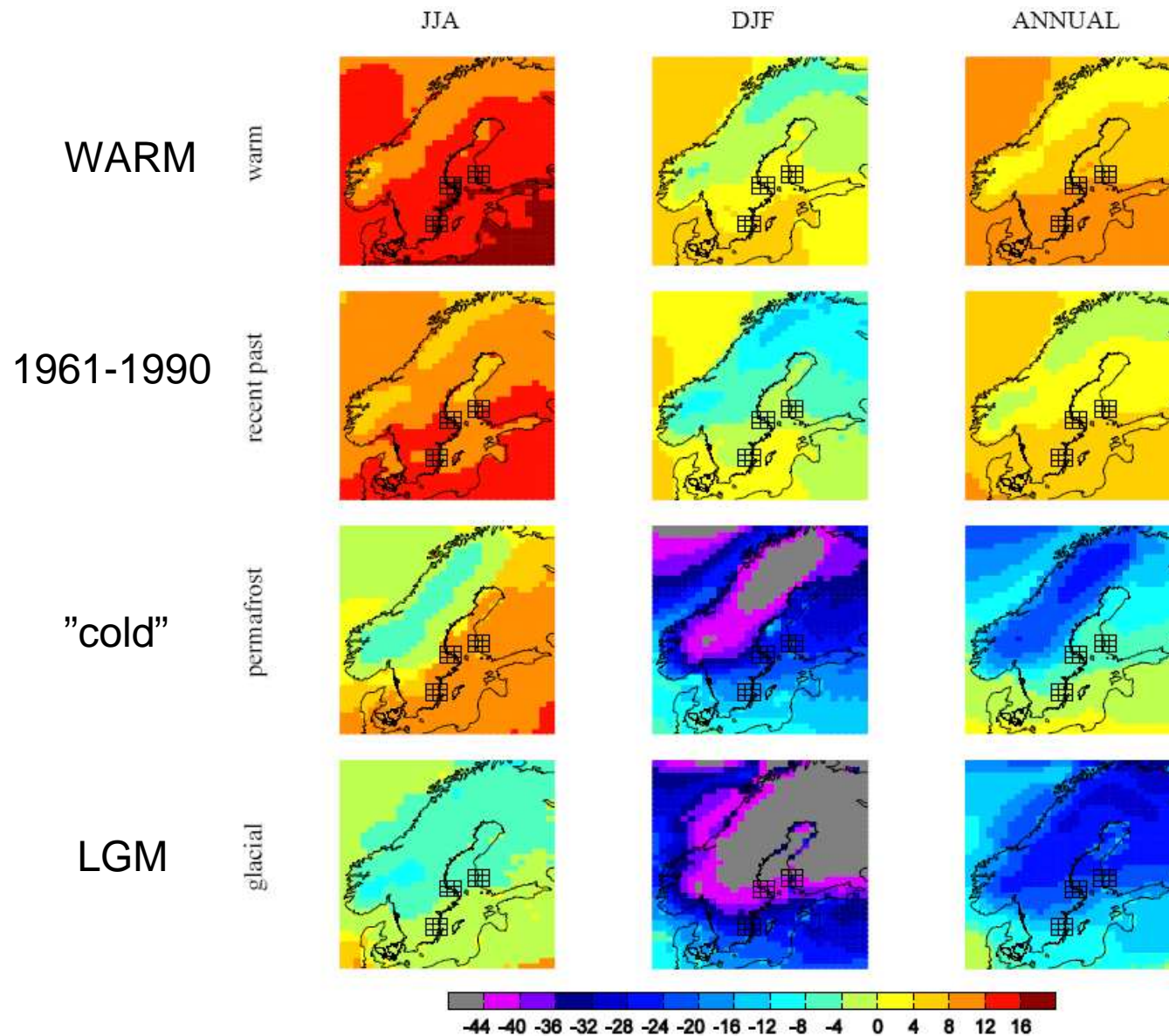
Permafrost



Insolation	1365 Wm <sup>-2</sup>	1365 Wm <sup>-2</sup>	1365 Wm <sup>-2</sup>
Orbital year	1990	21 ka BP	44 ka BP
CO <sub>2</sub>	750 ppm <sub>v</sub>	185 ppm <sub>v</sub>	200 ppm <sub>v</sub>
CH <sub>4</sub>	RP (1714 ppb <sub>v</sub> )	350 ppb <sub>v</sub>	420 ppb <sub>v</sub>
N <sub>2</sub> O	RP (311 ppb <sub>v</sub> )	200 ppb <sub>v</sub>	225 ppb <sub>v</sub>
Ozone	PI	PI	PI
Sulphate	PI	PI	PI
Dust, sea salt	PI	PI / $PI \times 3$	PI
Ice sheets	RP (Excluding GIS)	ICE-5G	Näslund, CLIMBER2, ICE-5G
Land-sea distr.	RP	ICE-5G	ICE-5G [Whitehouse], RP
Sea level	RP [+7 meters]	-120 m	-120 m [-70 m]
Topogr., bathym.	RP (Excluding GIS)	ICE-5G, RP	ICE-5G [Whitehouse]
Vegetation	RP / <i>GHG</i>	RP / <i>LGM</i>	RP

# Temperature climate in a glacial cycle

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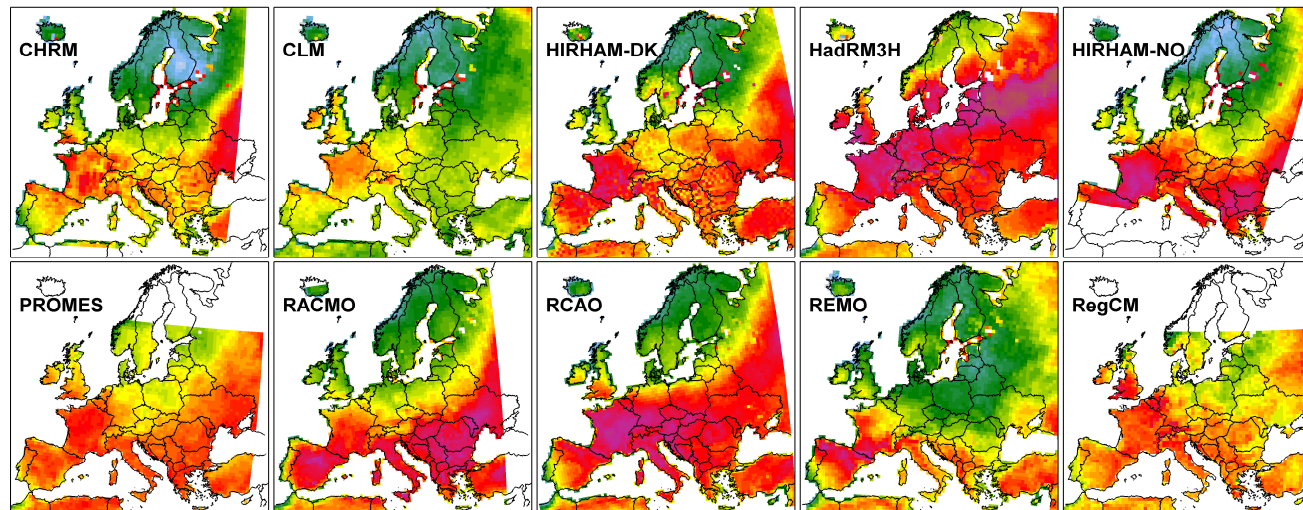




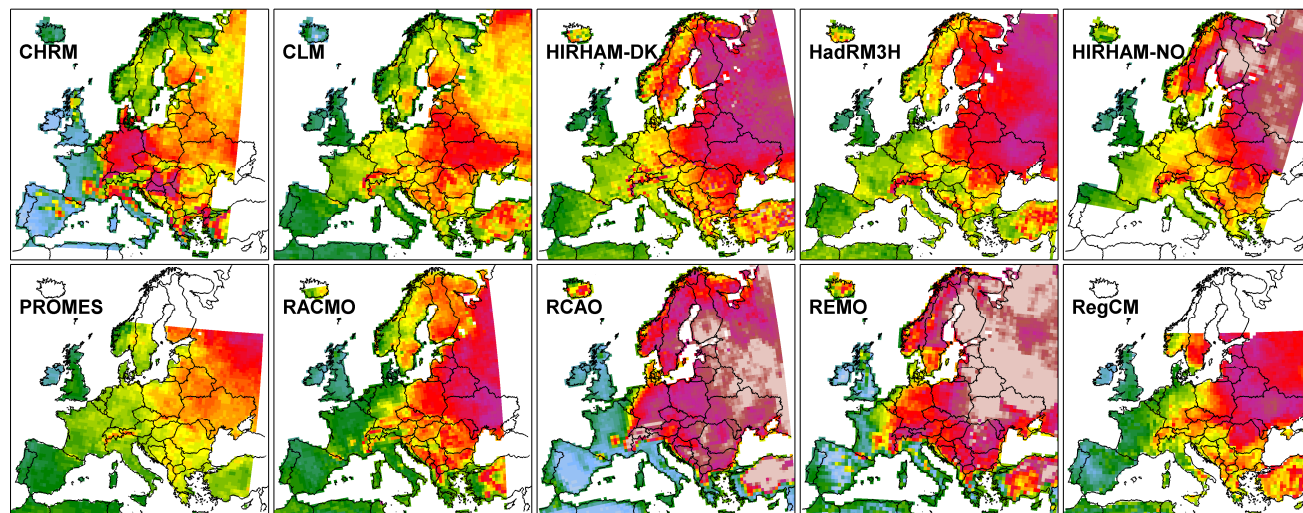
- 
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# Are RCMs comparable?

