The climate system and global climate models

Lectures during the course on

"Impact of climate change on the marine environment with special focus on the role of changing extremes"

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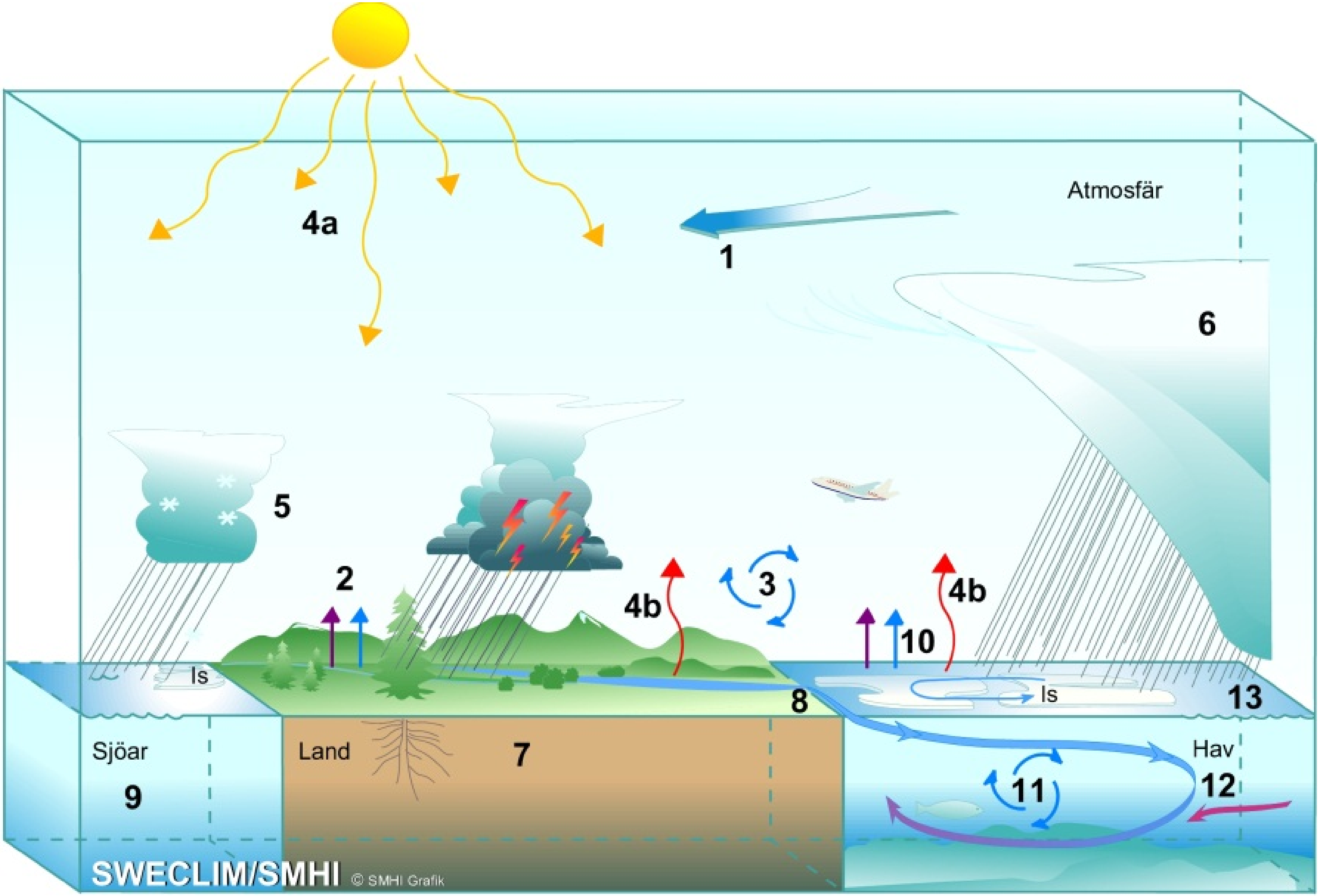
Erik Kjellström, SMHI

011-4958501

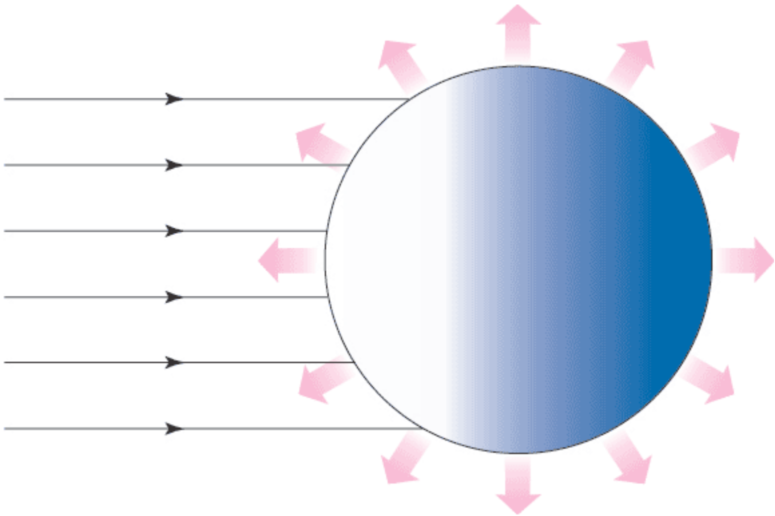
(erik.kjellstrom@smhi.se)

The climate system



A very simple climate model

- Assume balance between outgoing and incoming radiation on long term basis



$$F_E = \sigma T_E^4 = \frac{(1-A)F_{SE}}{4} = 239.4 \text{ W m}^{-2}$$

Solar constant (F_{SE}) 1368 W m^{-2}

planetary albedo (A) 30%

$$T_E = \sqrt[4]{\frac{F}{\sigma}} = 255 \text{ K}$$

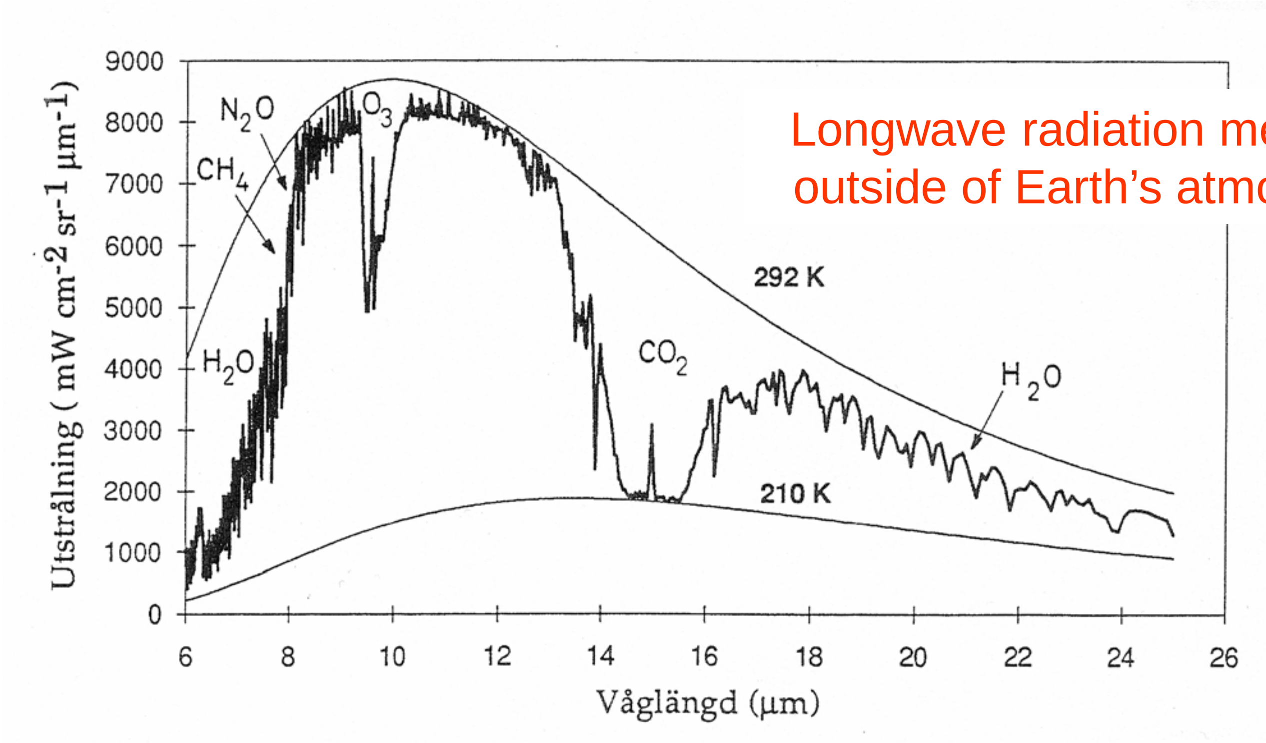
Reflection

- Incoming radiation may be reflected by clouds, particles or by the ground
- The albedo (A) is the ratio between reflected and incoming radiation
- Cloud albedo varies (50-90%)
- Global average ca 30% (including clouds)

Properties of the ground	**Albedo (%)**
Snow	75-95
Old snow	50-70
Ice	30-40
Sand	20-30
Grass	15-20
Forest	5-20
Water	3-10
Water (Sun close to horizon)	10-100

Longwave radiation

- Emitted radiation at the Earth's surface 4-100μm (maximum at around 10μm)
- Absorption in the atmosphere in wavelength bands



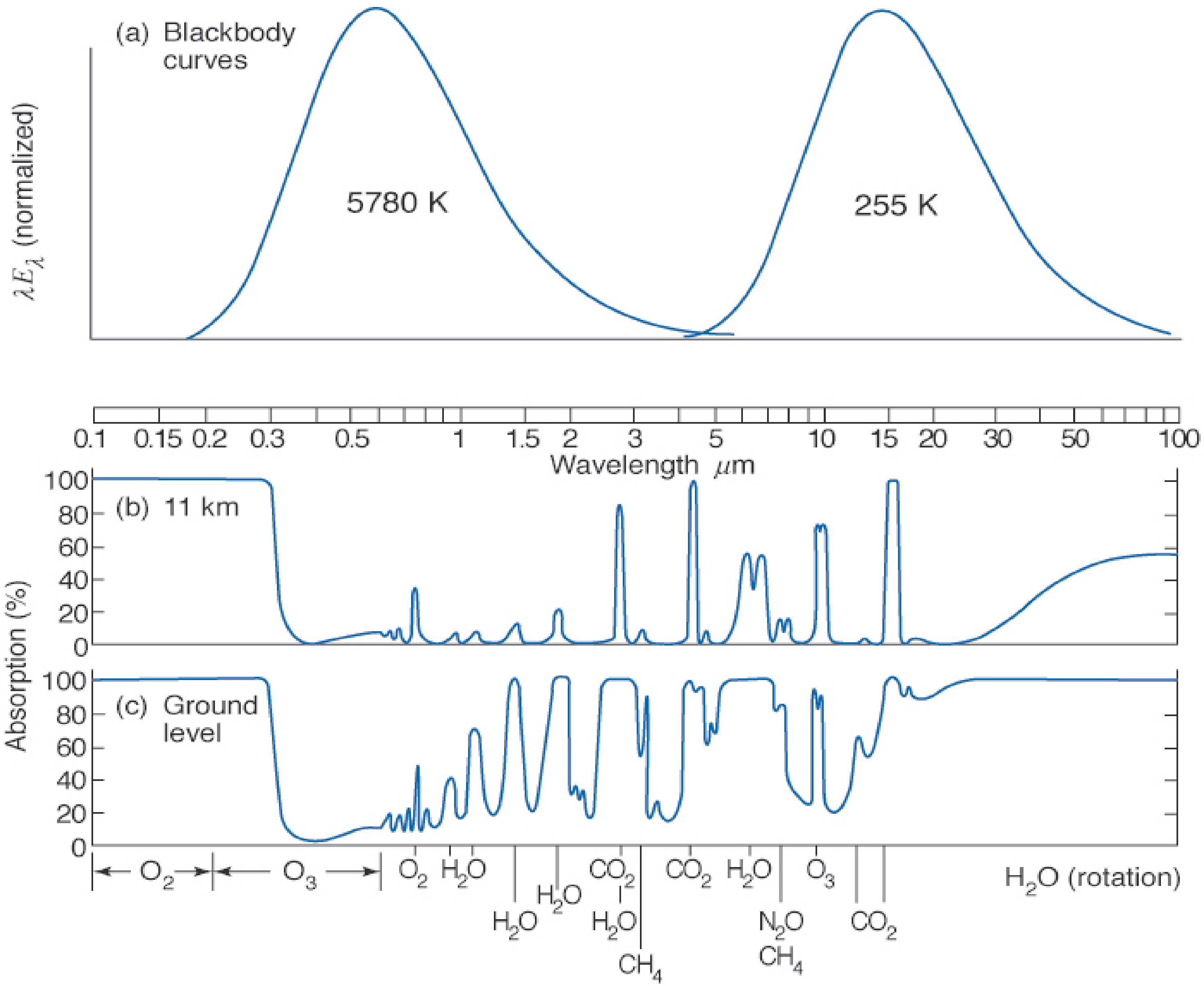
Gaseous constituents

Constituent	Mol. Wt.	Conc. by vol.
Nitrogen (N_2)	28.013	0.7808
Oxygen (O_2)	32.000	0.2095
Argon (Ar)	39.95	0.0093
Carbon dioxide (CO_2)	*44.01*	*387 ppmv (2009)*
Neon (Ne)	20.18	18
Helium (He)	4.00	5
Methane (CH_4)	*16.*	*1.78 "*
Hydrogen (H_2)	2.02	0.5 "
Nitrous oxide (N_2O)	*56.03*	*0.3 "*
Ozone (O_3)	*48.00*	*0-0.1 “*

In addition

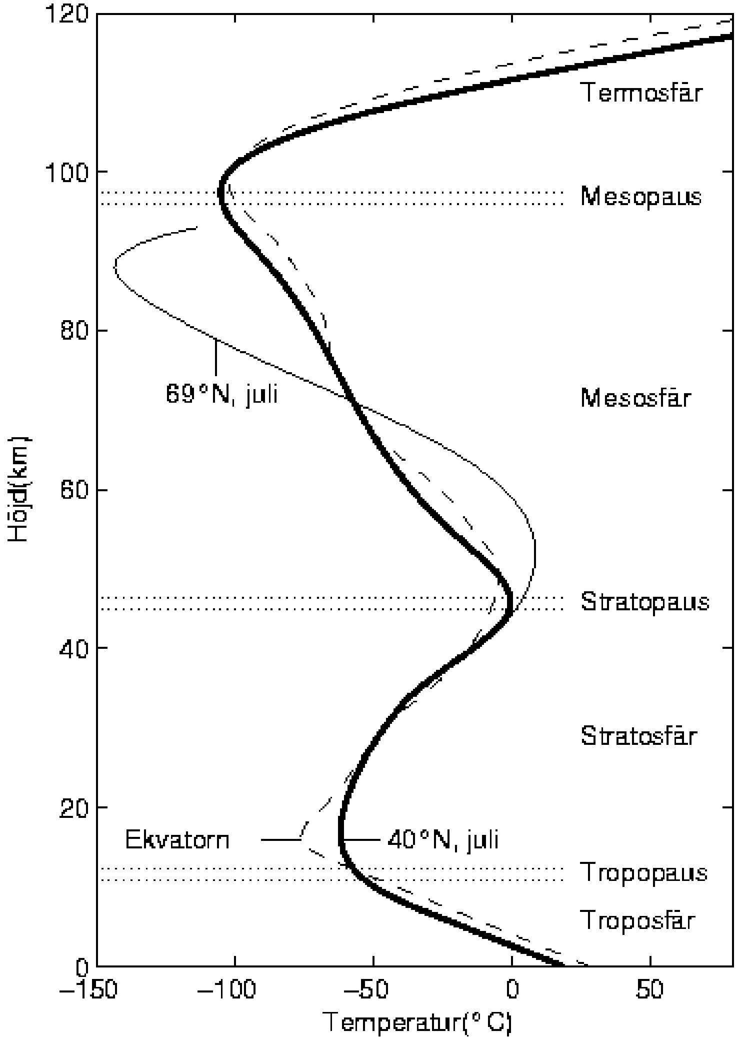
Water vapor (H_2O)	*18.02*	*variable*

Atmospheric absorption



Vertical distribution of temperature

- Troposphere, Stratosphere, Mesosphere and Thermosphere
- Tropopause, Stratopause, Mesopause
- Most water vapour and thereby related clouds and weather exists in the troposphere
- Ionosphere (upper part of the mesosphere and the thermosphere)

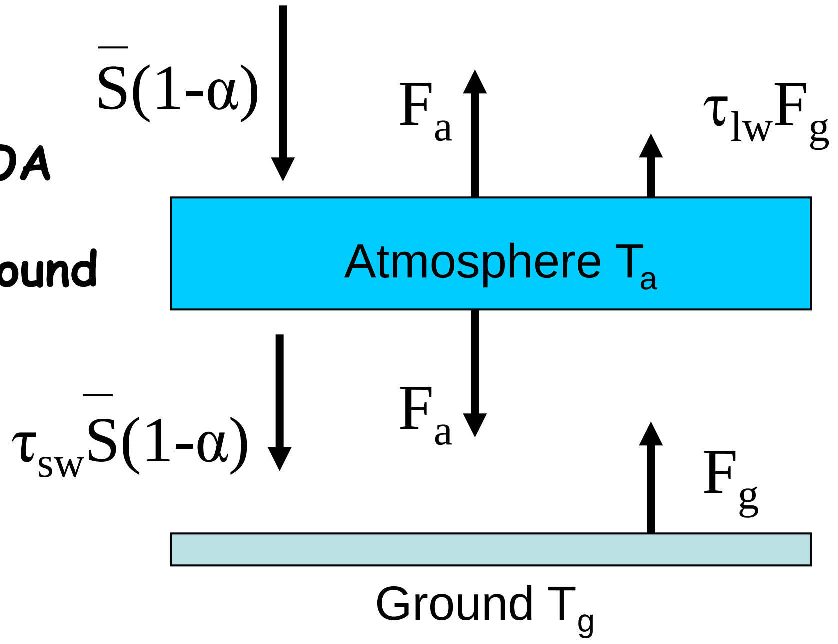


The greenhouse effect

- Most incoming solar radiation (shortwave) passes through the atmosphere
- Outgoing terrestrial radiation (longwave) is absorbed and reemitted in the atmosphere
- Reemission takes place at higher levels where temperatures are lower
- This implies that less energy escapes to space than what would be the case without an atmosphere
- The net effect is a warming of the surface

A simple model including the greenhouse effect

$$\begin{cases} \bar{S}(1-\alpha) = F_a + \tau_{lw} F_g & \textbf{At the TOA} \\ F_g = F_a + \tau_{sw} \bar{S}(1-\alpha) & \textbf{At the ground} \end{cases}$$



eliminate F_a

$$F_g = \sigma T_g^4 = \bar{S}(1-\alpha)\frac{1+\tau_{sw}}{1+\tau_{lw}}$$

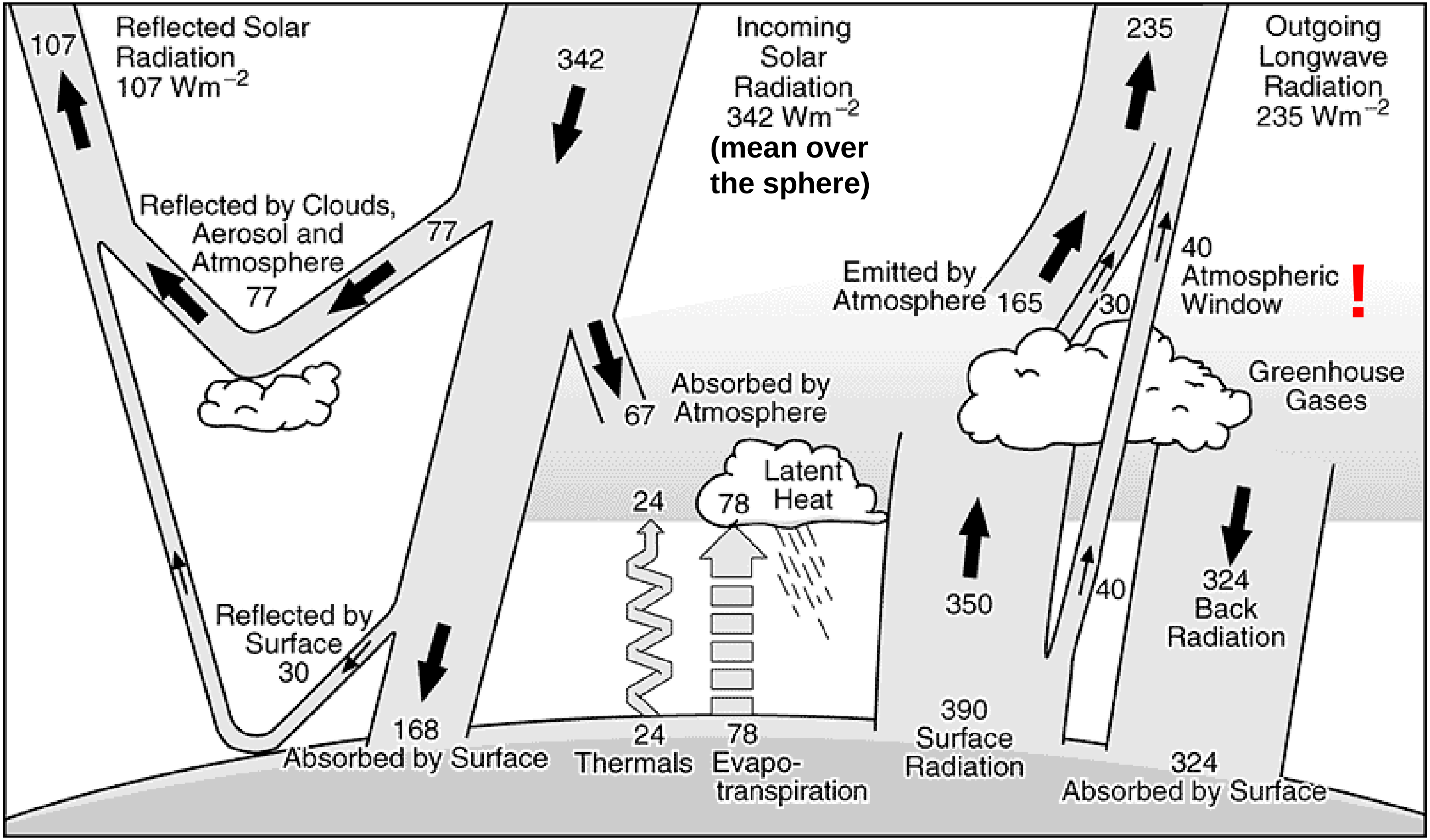
$$\bar{S} = 342\ \text{Wm}^{-2},\ \alpha = 0.31,\ \tau_{sw} = 0.71,\ \tau_{lw} = 0.10$$

$$\Rightarrow T_g \approx 284\text{K} = 11^\circ\text{C}$$

Global energy balance

Albedo=107/342=31%

342-107=235!!

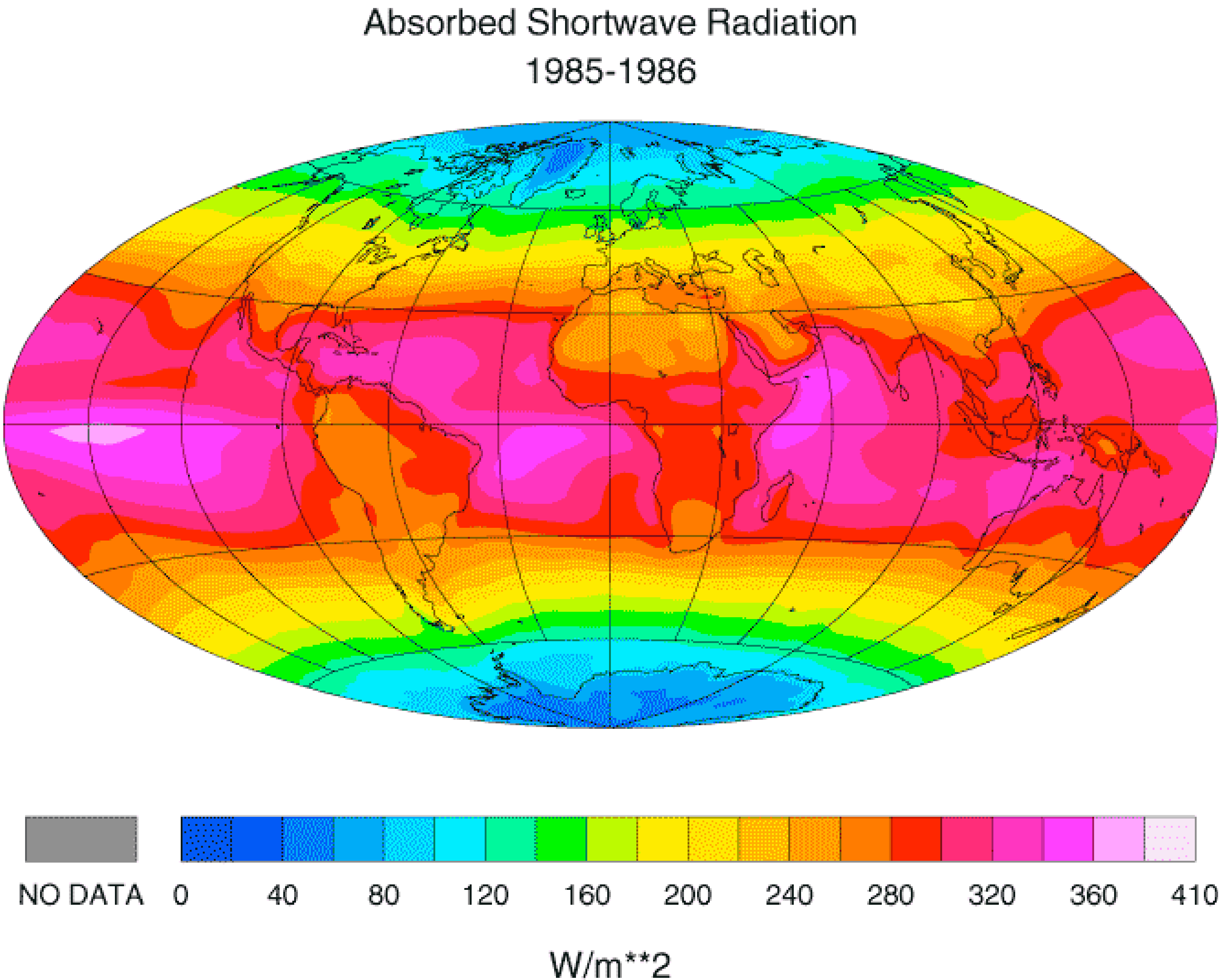


Absorberat i mark/hav=168/342=49%

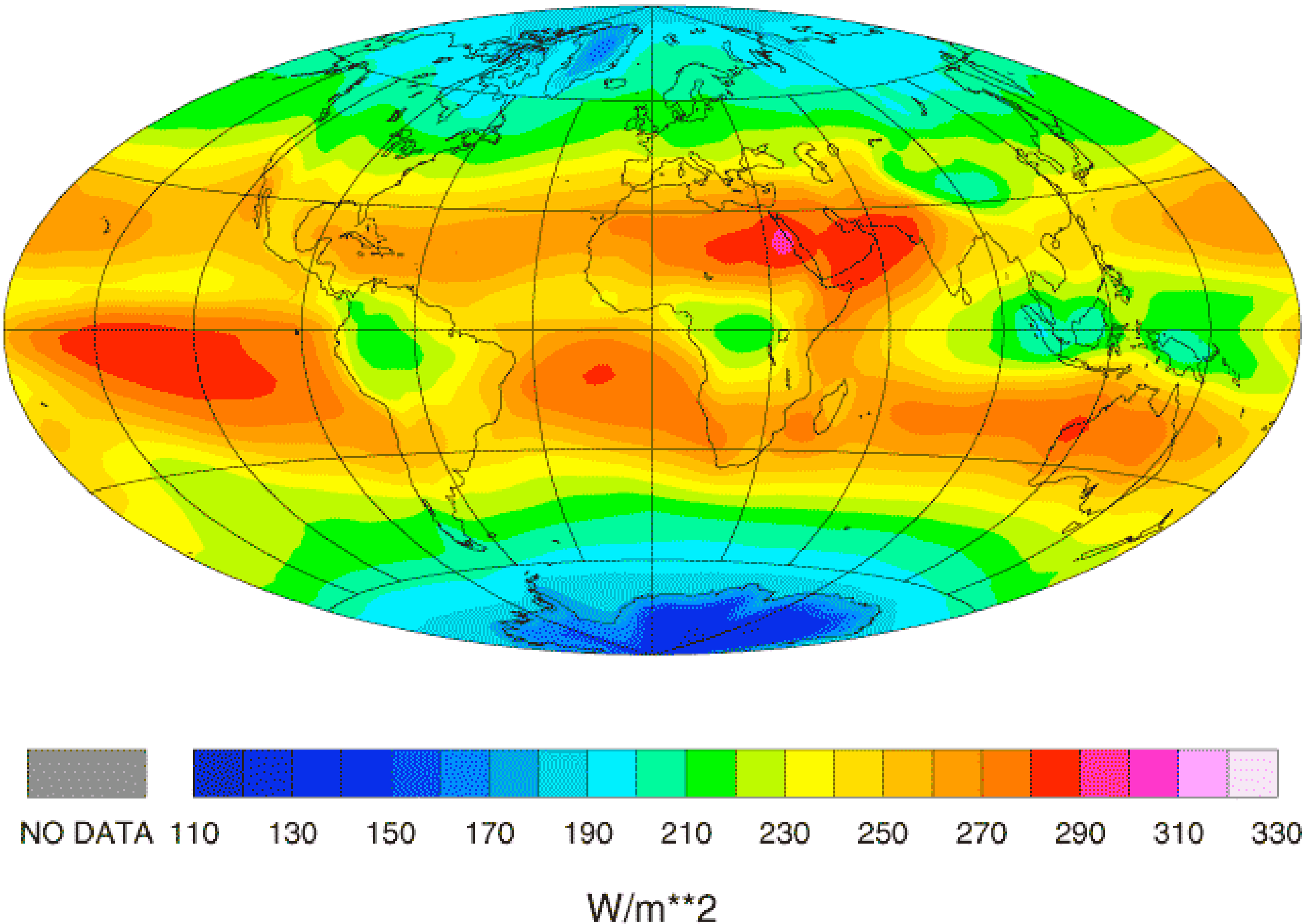
168-24-78-390+324=0!!