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A2-CTRL  
°C 0 2 4 6 8 10 12



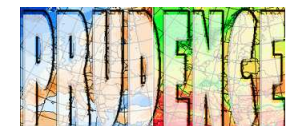
JJA,  $T_{2m}$  max, 95<sup>th</sup> percentile

- Change in daily temperatures in 10 RCMs in the common PRUDENCE GCM (HadAM3H/A2) experiment.

- 2071-2100 vs 1961-1990

DJF,  $T_{2m}$  min, 5<sup>th</sup> percentile

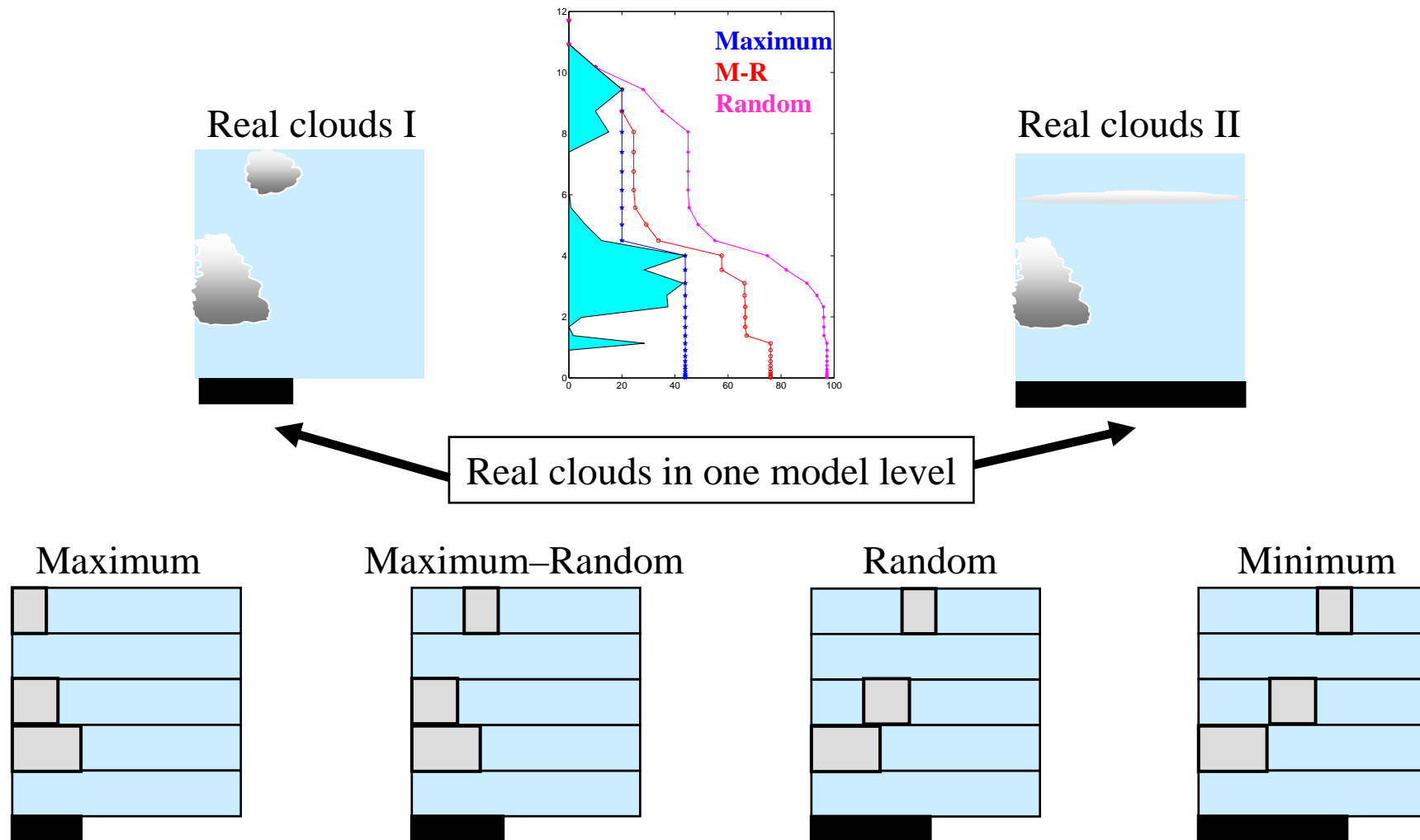
Kjellström et al., 2007  
*Climatic Change*



# Issues of parameterization

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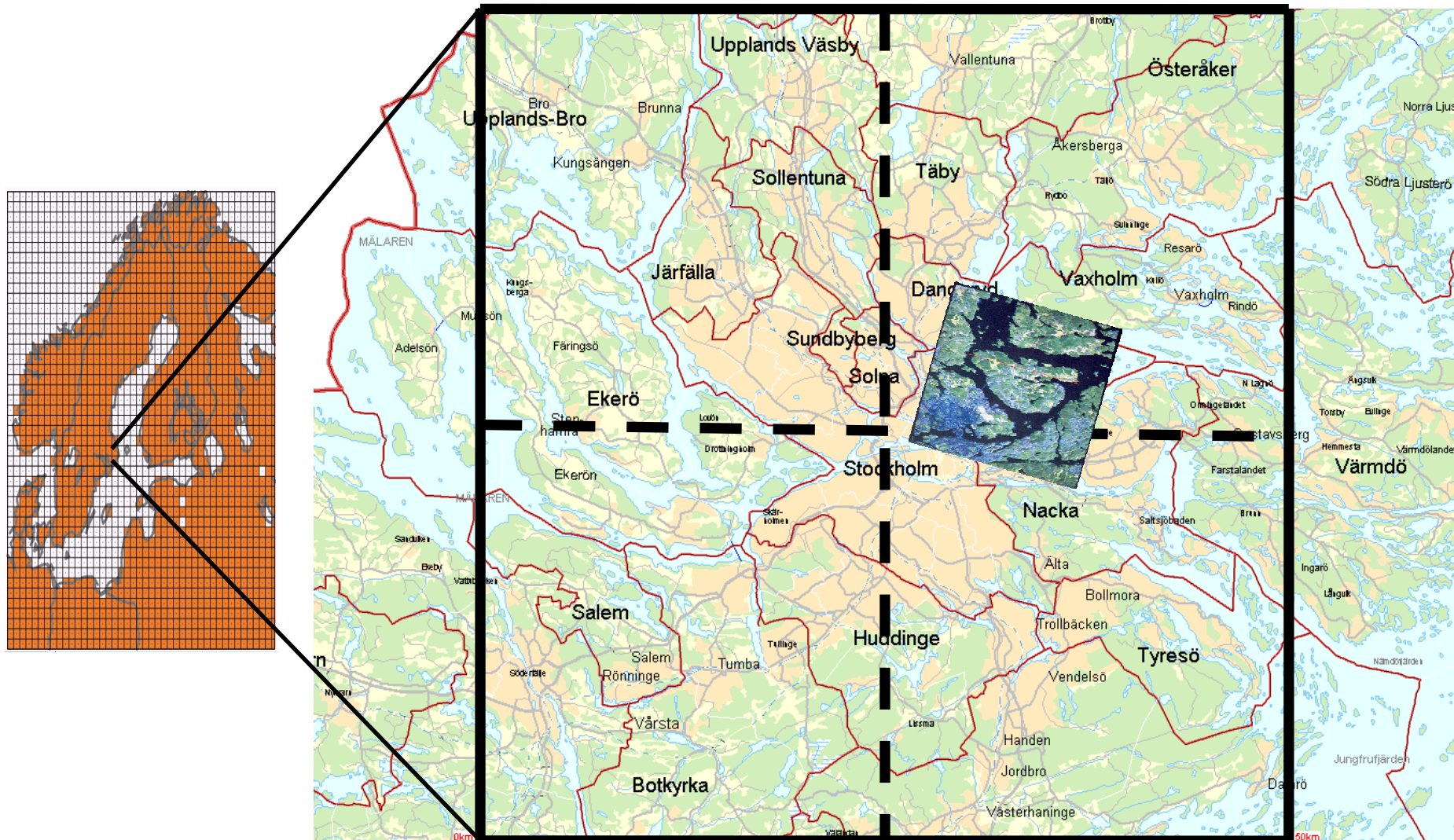
How to distribute clouds?