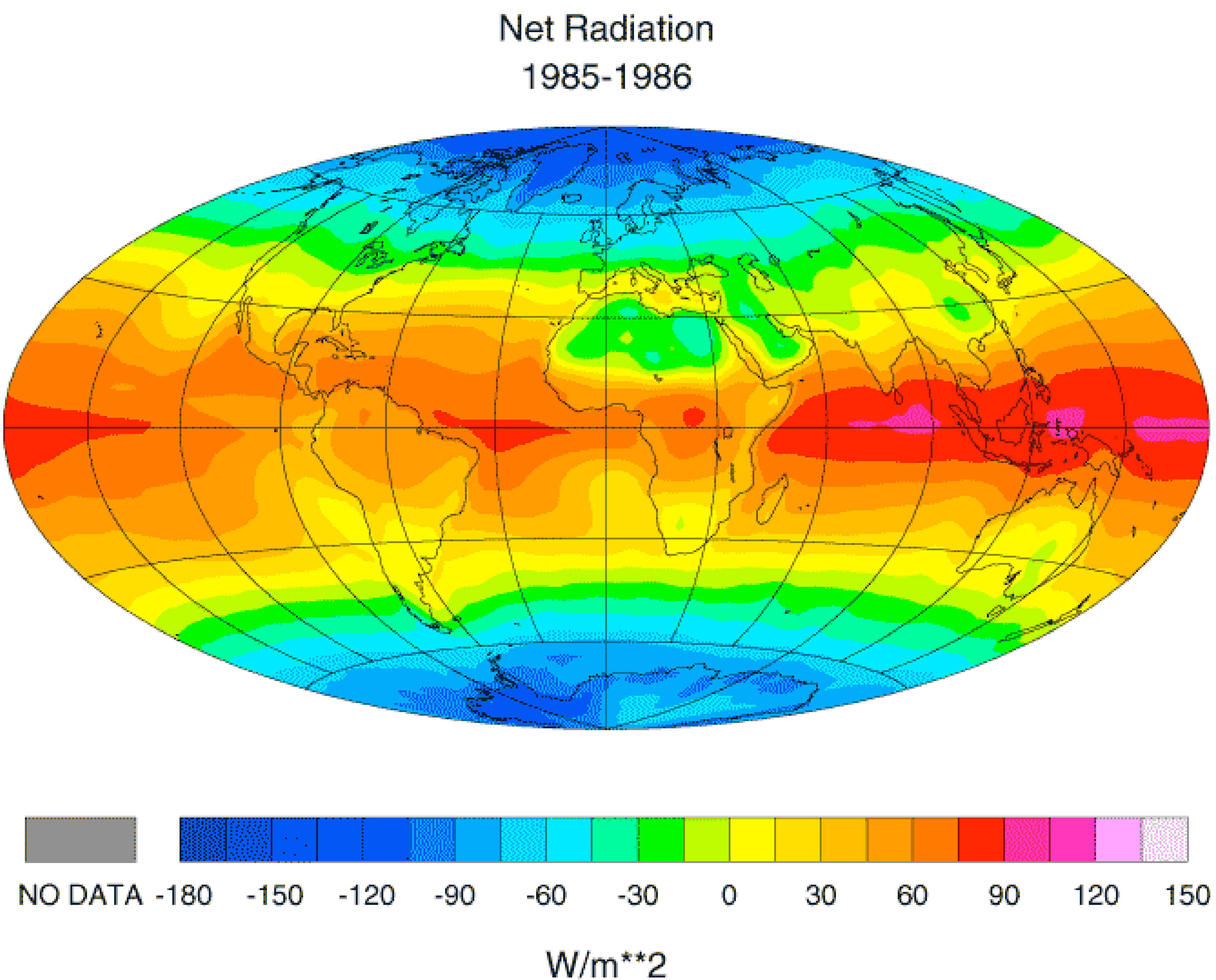
Atmosfärens transmisitivitet (sw)=168/(342-107)=0.71

Atmospheric transmisitivitet (lw)=40/390=0.10


Absorbed Shortwave Radiation
1985-1986
NO DATA
0
40
80
120
160
200
240
280
320
360
410
W/m**2

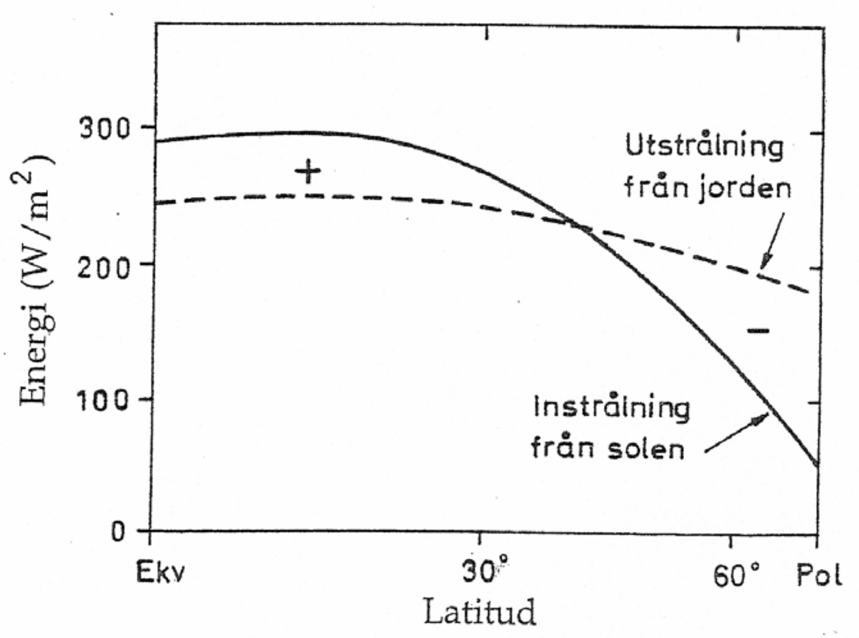
Outgoing Longwave Radiation
1985-1986




Net Radiation
1985-1986
NO DATA
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
W/m**2

Radiation balance of the Earth

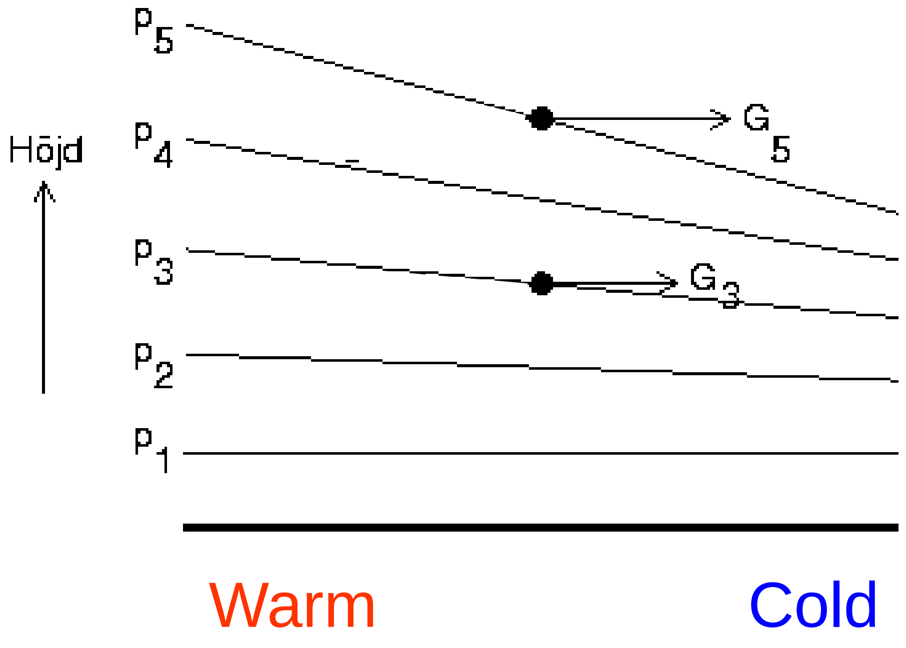
- Net energy gain (loss) at low (high) latitudes …



- … leads to heat transport in the atmosphere and oceans

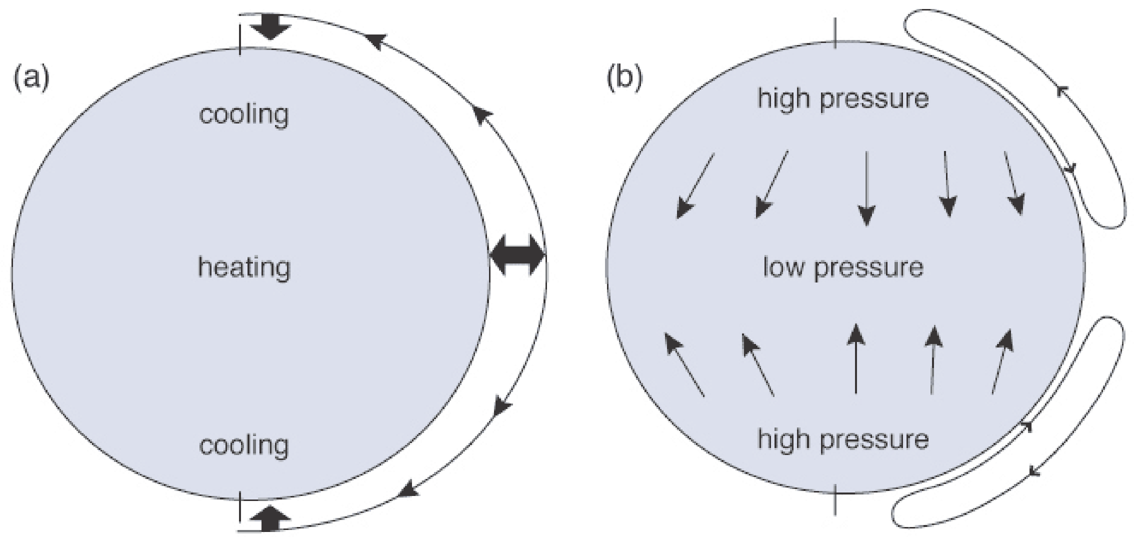
Differential heating leads to motion

Different temperature in different air masses lead to different decrease of pressure with increasing altitude (less decline with altitude in warm air). Leads to sloping pressure surfaces at height which implies increasing pressure gradient



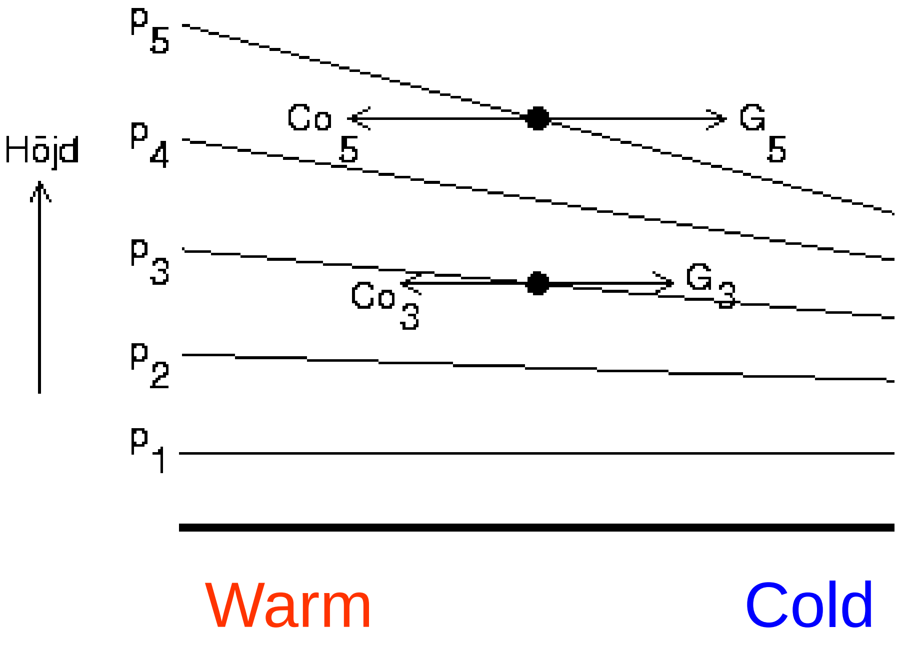
Differential heating leads to motion

No rotation



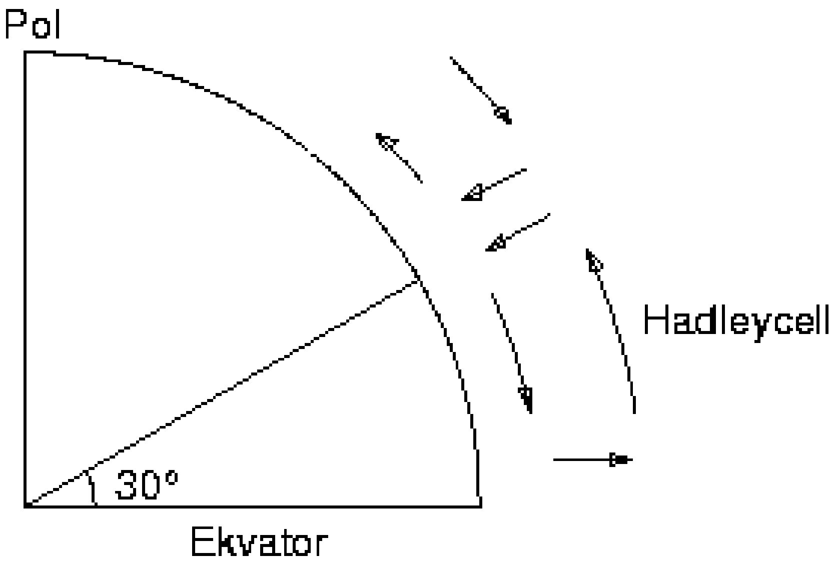
Earth's rotation deflects air motion (the Coriolis effect)

Deflection to the right of the motion in the northern hemisphere (to the left in the southern). Air moving from the equator towards the poles is deflected by the Coriolis force leading to westerly winds.



The Hadley Circulation

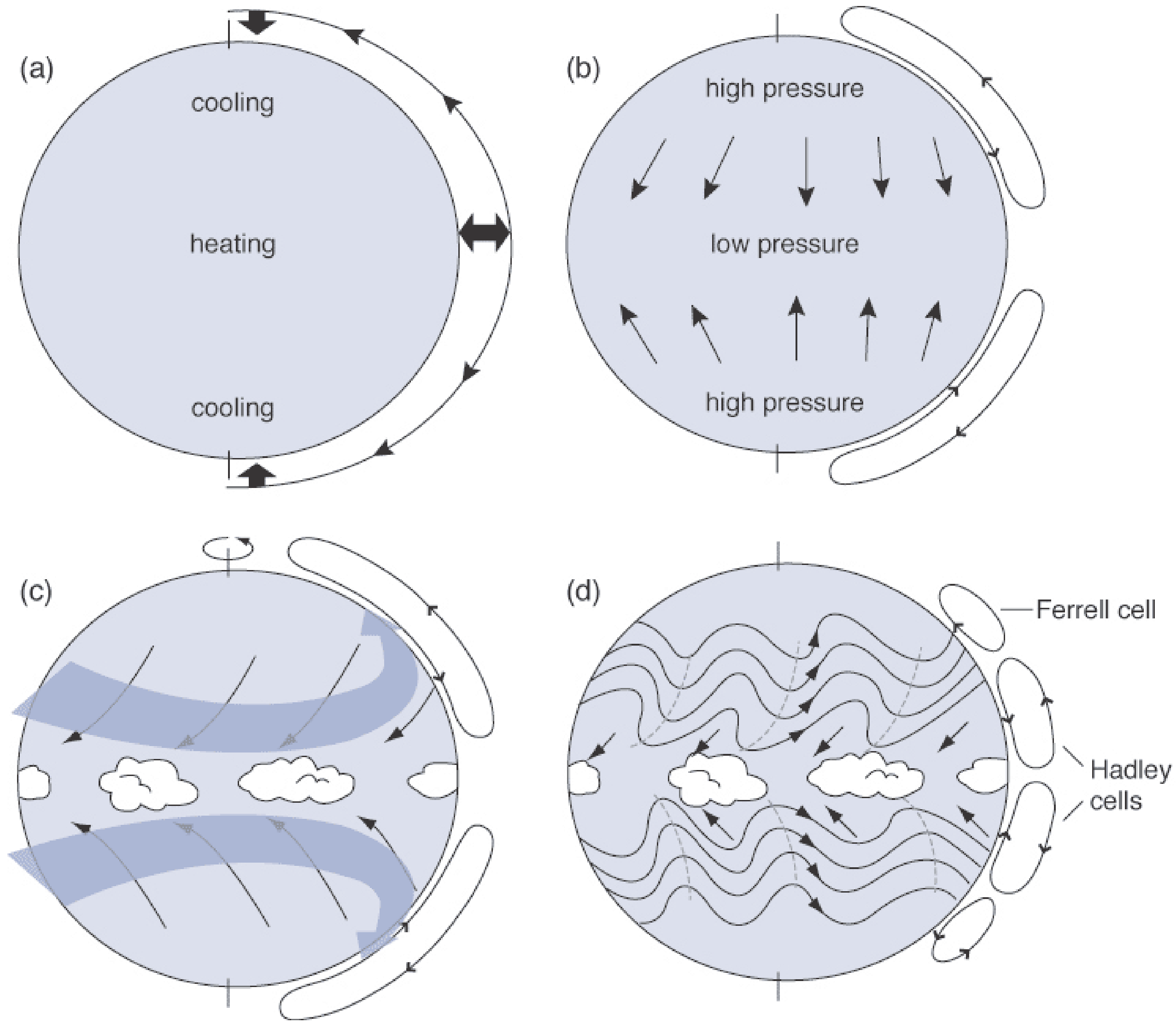
- Heating and cooling generates horizontal pressure gradients
- Winds from warm areas towards colder areas at high altitudes
- Rising air in the tropics
- Sinking air in the subtropics
- Winds towards the equator at low levels (Trade winds)
- Coriolis force is relatively small leads to a closed N-S circulation



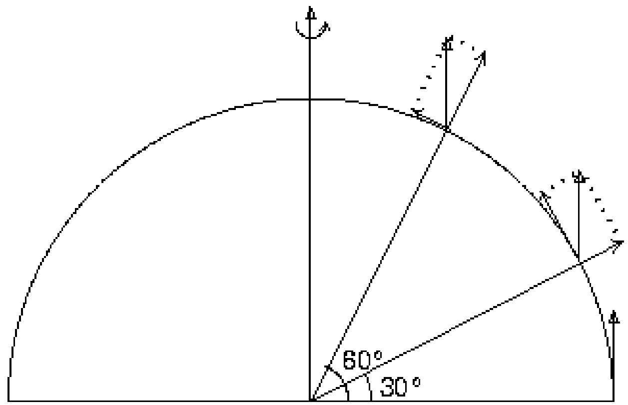
The Hadley Cell and circulation characteristics in Mid Latitudes

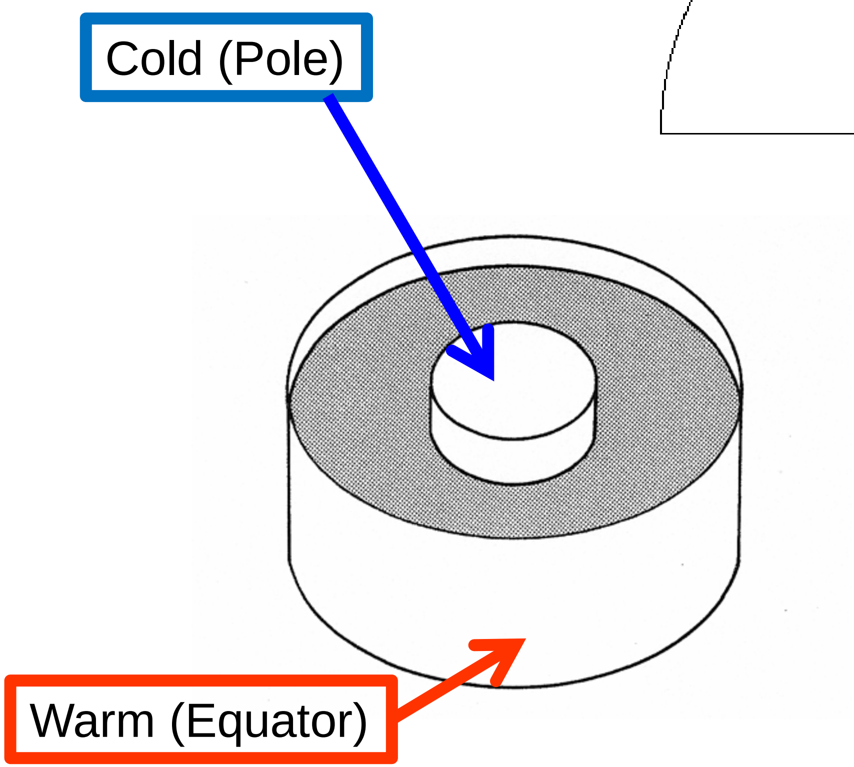
No rotation

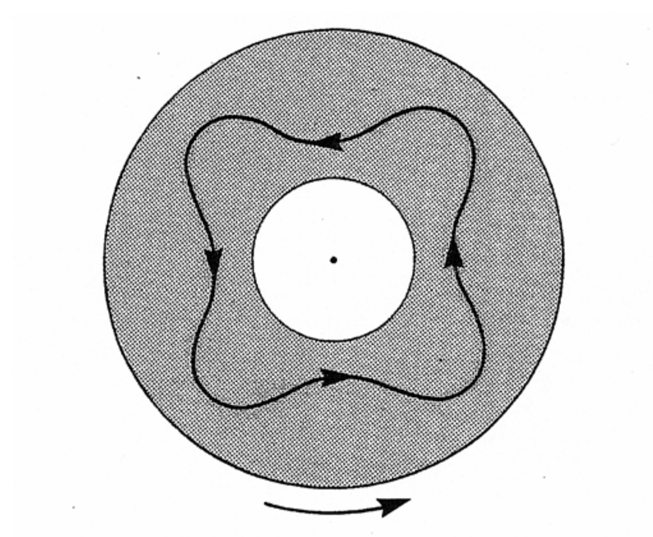
Rotating Earth



The Mid-latitudes



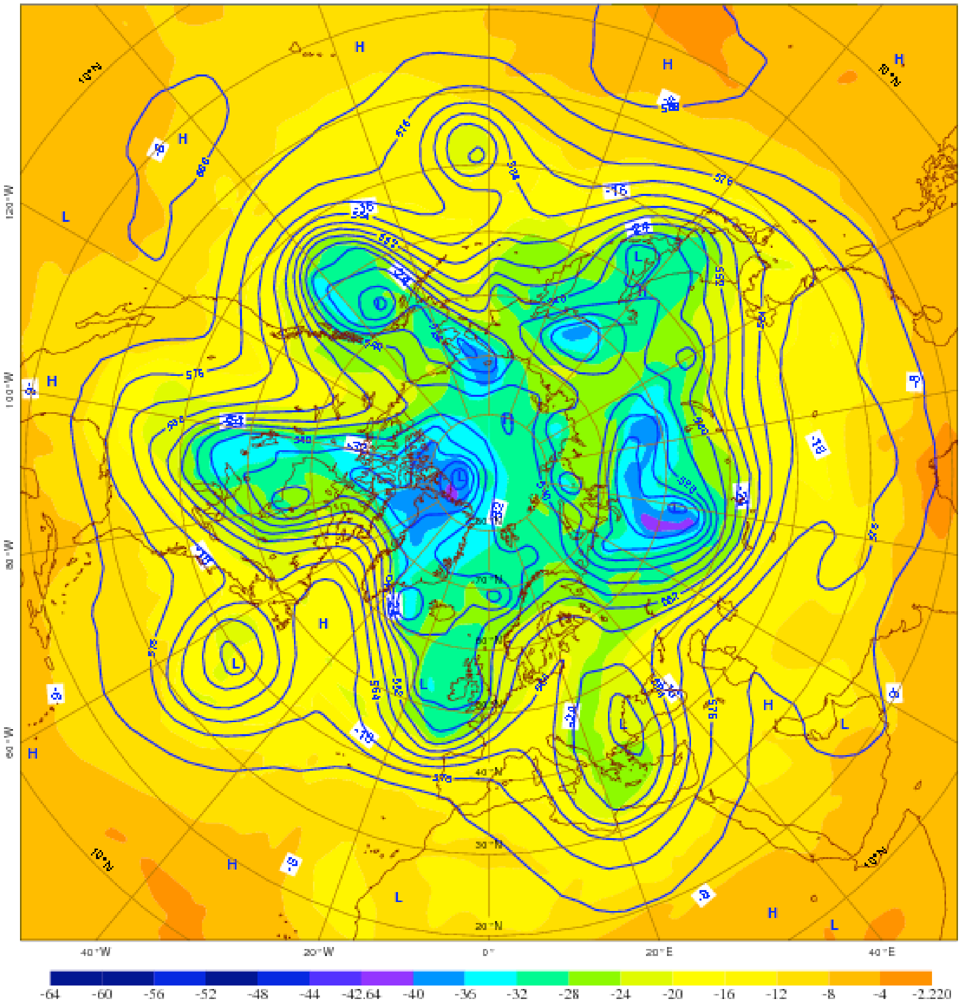




The Mid-latitudes

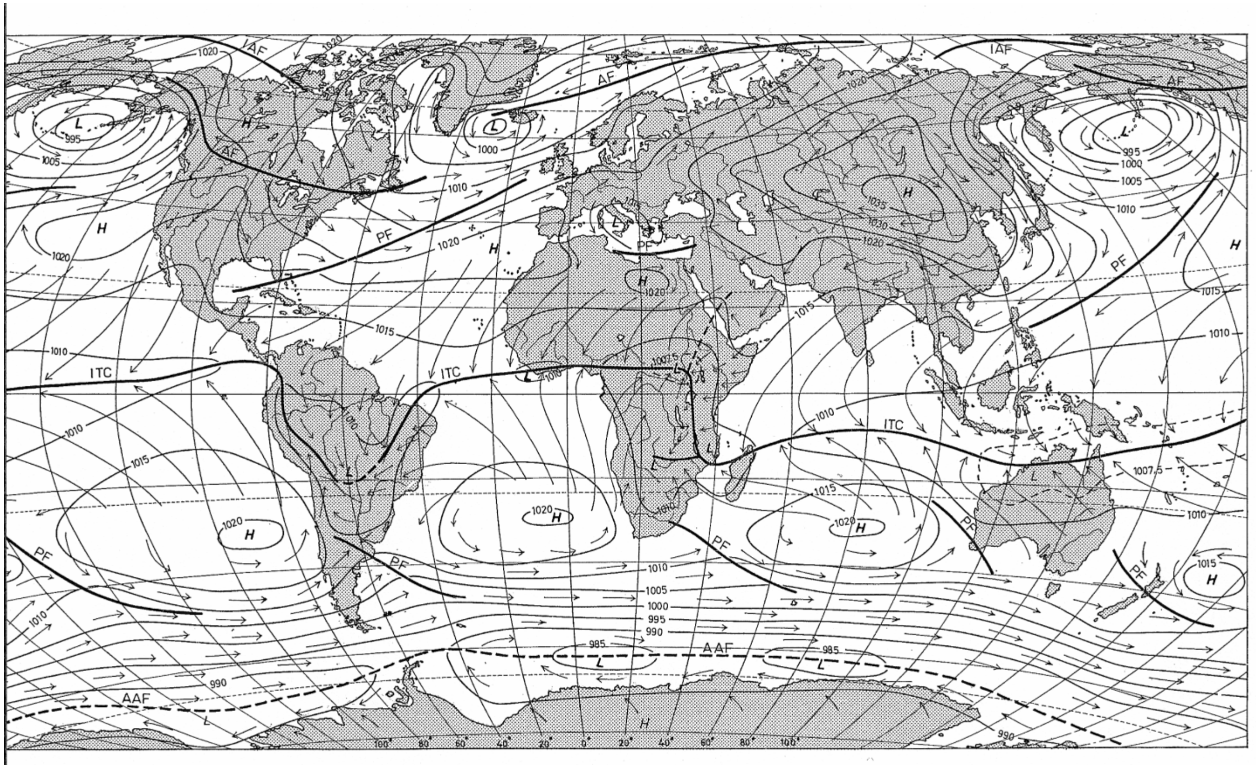
- Rossby waves
- 3-5 long waves
- Super-imposed shorter waves
- Pattern depend strongly on land-sea contrasts and orography

ECMWF Analysis VT:Monday 28 April 2008 00UTC 500hPa Temperature/ Geopotential

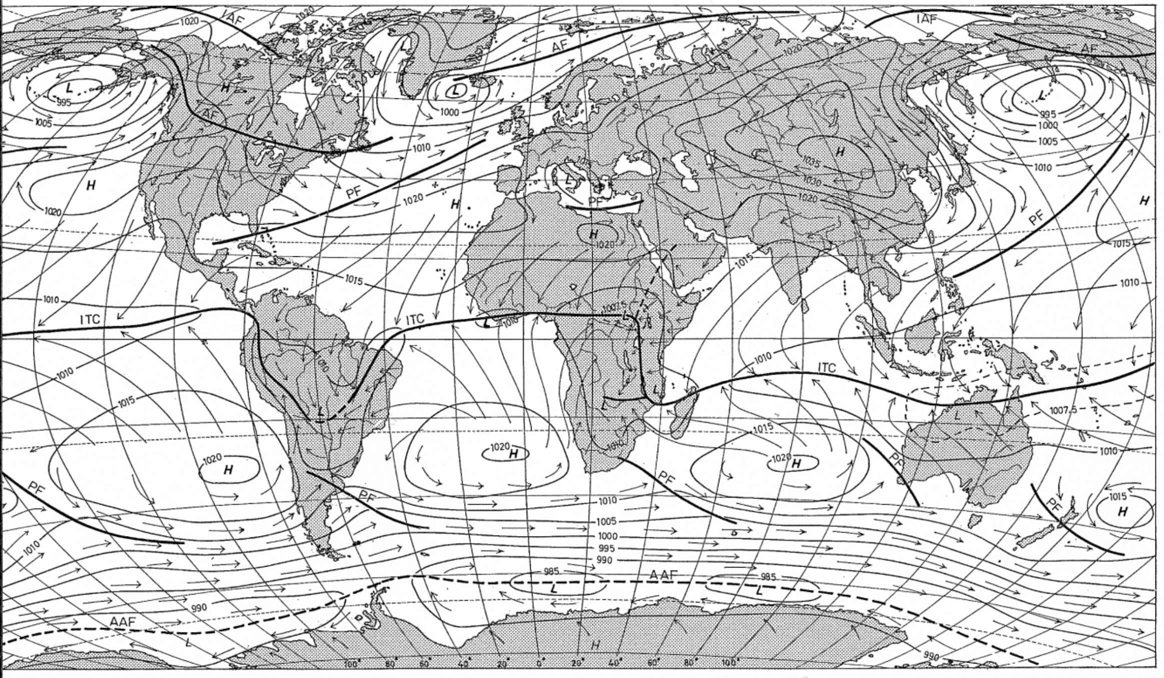


Climatological features

- Tradewind belts (Atlantic, Pacific)
- Intertropical convergence zone
- Monsoons (Indian Ocean sector)
- Westerly wind belts (strongest in winter)
- Subtropical anticyclones (summer)