# Horizontal resolution in a RCM

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50 and 25 km





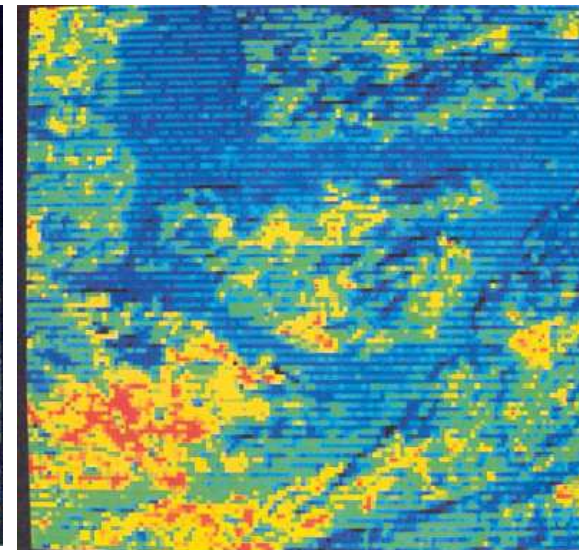
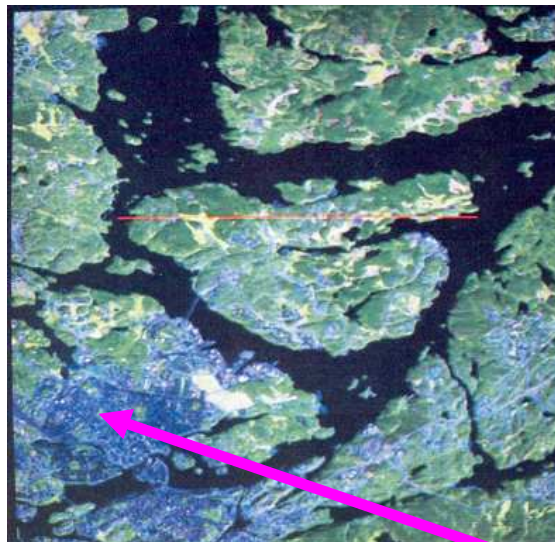
# How representative are observations?

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Example from Stockholm

- Spatial inhomogeneities

land / water  
forests / open areas  
rural / urban areas

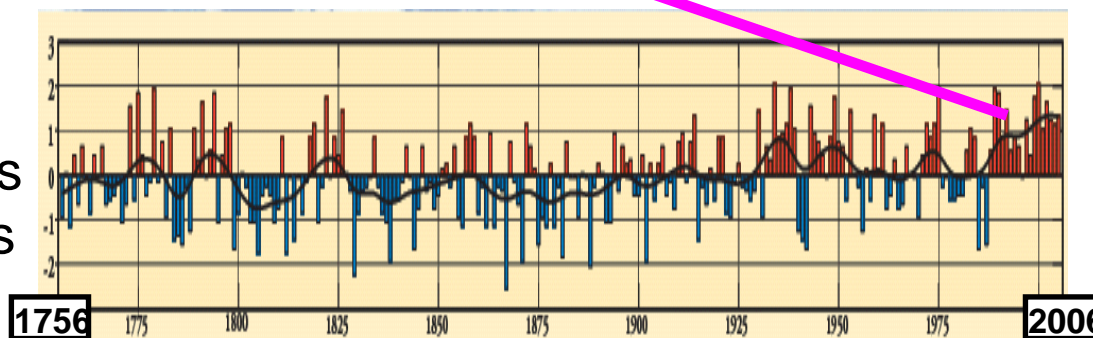


Lunden, B., 1987. Satellite Thermography a Study of a Landsat-5 Sub-Scene over Stockholm.

Geografiska Annaler. Series A, Physical Geography, Vol. 69, Nr. 3/4. 367-374.

- Temporal inhomogeneities

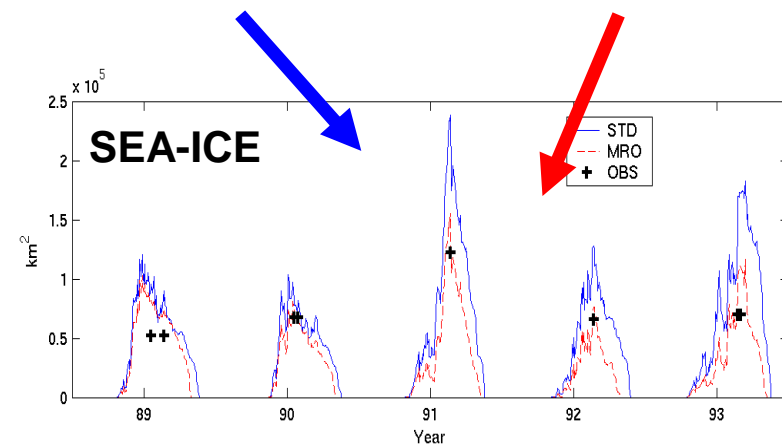
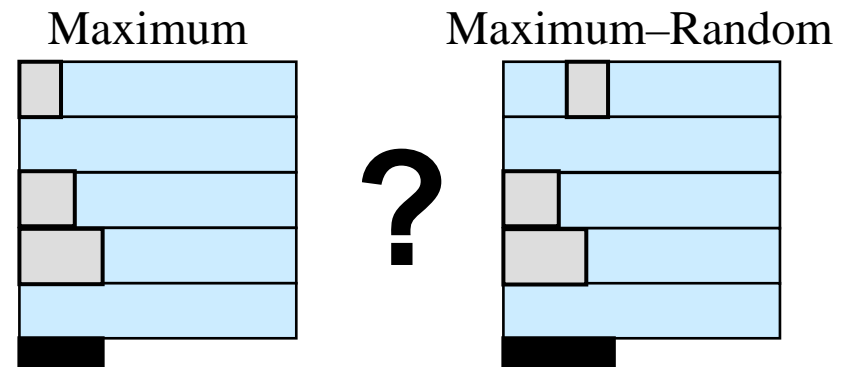
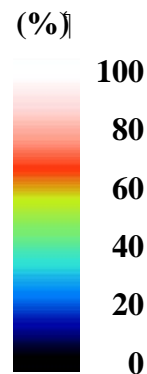
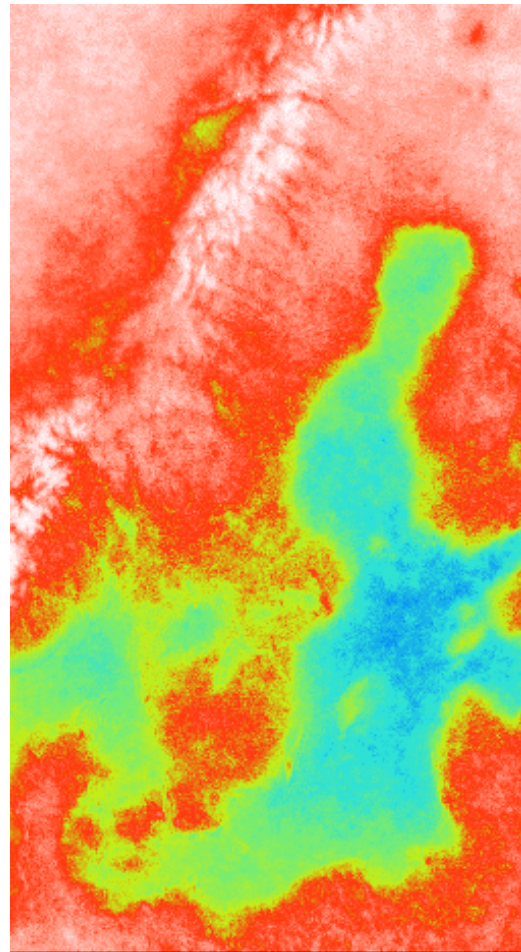
Changing local conditions  
Relocation of instruments  
Changing instruments  
Urbanization



Moberg, A., H. Bergström, J.R. Krigsman, and O. Svanered. 2002. Daily air temperature and pressure series for Stockholm (1756-1998). *Climatic Change* 53, 171-212.