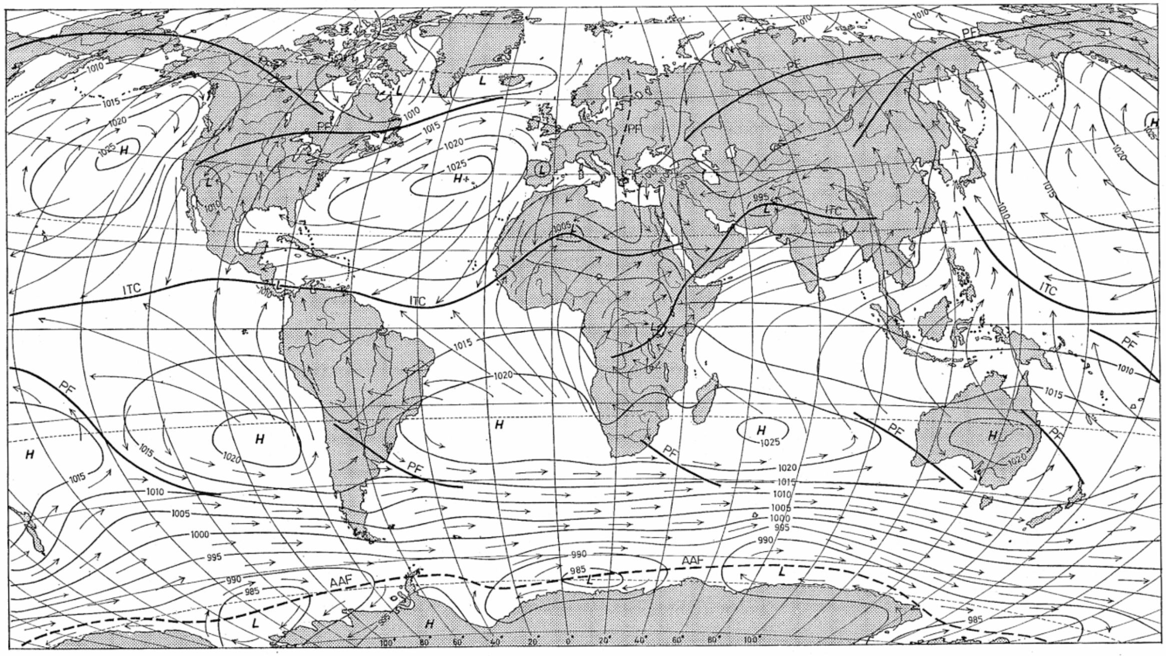


January



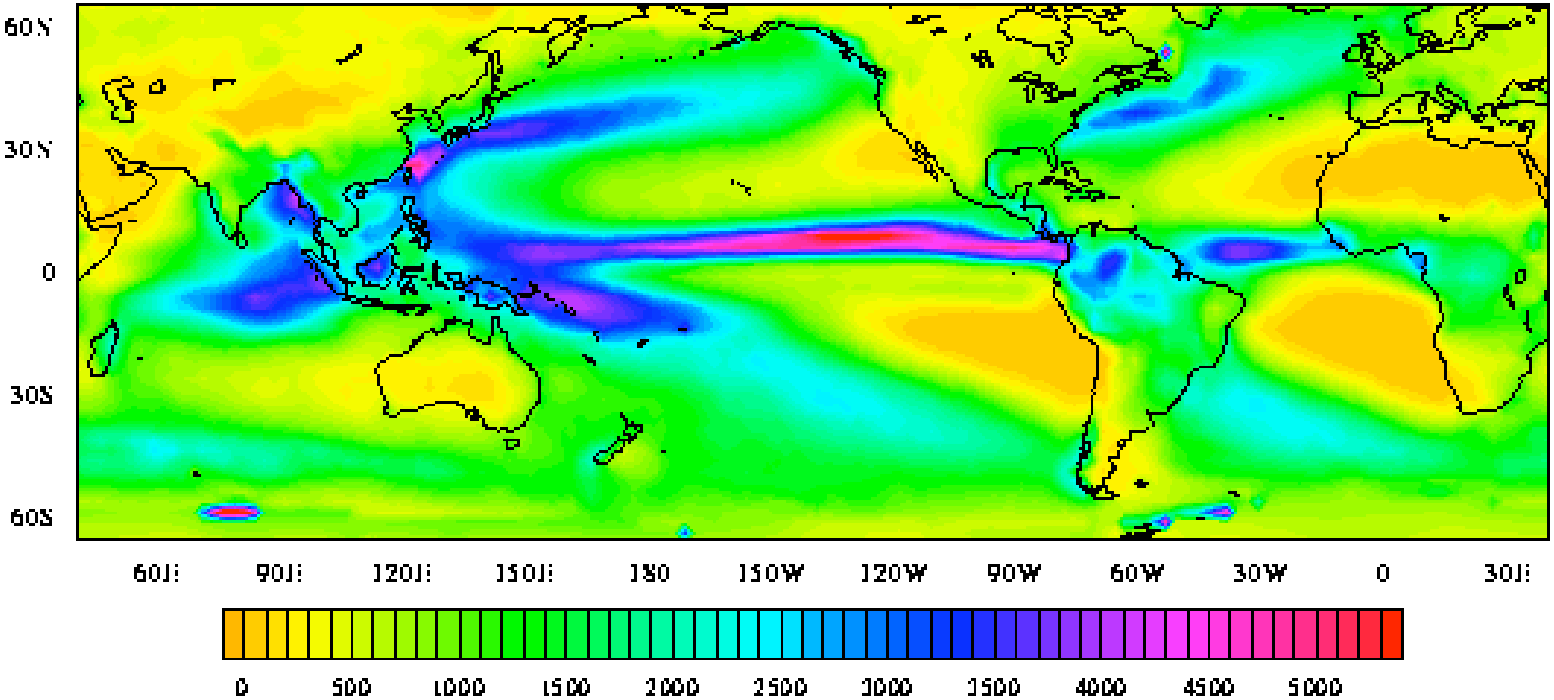
January

July



Icelandic Low and Azores High both lead to transport of maritime air towards northern Europe

Global rainfall

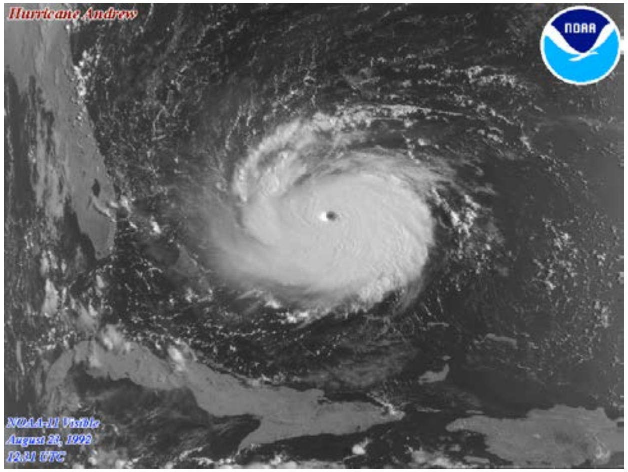


- Maxima along the ITCZ and in the Mid-latitude westerlies
- Minima in the subtropics

Weather systems

- Baroclinic waves….
  extratropical cyclones

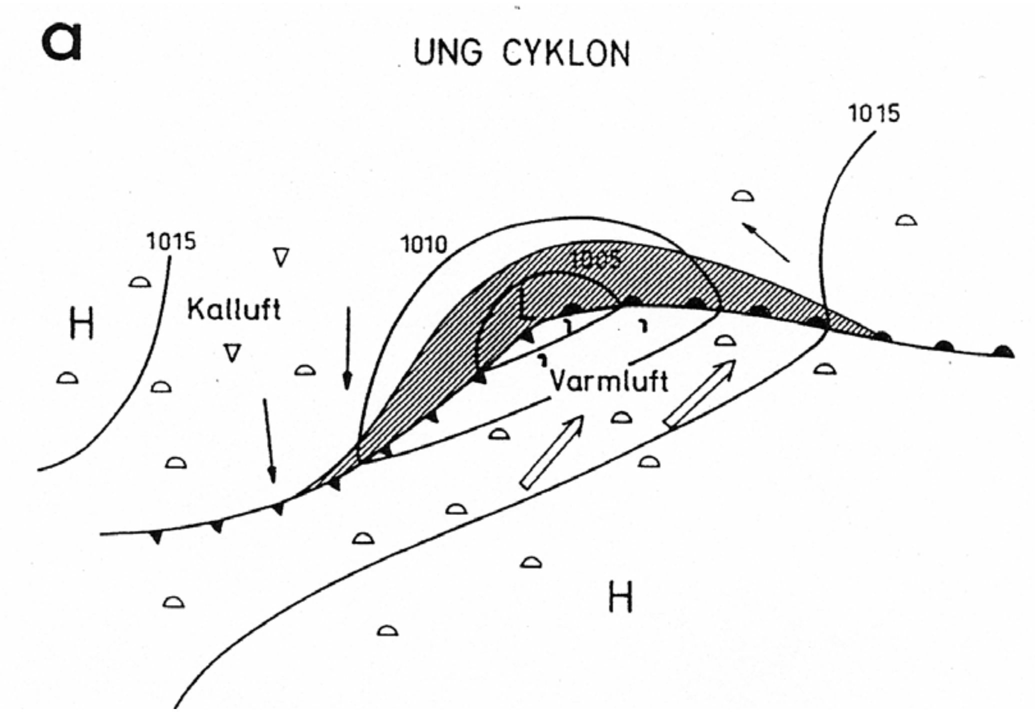
  fronts
- Tropical cyclones
- Severe convective storms



Mid-latitude cyclones

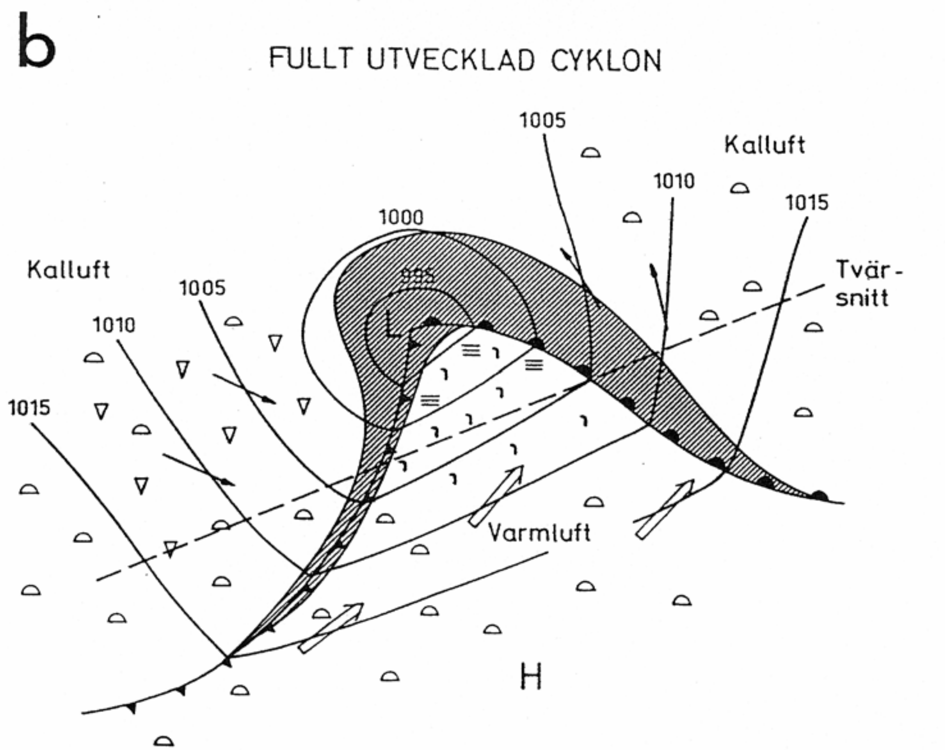
- Disturbances on the Polar front in the form of small waves lead to warm (cold) air moving towards the cold air east (west) of the low pressure

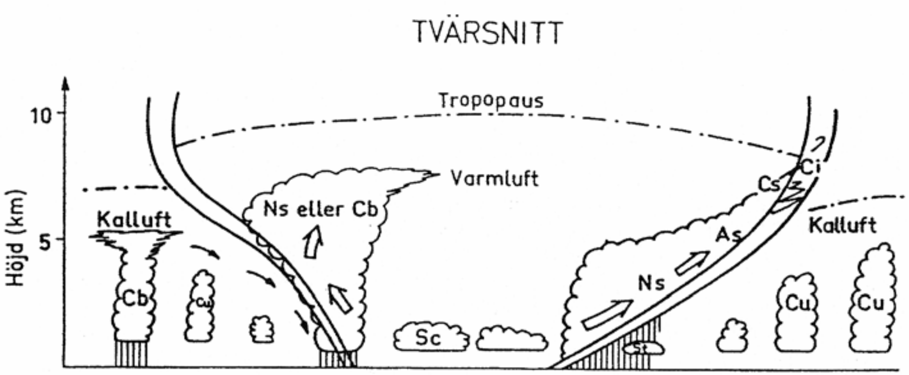
- Warm air ascends generating clouds and precipitation
- Lowering of the centre of mass of the atmosphere leads to release of potential energy (converted into kinetic energy = winds)



Cyclone development

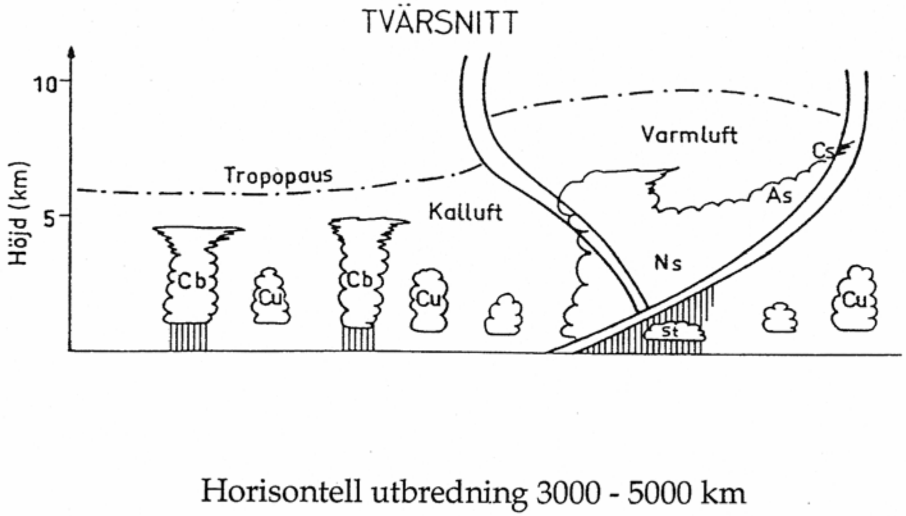
- The cold air moves faster than the warm air
- The warm sector gets smaller and the cyclone gets occluded
- Deepening as long as divergence at higher levels exceeds frictional convergence at low levels

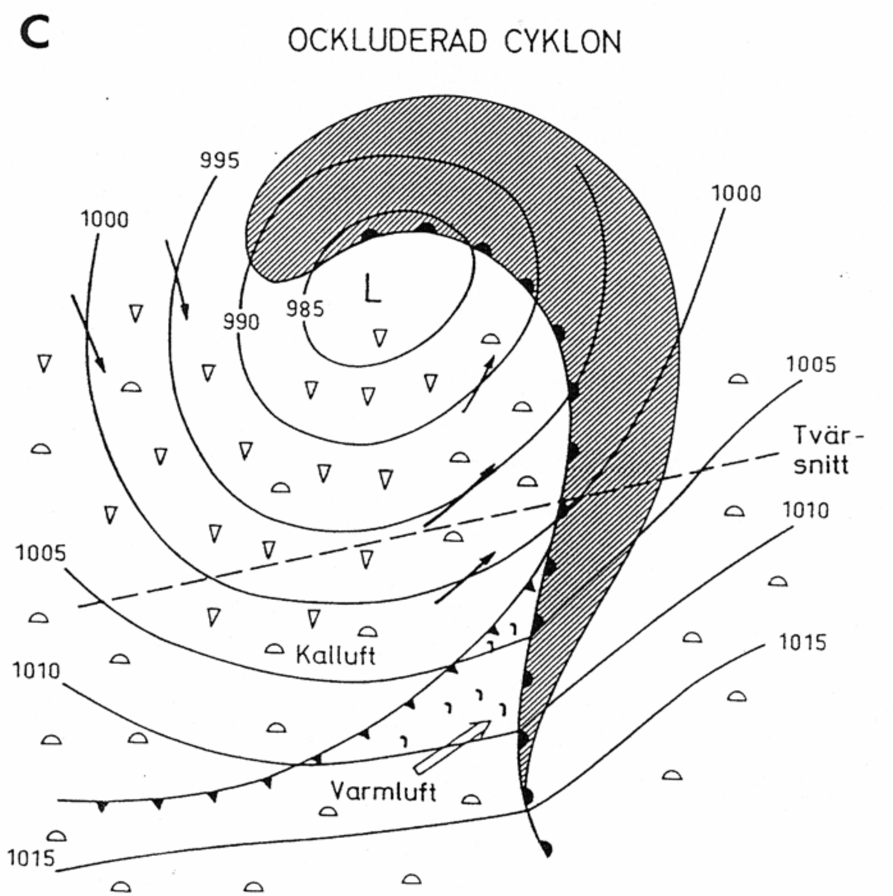




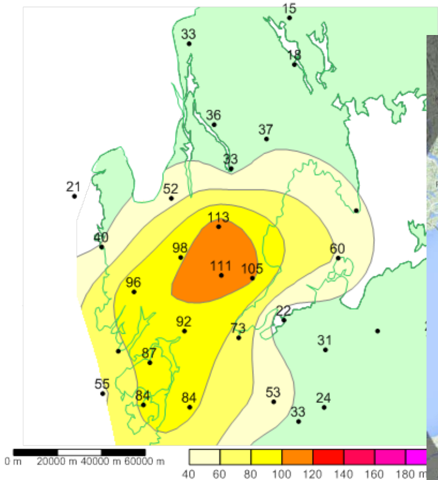
Cyclone development

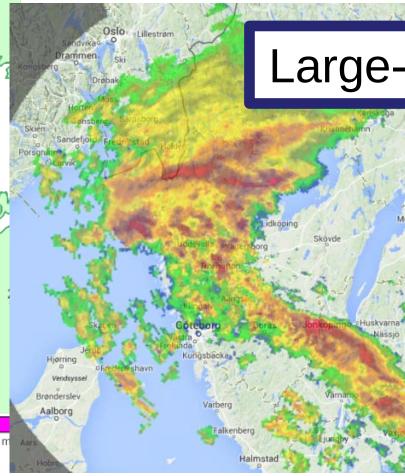
- Dissolving stage
- Friction fills the cyclone
- Warm air at high levels implying that the potential energy is used
- Clouds start to dissolve



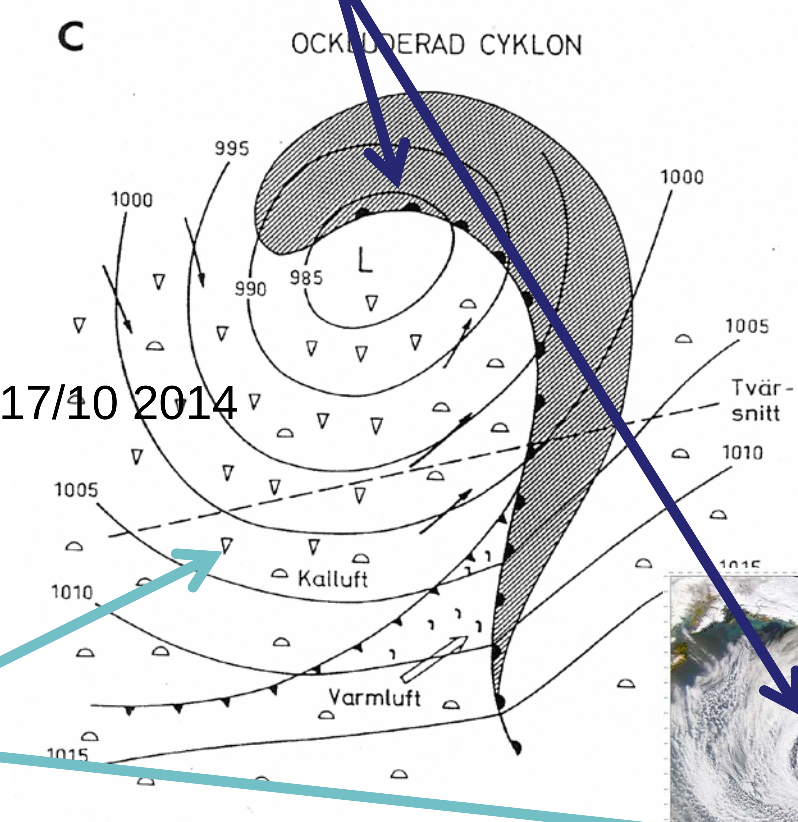


Precipitation associated with cyclones

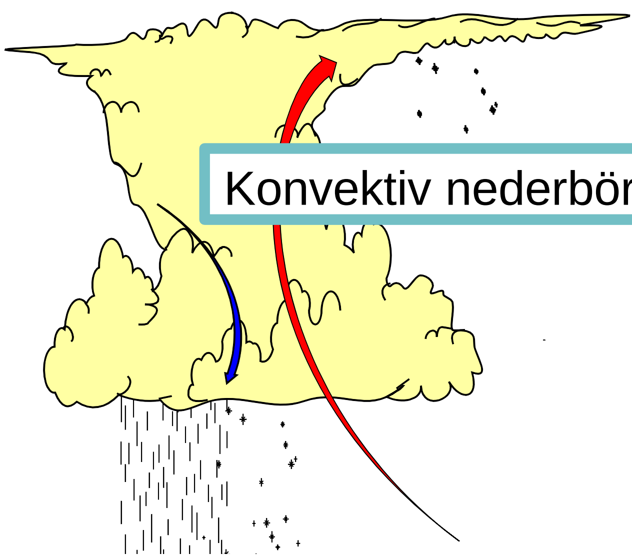




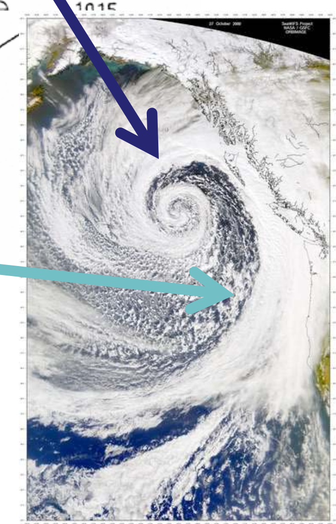
Large-scale frontal precipitation



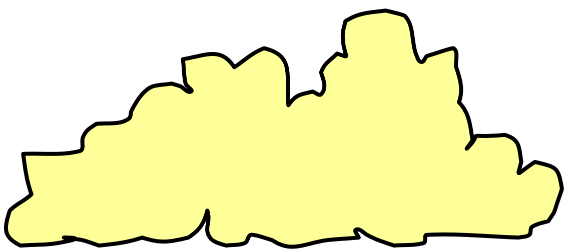
Precipitation over Western Sweden 16-17/10 2014