# Making use of high-quality observations **SMHI**

May help improving parameterisations for subsequent use in GCMs



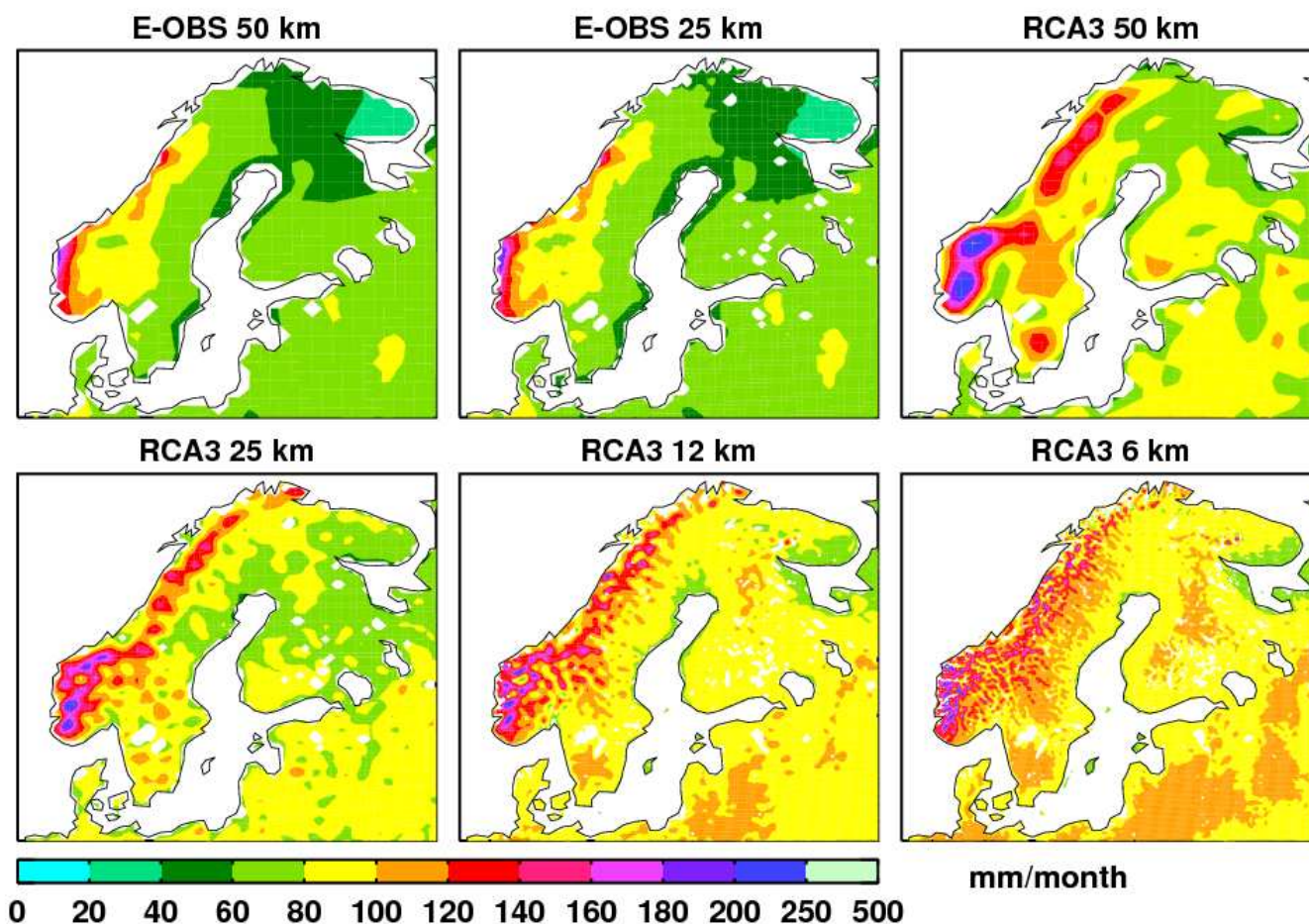
Afternoon cloud frequency in July according to the  
SCANDIA 1991-2000 cloud climatology from NOAA AVHRR



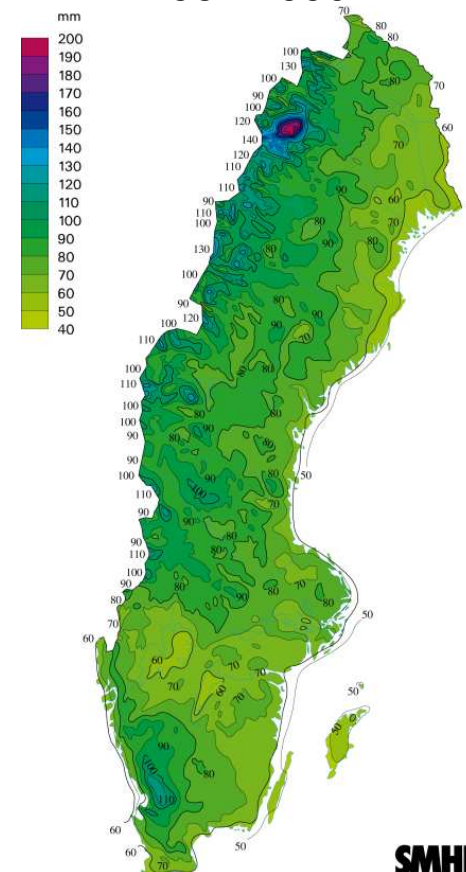
# Is the horizontal resolution adequate?

**SMHI**

Precipitation during summer (JJA) 1987-2007



Precipitation in July  
1961-1990

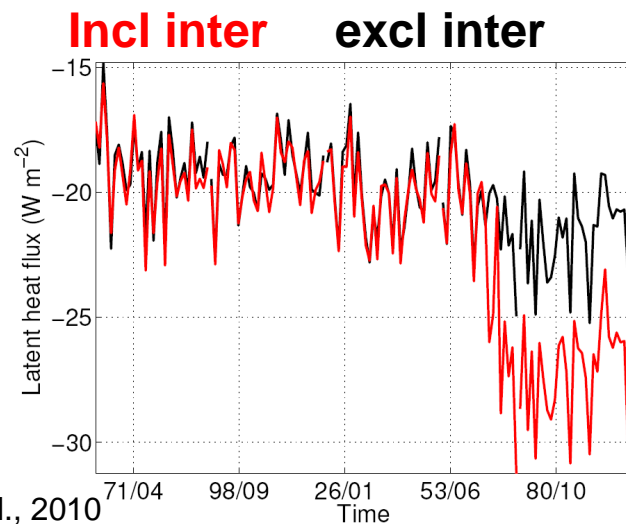
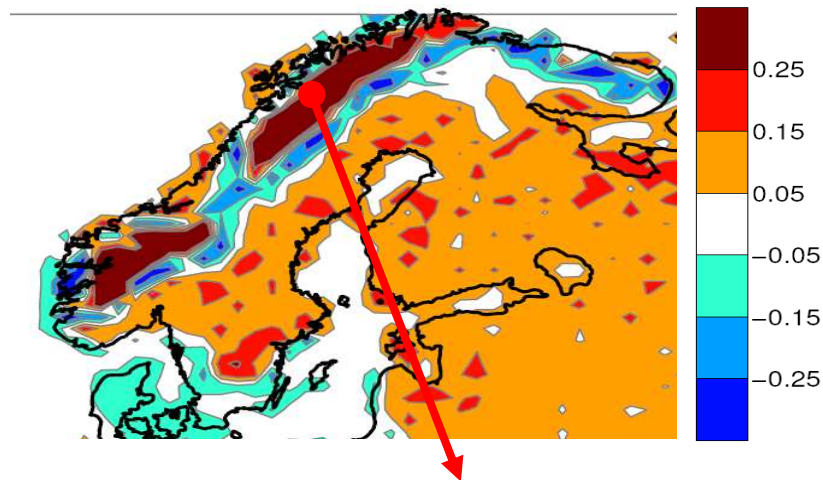


RCA3 at 50, 25, 12 and 6 km horizontal resolution

# Are all relevant processes represented? SMHI

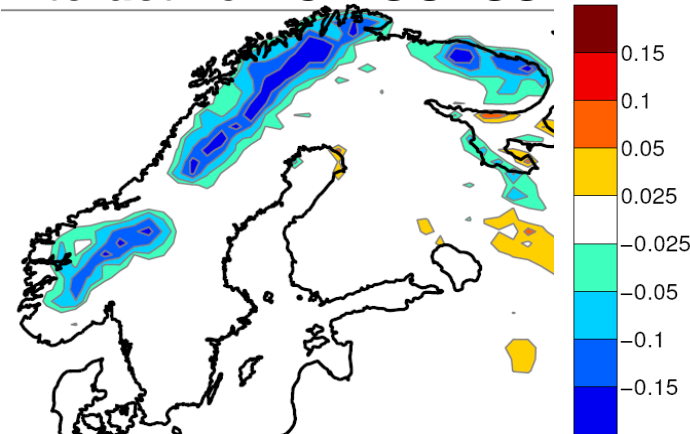
European hotspots – Scandinavian mountains

Annual change in fraction of deciduous trees

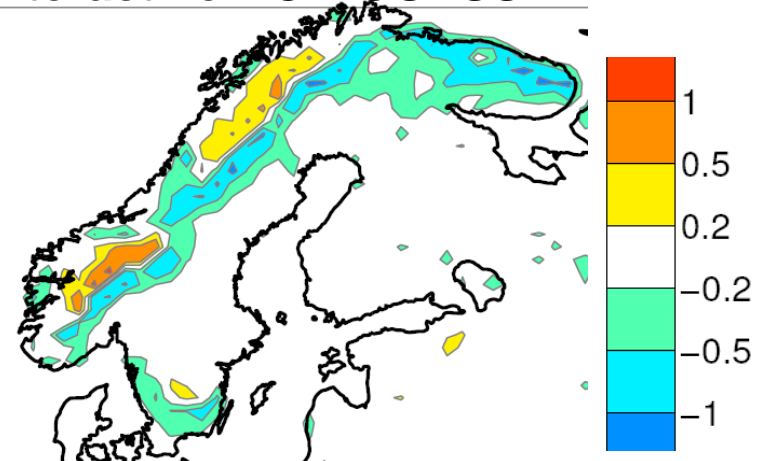


Smith et al., 2010

Spring albedo decreases more in interactive RCA-GUESS



Spring T2m increases more in interactive RCA-GUESS



## Limitations in RCM scenarios

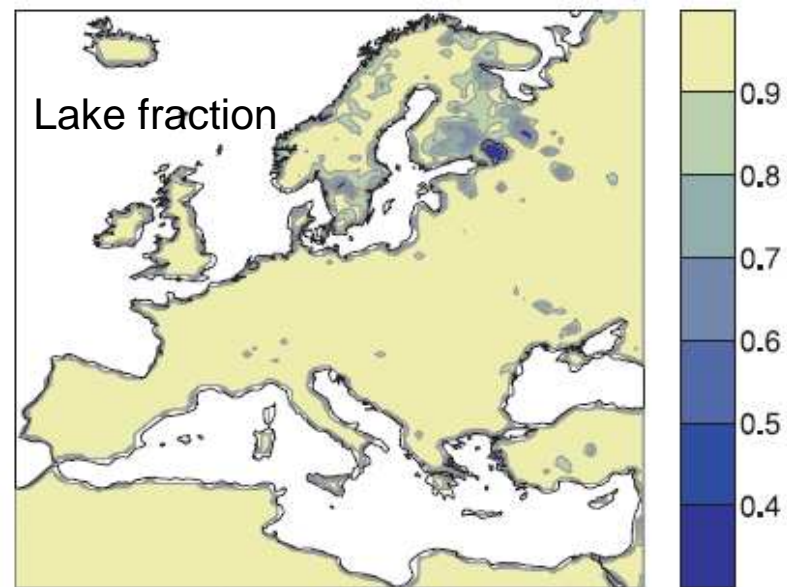
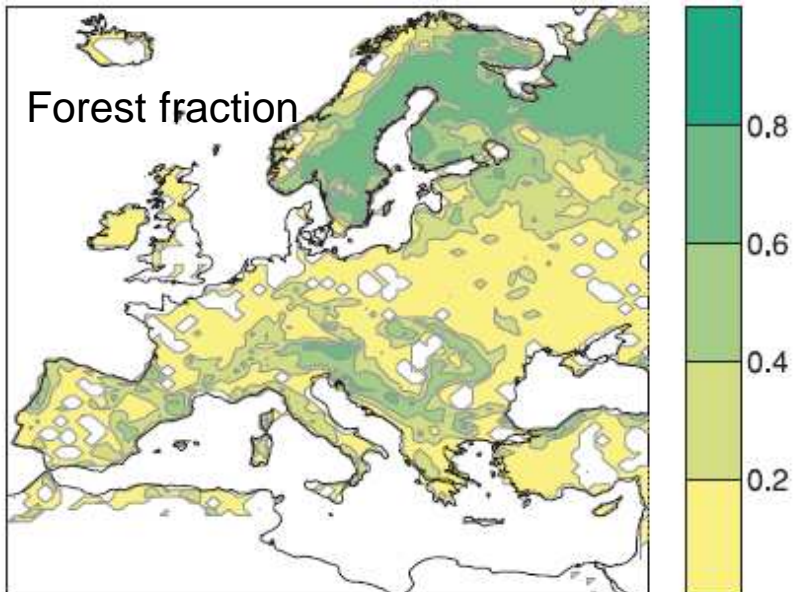
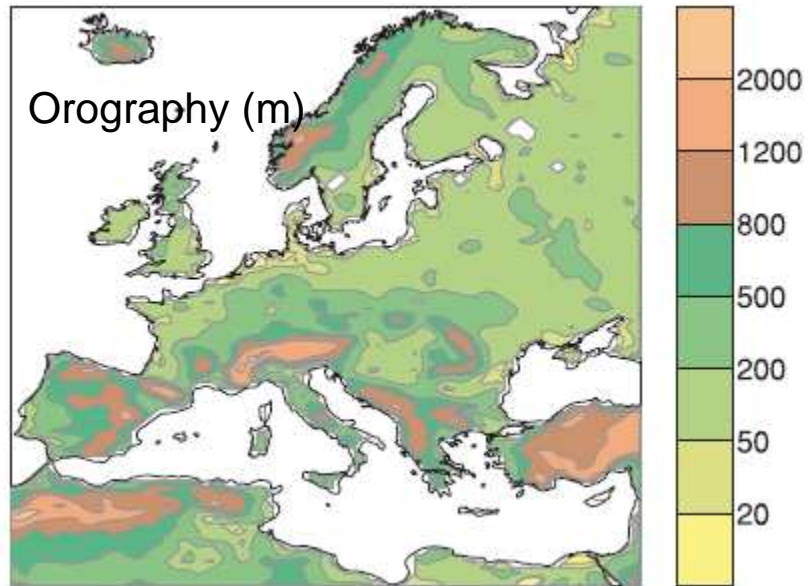
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- RCMs have errors (e.g. too few dry days)
- RCMs are not fully evaluated, partly due to lack of good observational data at the resolution of the models
- Horizontal resolution in many RCM scenarios is still relatively coarse
- Forcing conditions from GCMs may not be realistic (e.g. too zonal)
- RCM scenarios are not always consistent with the scenarios in the GCMs (e.g. different description of aerosols, land use, etc)
- RCMs do not include all relevant processes (e.g. coupled models)
- Although there are quite many RCM scenarios they don't sample the full range of GCM scenarios (that in turn does not sample the full range of uncertainty)