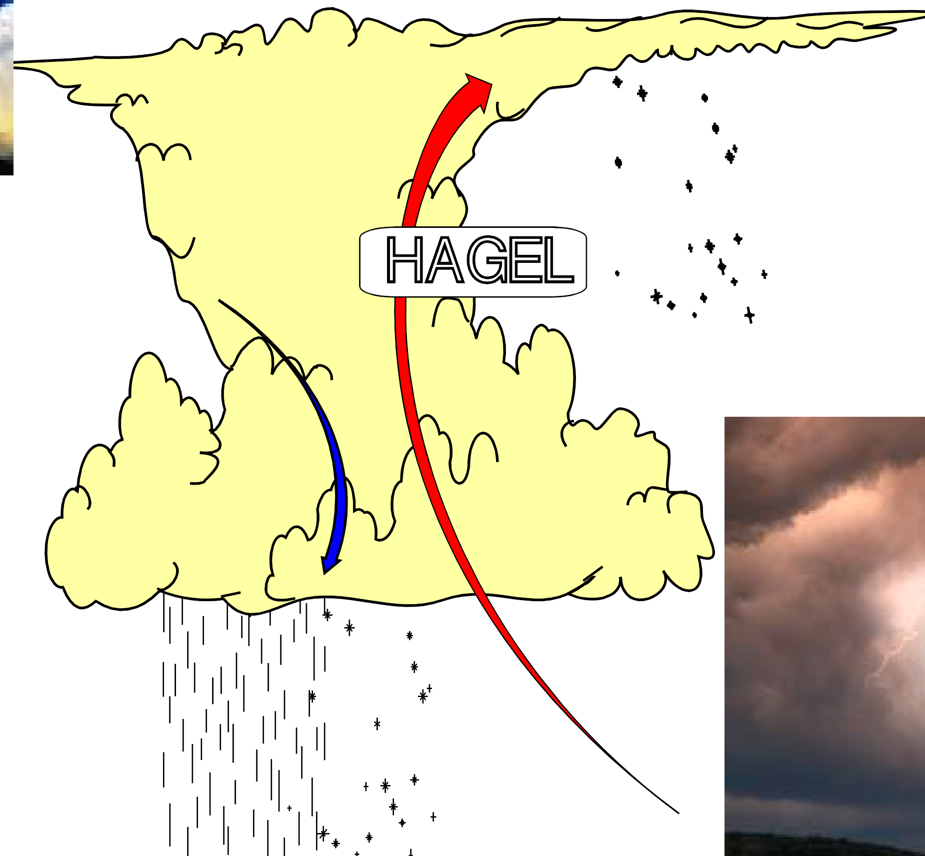


Konvektiv nederbörd

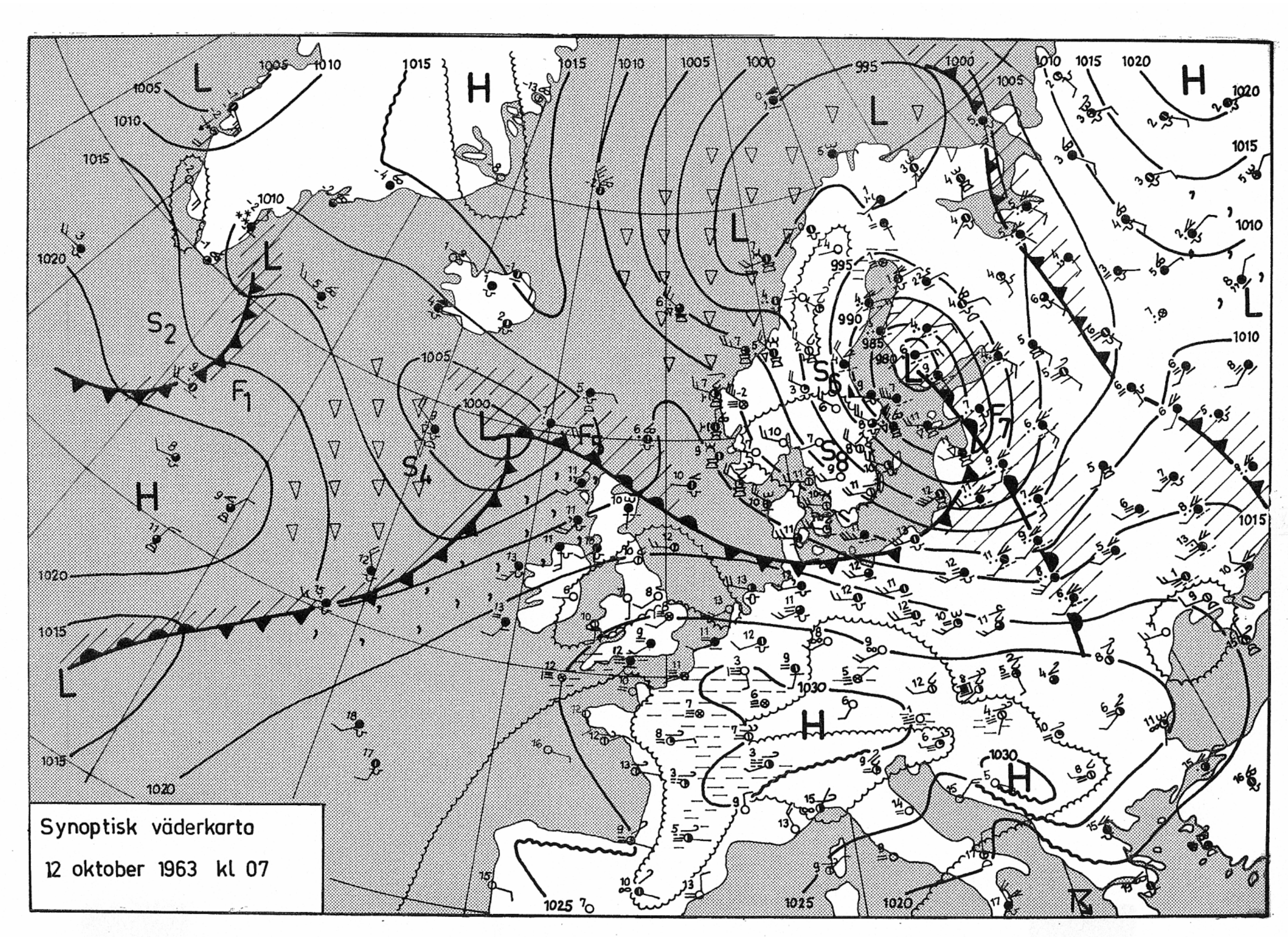


Convective storms



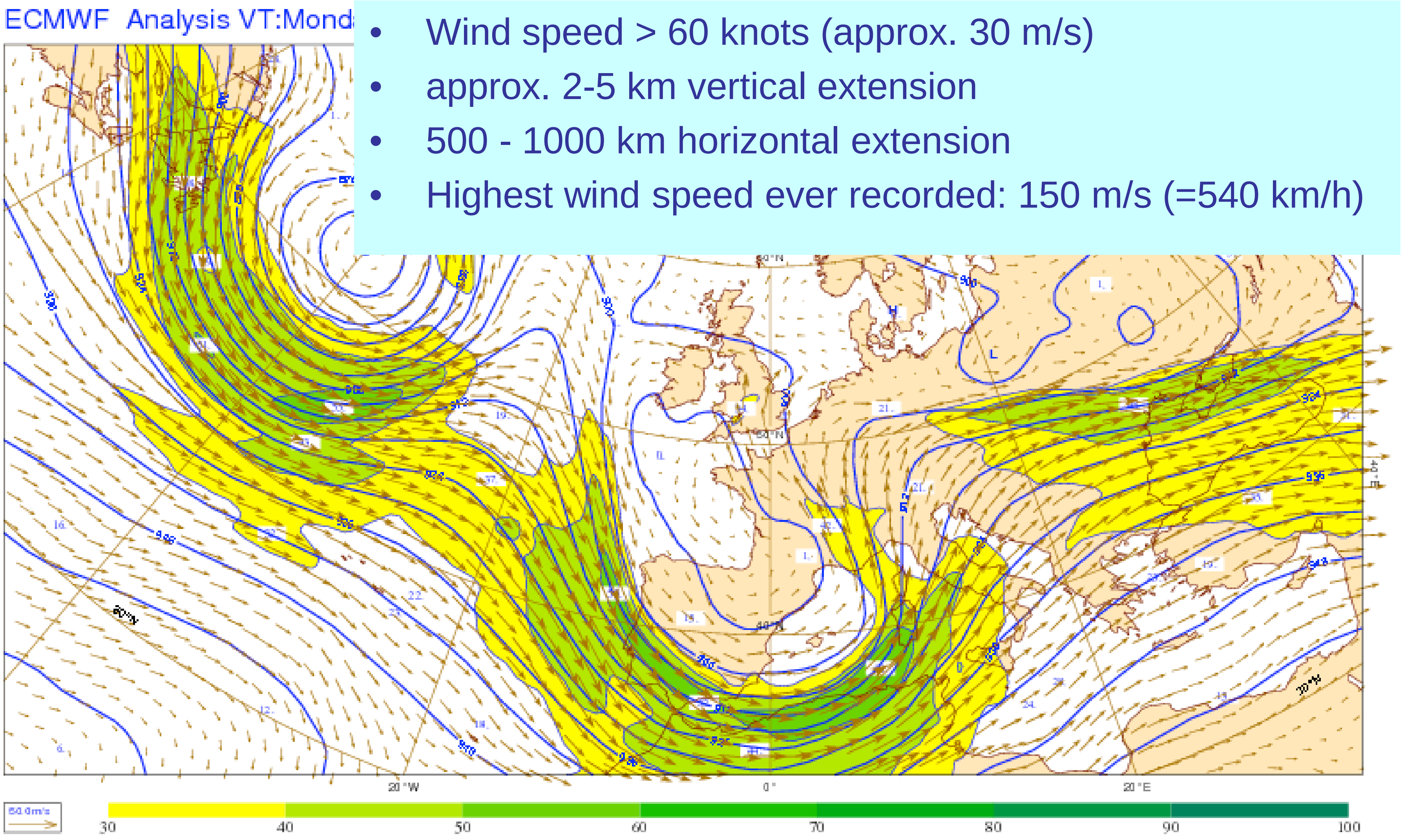


Cyclones on the Polar front

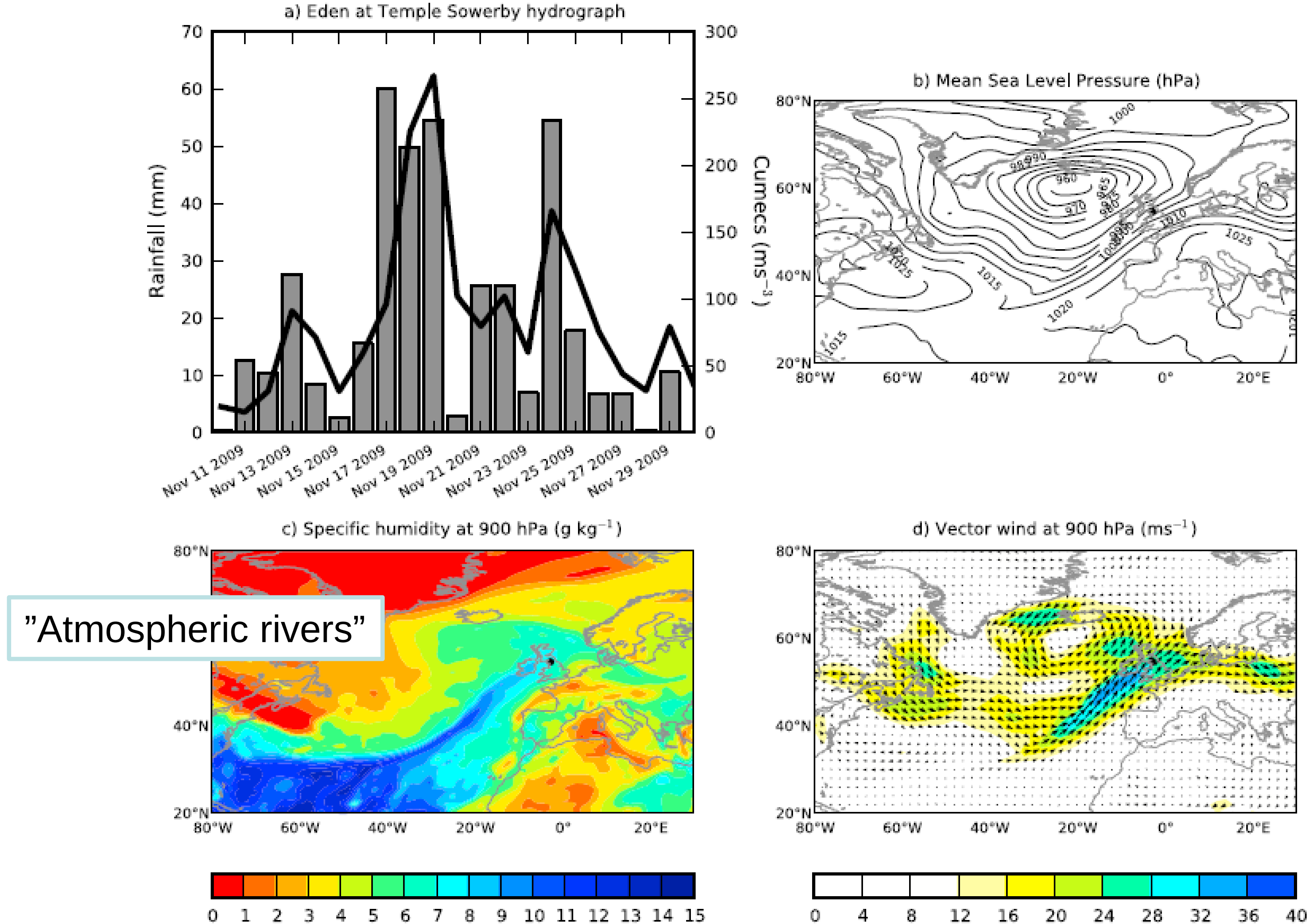


Jet streams

- Wind speed > 60 knots (approx. 30 m/s)
- approx. 2-5 km vertical extension
- 500 - 1000 km horizontal extension
- Highest wind speed ever recorded: 150 m/s (=540 km/h)



Can give large amounts over days



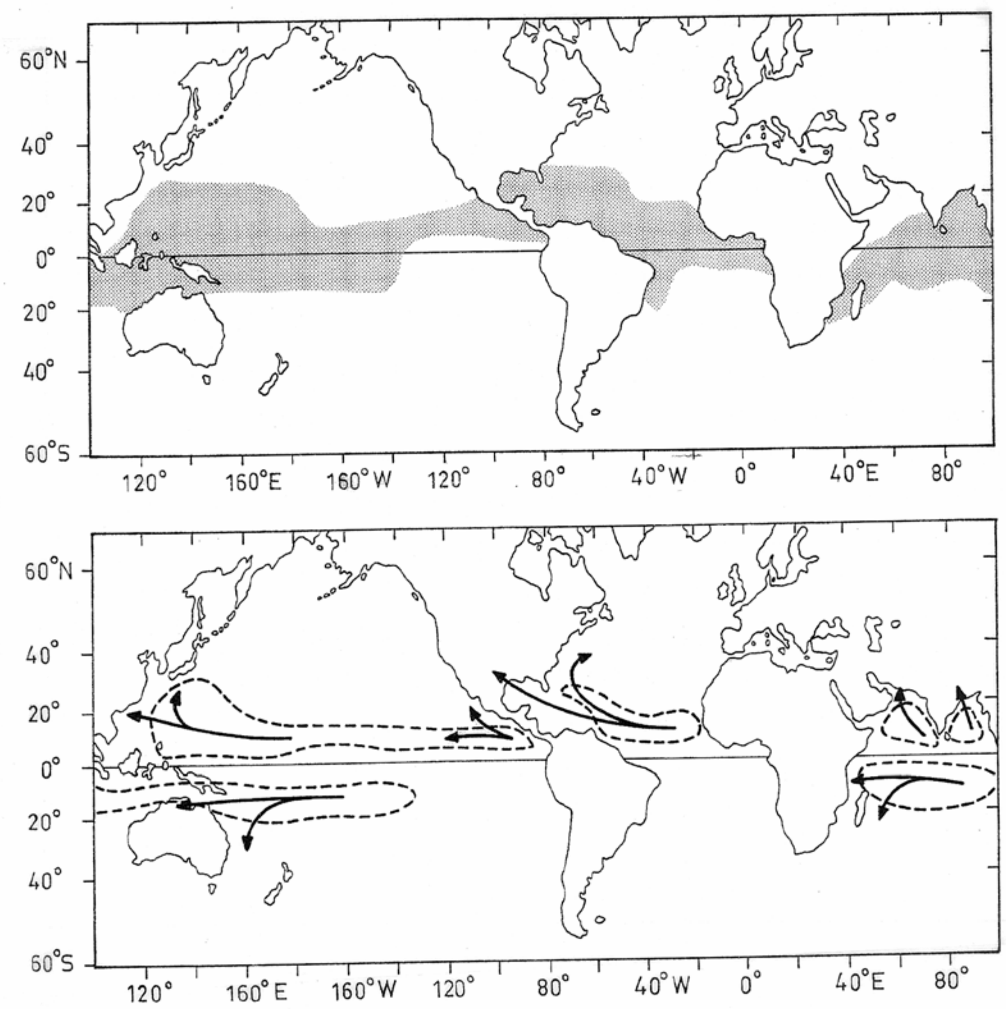
Lavers et al., GRL, 2011

Weather in the tropics

- Trade winds, moistening and destabilization of the atmosphere from the subtropics towards ITCZ leading to deeper and deeper convective clouds (Sc, Cu, Cb)
- ITCZ, deep convection, heavy showers, thunderstorms
- Tropical cyclones
- Easterly waves
- Monsoonal circulation
- El Nino/Southern Oscillation

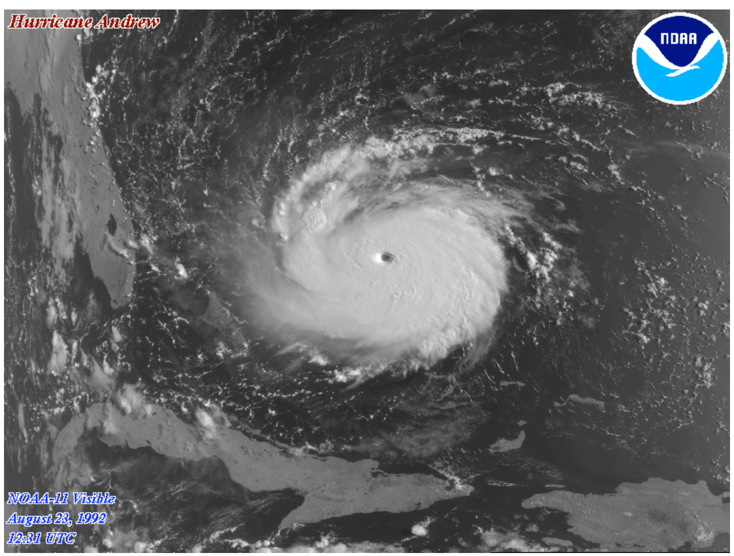
Tropical cyclones

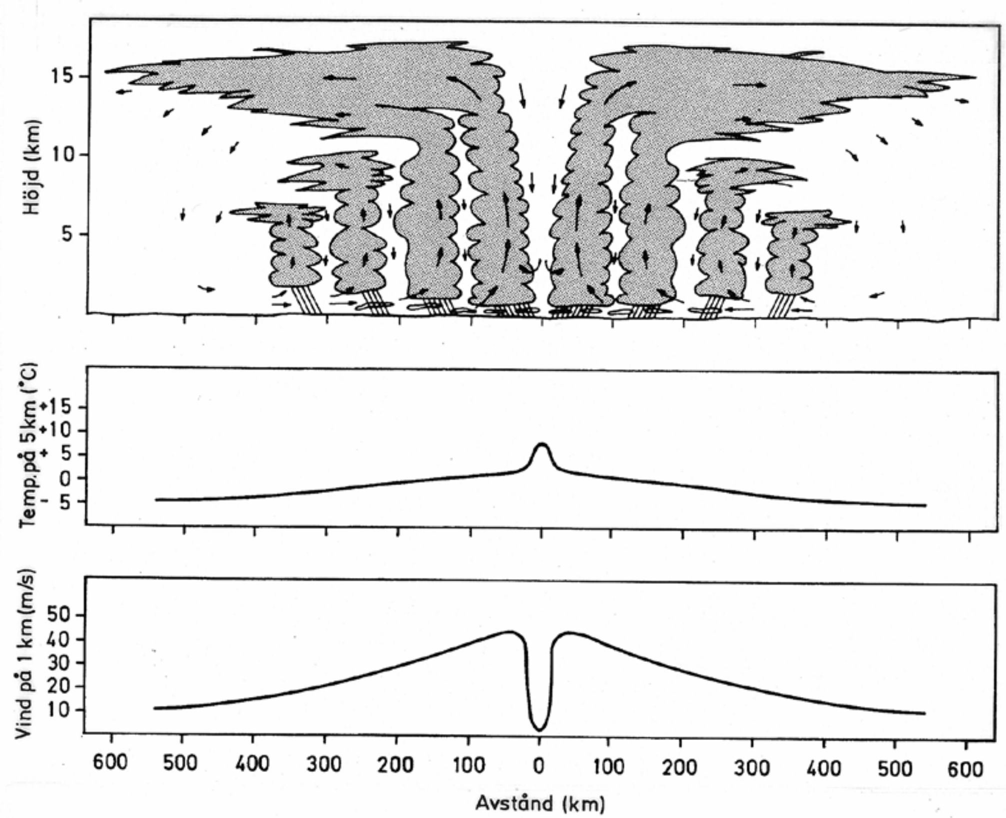
- Growing disturbance (for instance meso-scale convective systems)
- Require warm (+27C) surface water as source of moisture (energy)
- Require some rotation
- Vertical wind shear hampers cyclone formation
- Friction over land leads to dissipation



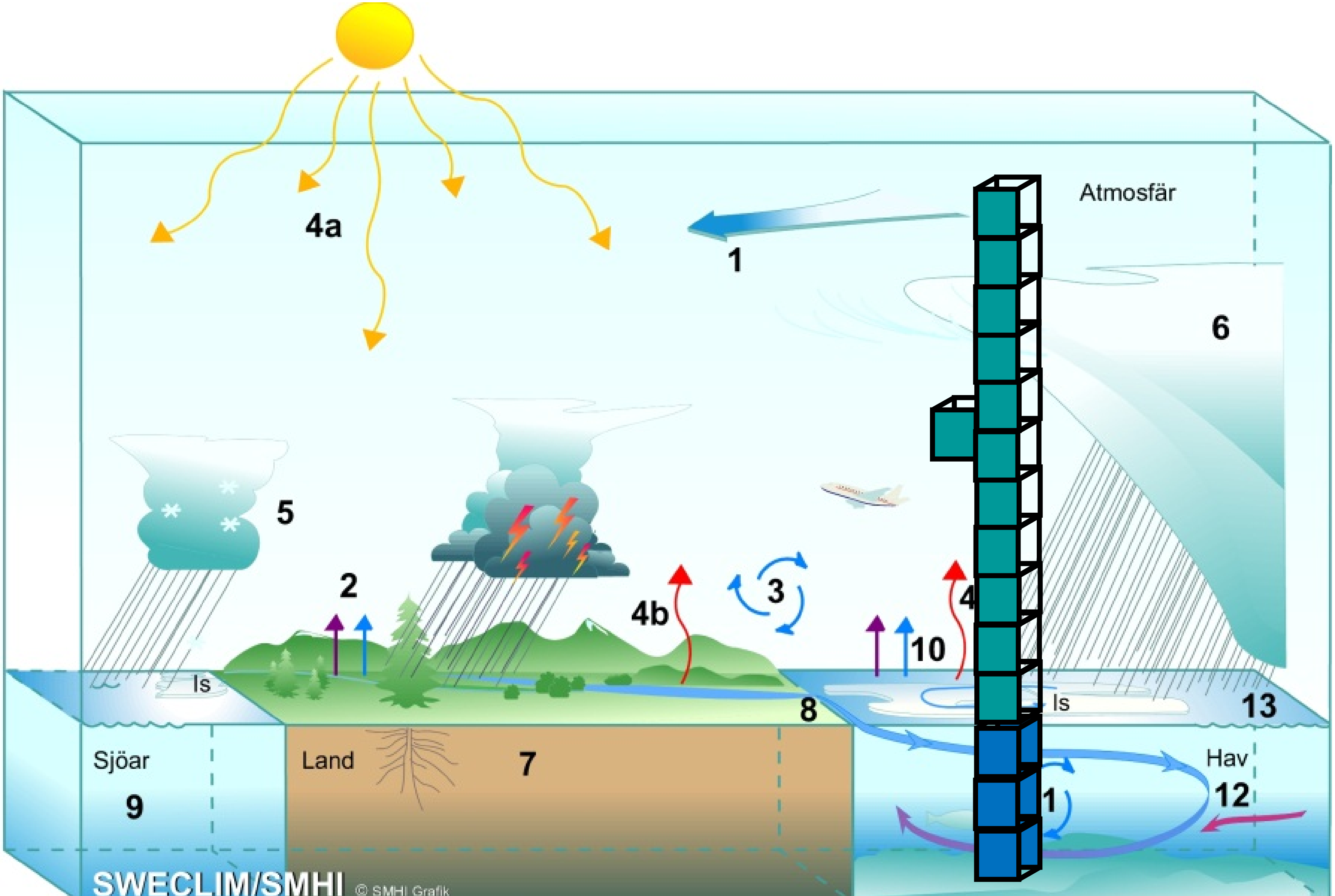
Structure of a tropical cyclone

- Increasing wind speed towards centre (conservation of angular momentum)
- Strong convection close to centre
- Deep low in the centre (warm air with low density)
- Eye in the centre with descending air motion





Climate models



Equations describing the atmosphere

$$\frac{\partial u}{\partial t} + \vec{V} \cdot \nabla u + \omega \frac{\partial u}{\partial p} - fv + \frac{\partial \phi}{\partial x} = F_X$$

$$\nabla \cdot \vec{V} + \frac{\partial \omega}{\partial p} = 0$$

$$\frac{\partial v}{\partial t} + \vec{V} \cdot \nabla v + \omega \frac{\partial v}{\partial p} + fu + \frac{\partial \phi}{\partial y} = F_y$$

$$p\alpha = RT$$

$$\frac{\partial \phi}{\partial p} = -\alpha$$

$$\frac{\partial q}{\partial t} + \vec{V} \cdot \nabla q \cdot + \omega \frac{\partial q}{\partial p} = S_q$$

$$\frac{\partial T}{\partial t} + \vec{V} \cdot \nabla T + \omega \frac{\partial T}{\partial p} - \alpha\omega / Cp = Q / Cp$$

Calculating time tendencies

Change in temperature (T) with time (t)

$$\frac{\partial T}{\partial t} + \vec{V} \cdot \nabla T + \omega \frac{\partial T}{\partial p} - \alpha\omega / Cp = Q / Cp$$

Relation between temperature and wind fields

Other factors influencing temperature

How to run a NWP/GCM?