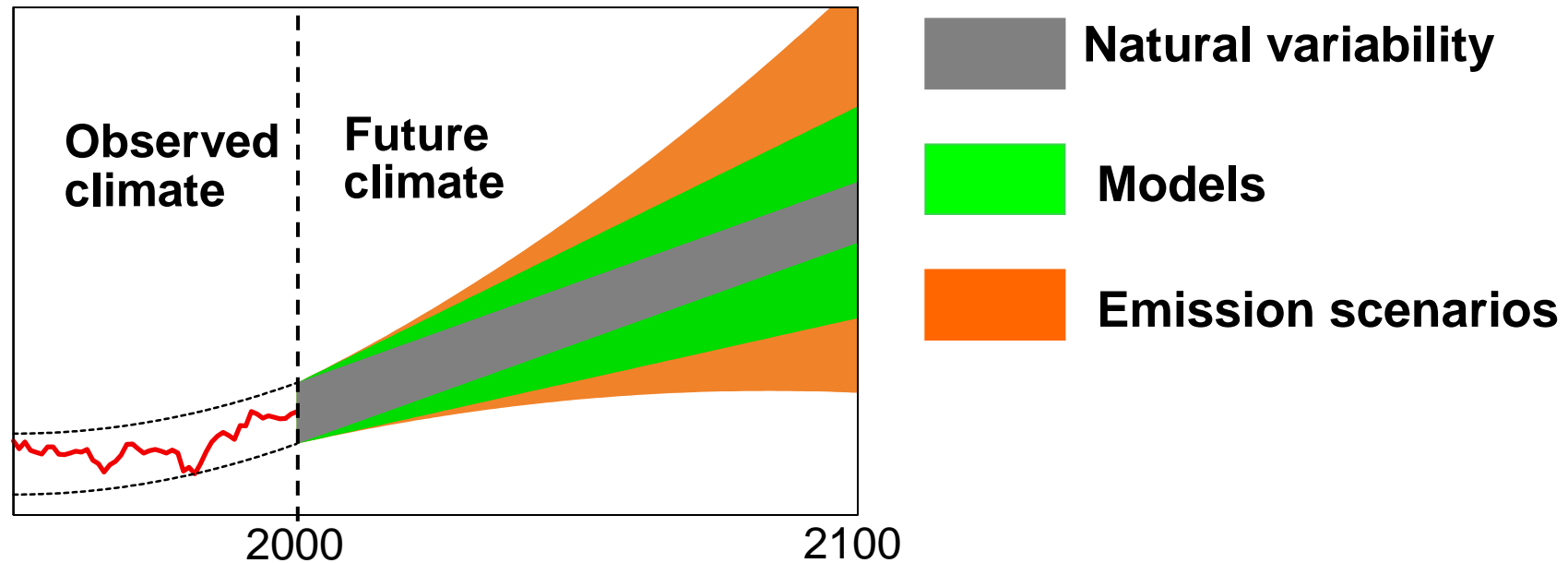


# Horizontal resolution 50km

SMHI



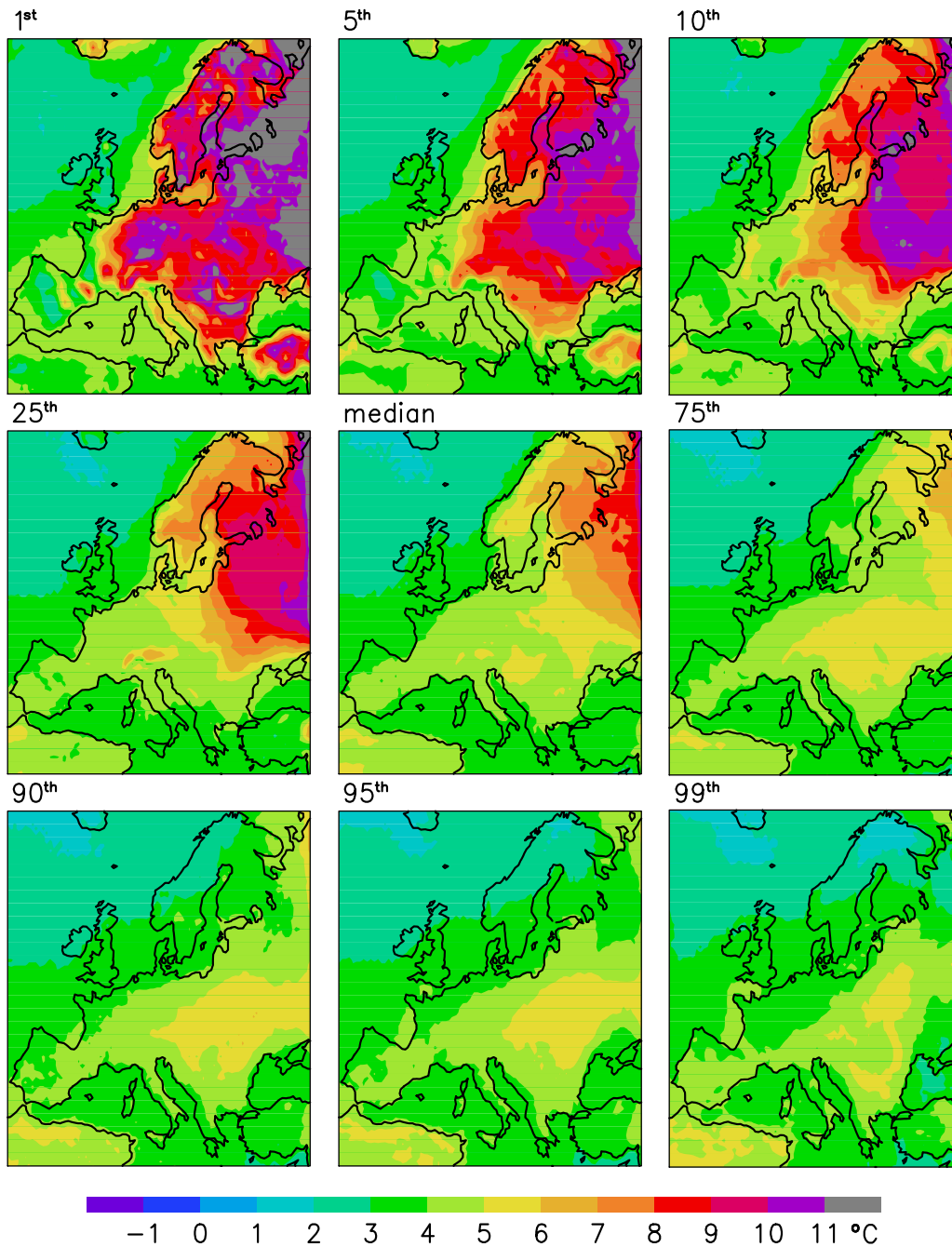
# Schematic view of the uncertainties in climate change as a function of time



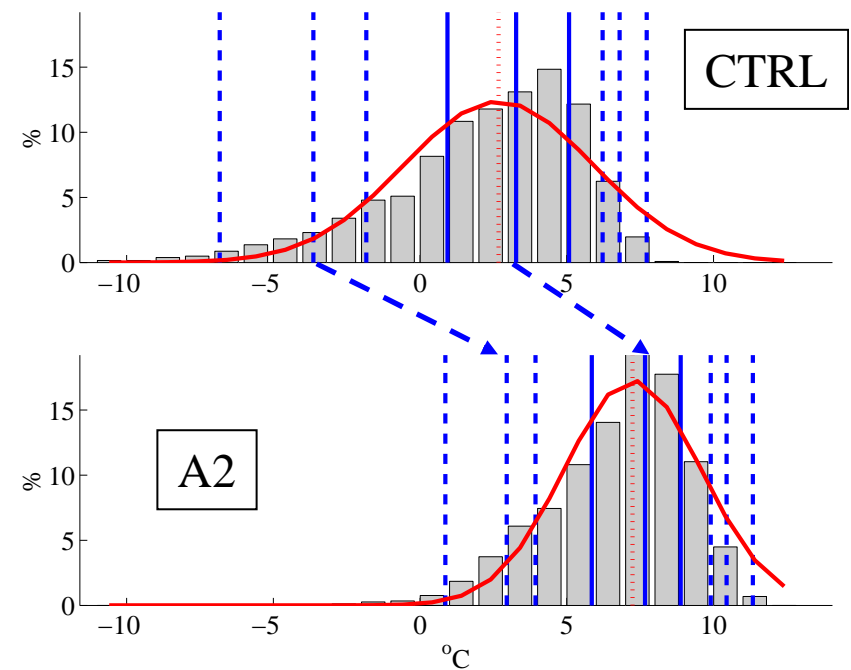
MAGNITUDE OF UNCERTAINTIES	Near future	End of the century
Natural variability	+	+
Models	(+)	++
Emission scenarios		++

## Change in winter (DJF) temperatures

Daily average  $T_{2m}$  in Lund



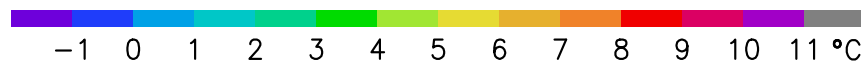
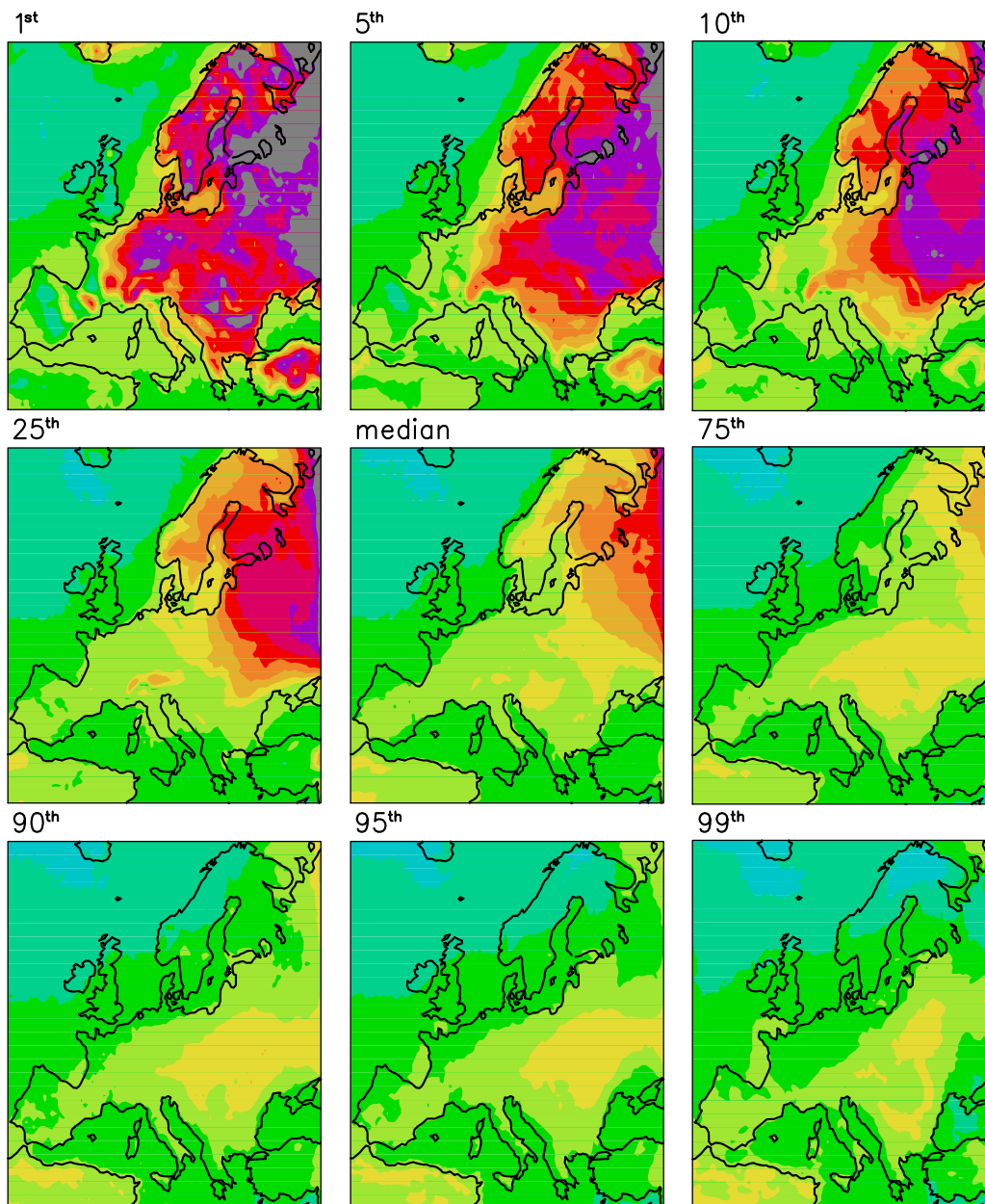
**RCAO-E A2-CONTROL**



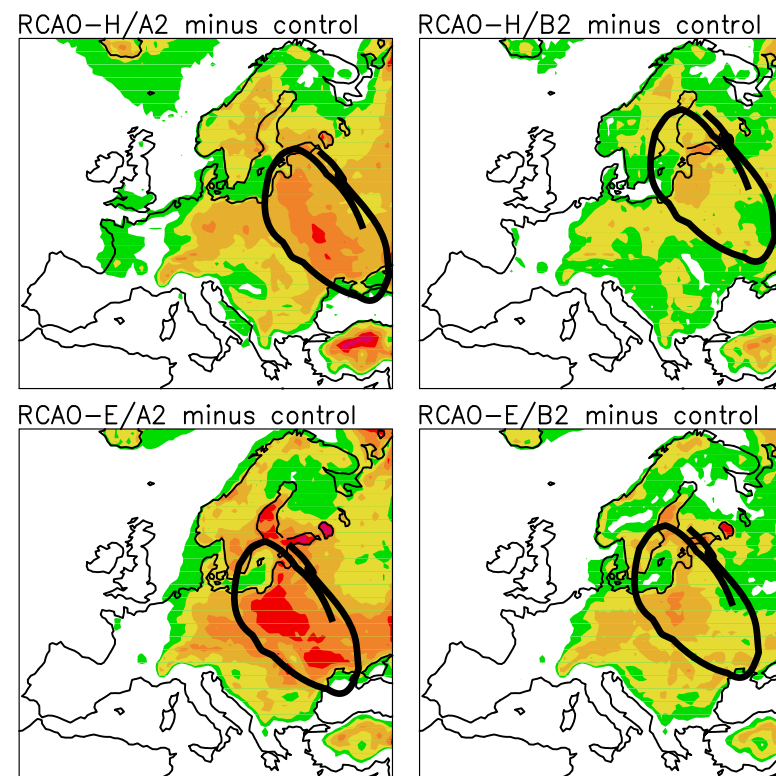


## Change in winter (DJF) temperatures

$$\Delta p5 - \Delta p50$$



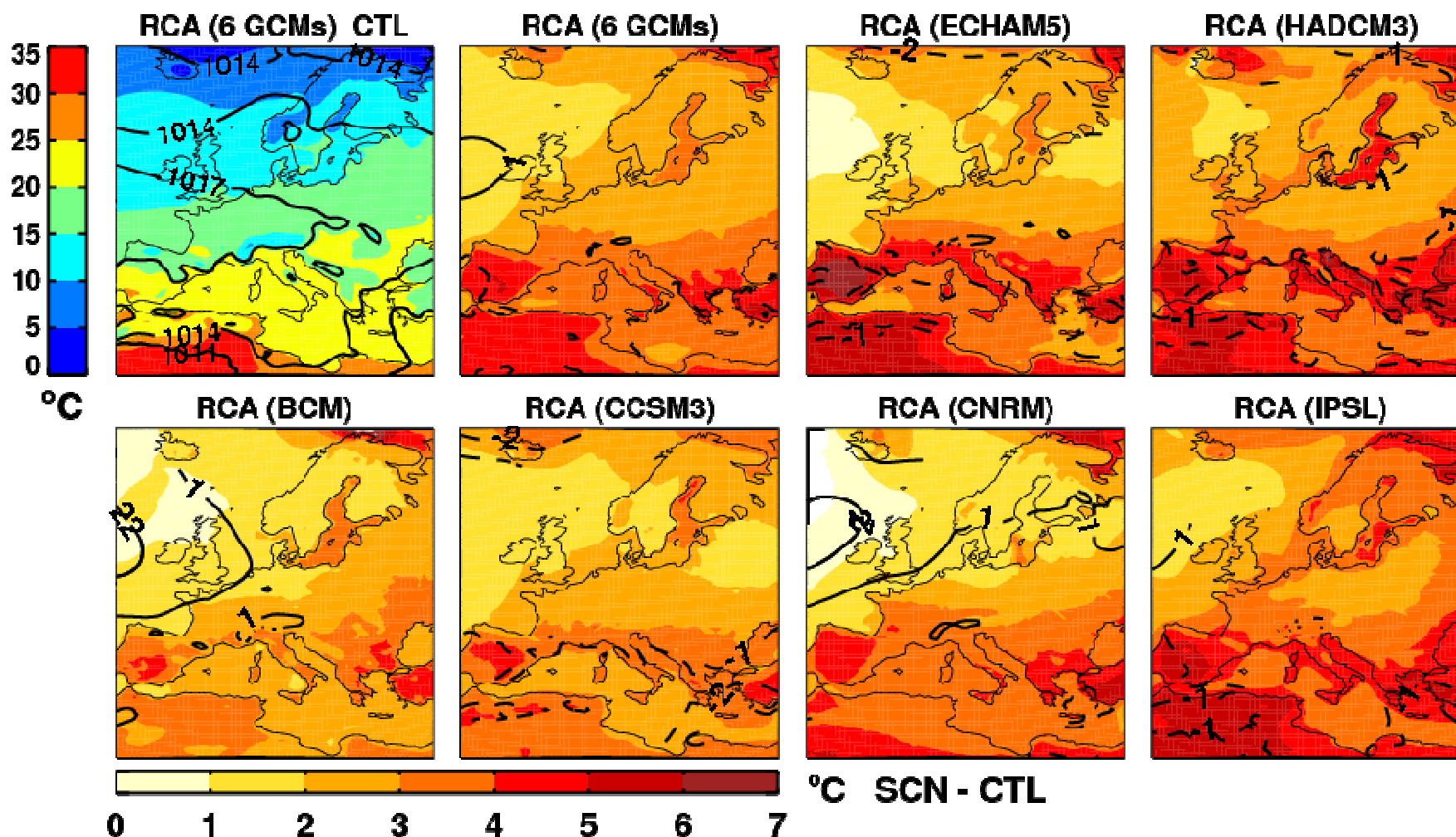
**RCAO-E A2-CONTROL**



# Changes in summer temperatures

SMHI

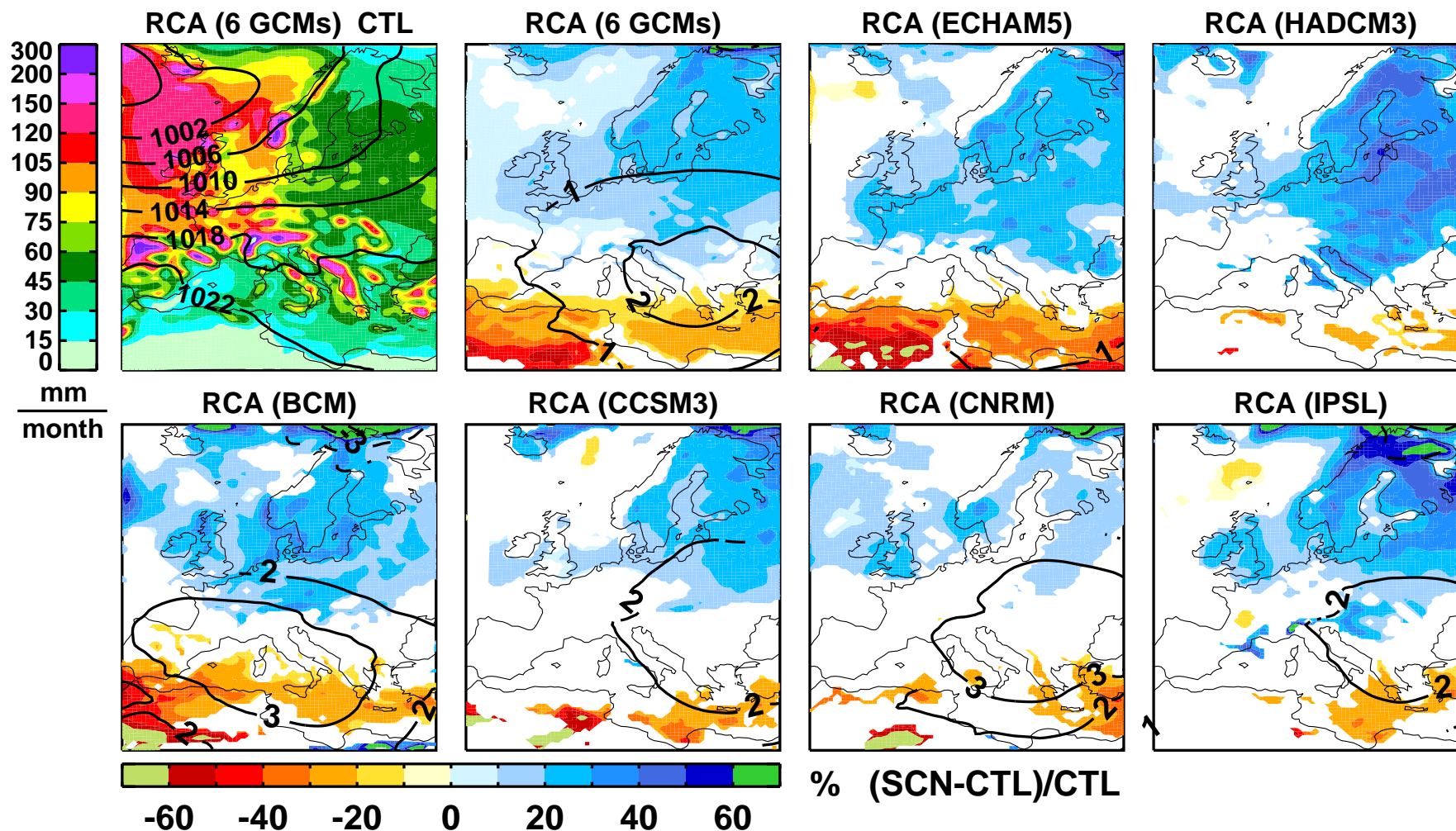
2m temperature Summer (JJA) SCN: 2071-2100 CTL: 1961-1990 (SLP: 1 hPa)



# Changes in winter precipitation

SMHI

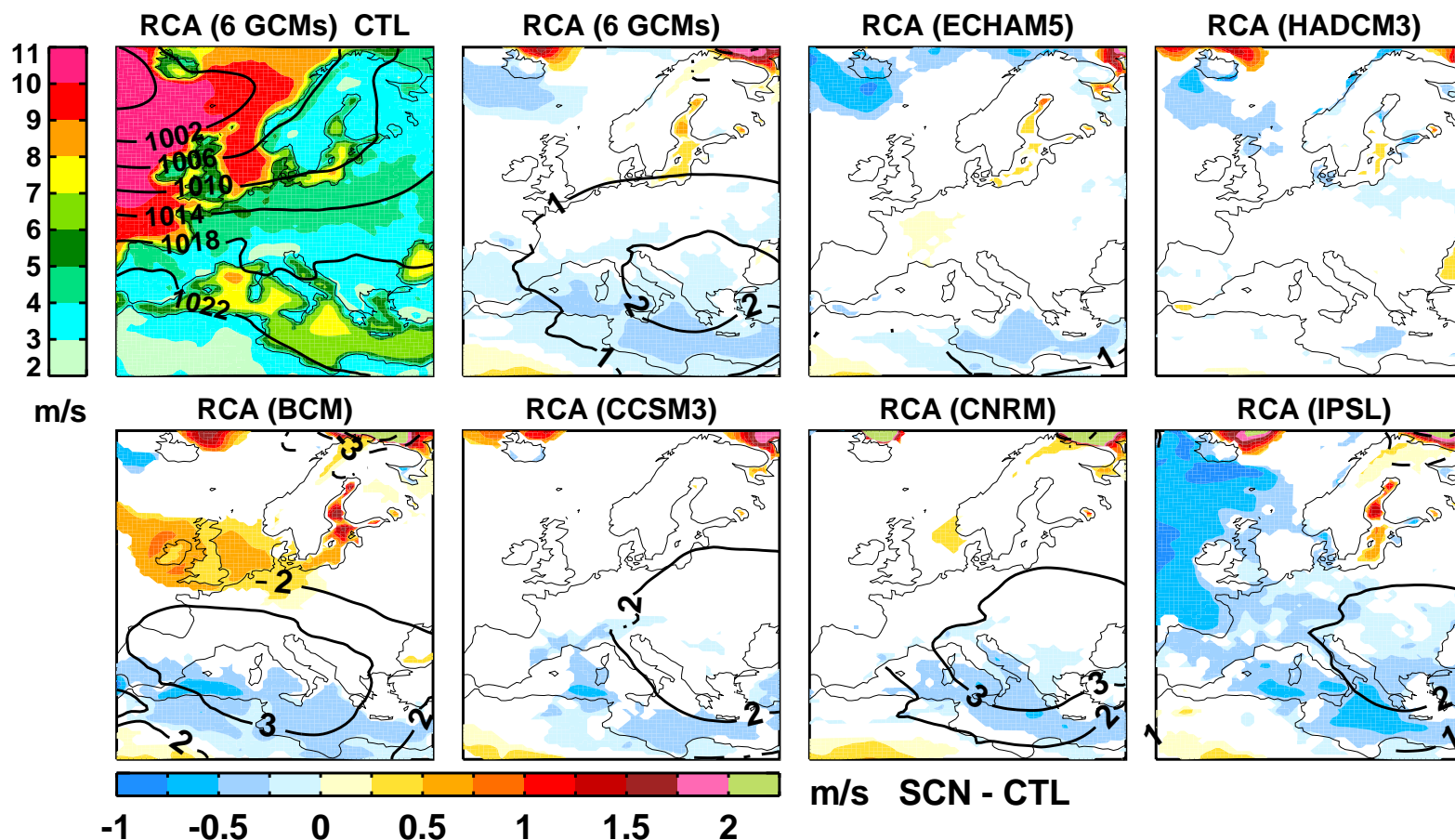
Precipitation Winter (DJF) SCN: 2071-2100 CTL: 1961-1990 (SLP: 1 hPa)



# Change in winter (DJF) wind speed

SMHI

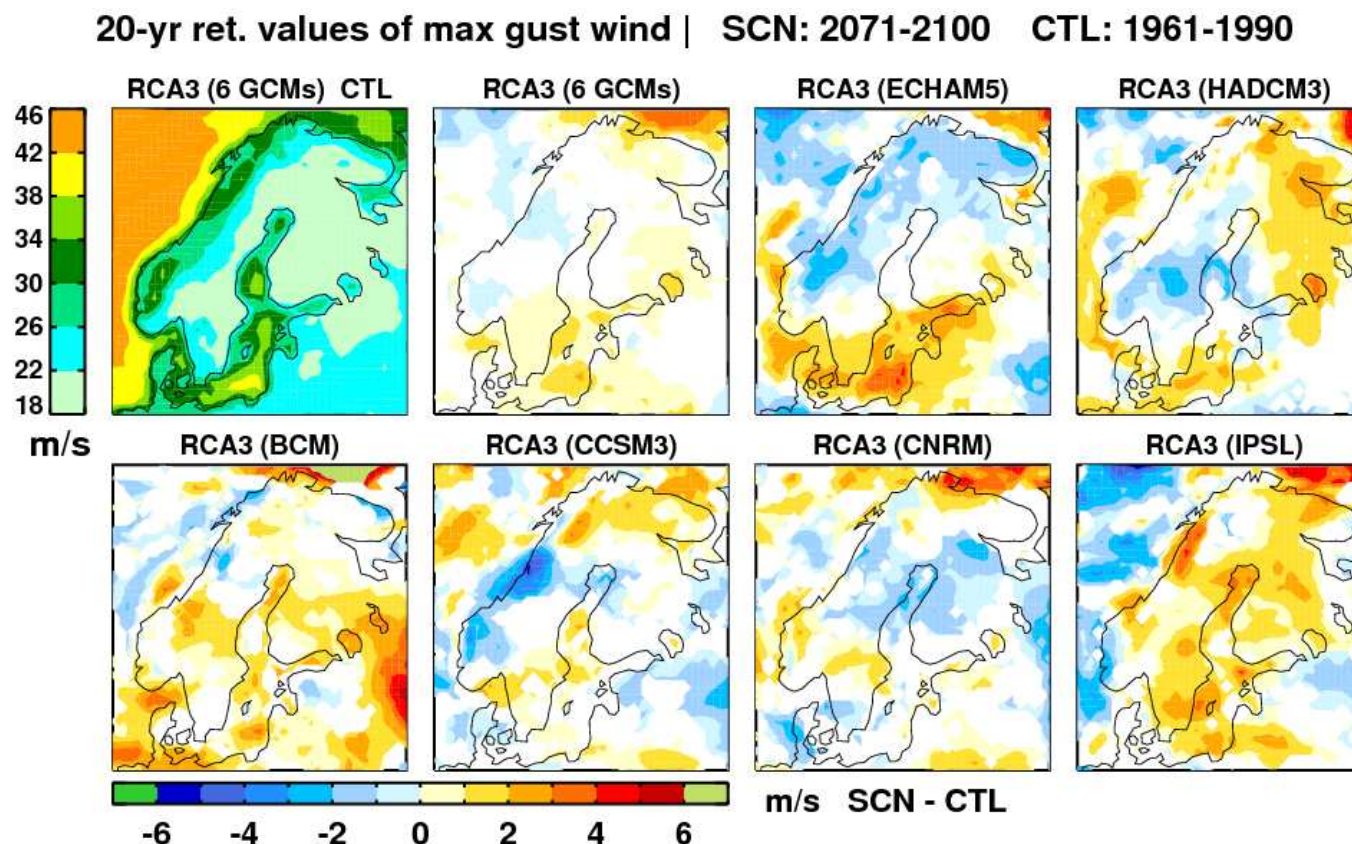
Wind Winter (DJF) SCN: 2071-2100 CTL: 1961-1990 (SLP: 1 hPa)





# Wind extremes

20-yr return periods in  $W_{max}$  CTL: 1961-1990 SCN: 2071-2100



- ✓ increasing over the Barents Sea (due to less sea ice)
- ✓ tendency for increasing wind extremes over the Baltic Sea
- ✓ ensemble mean is sensitive to the number of simulations