- Initialisation and ”spin up”
- Calculate tendencies for the 3-D state as a function of
  - (present state, constraining boundary conditions, other “external” factors)
- Apply tendensies to get a new 3-D state Δt later
- Repeat ...

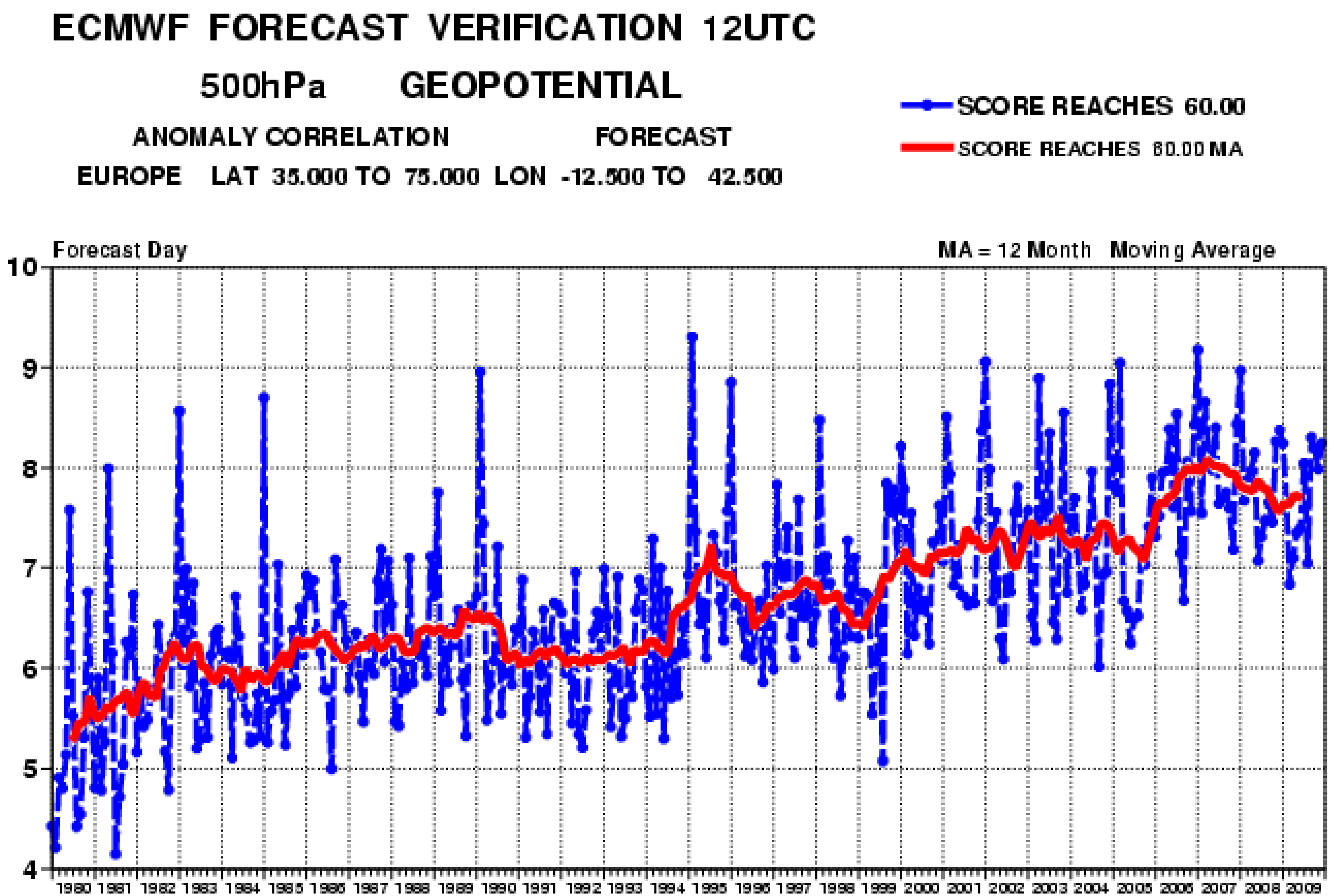
Ex. 100 years simulation, $\Delta t = ½h \Rightarrow$ 1,8 million repetitions in, for instance., 5000x20 (=100 000) grid squares $\Rightarrow$ 180 billion computations!!

Numerical models of the atmosphere

	Hor. scales	Vert. Scales	time range
• Global climate models	100-500 km	1000 m	100 years
• Global weather prediction	15-40 km	500 m	10 days
• Limited area weather pred.	2-5 km	500 m	2 days
• Cloud resolving models	500 m	500 m	1 day
• Large eddy models	50 m	50 m	5 hours

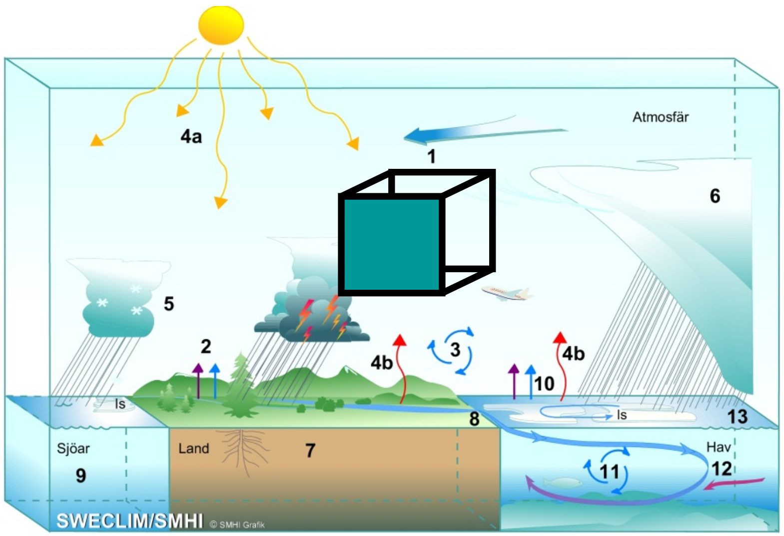
Different models need different level of parametrization

Verification and skill of forecast models



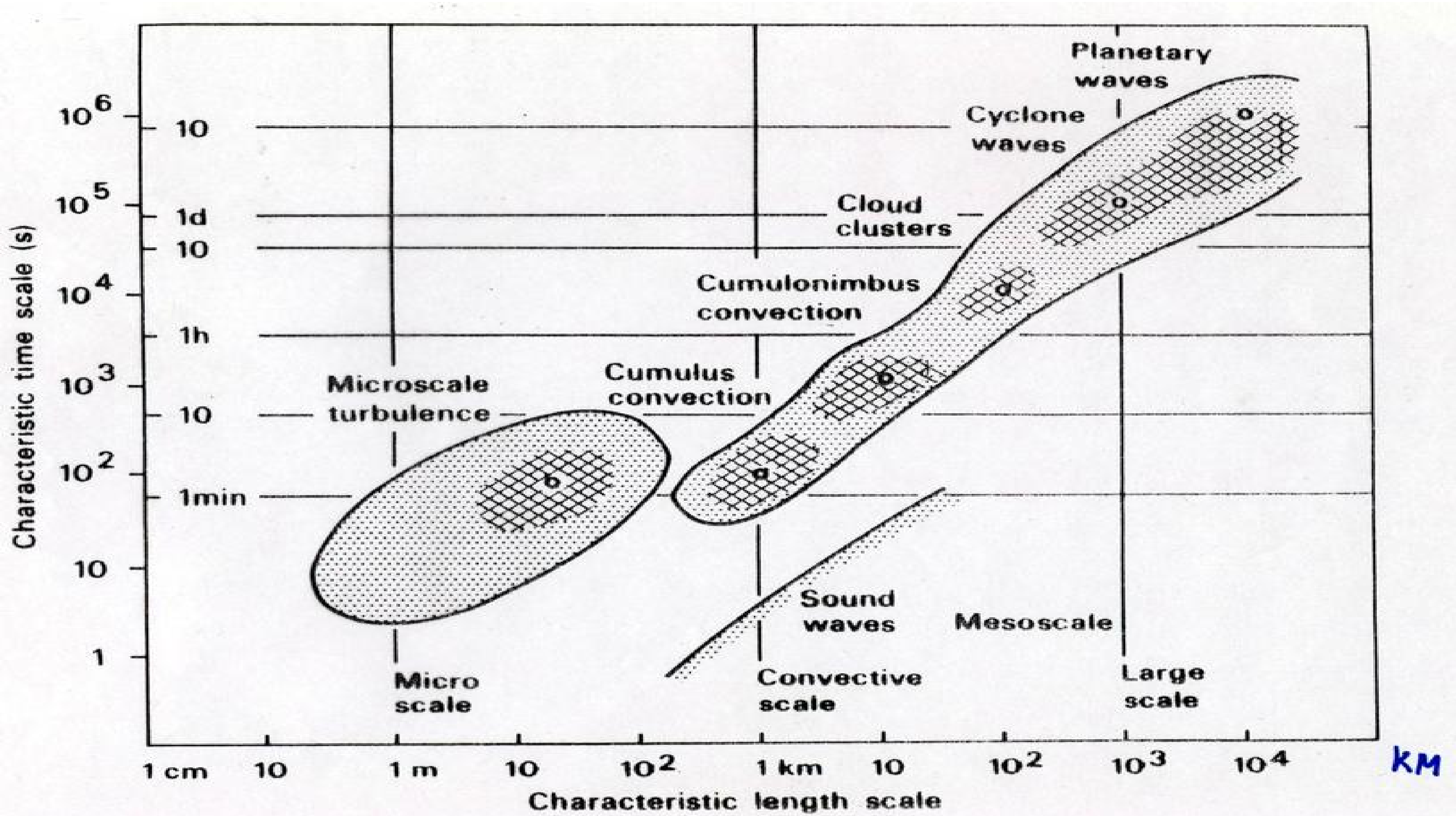
Improvement with time due to better model and observations!

Limitations of a NWP (or GCM)

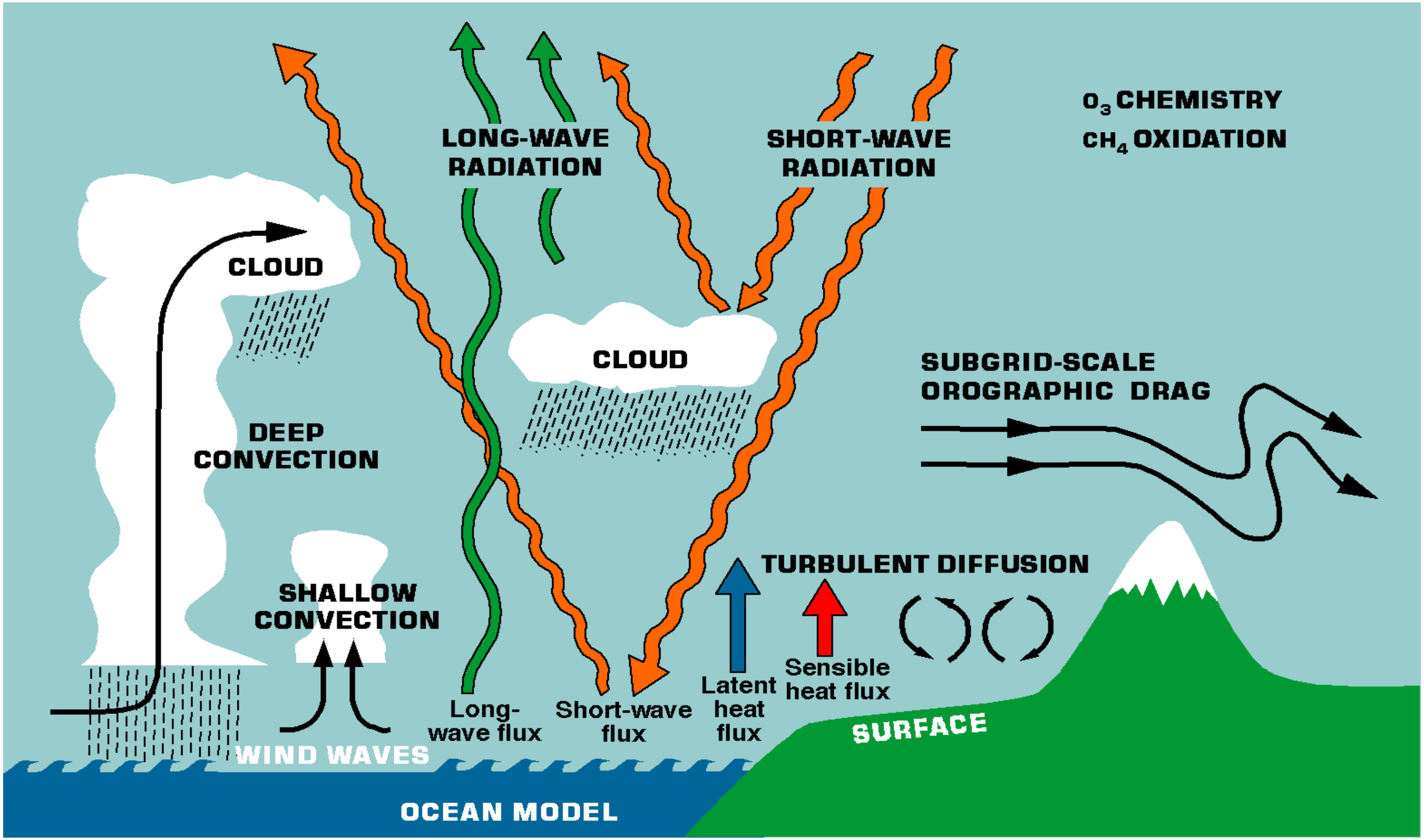


- All processes are not resolved
- Need to be described in an approximative way (e.g. turbulence, clouds and precipitation, …)
- Parametrisations (express small scale phenomenon with large scale variables)
- NWPs (GCMs) are compromises between details in the physical description and computational speed

Space and time scales

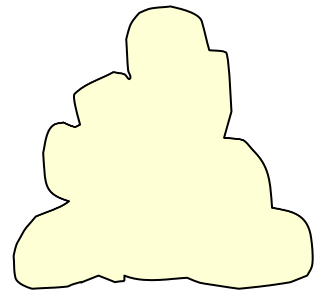


Parametrized processes in the ECMWF model

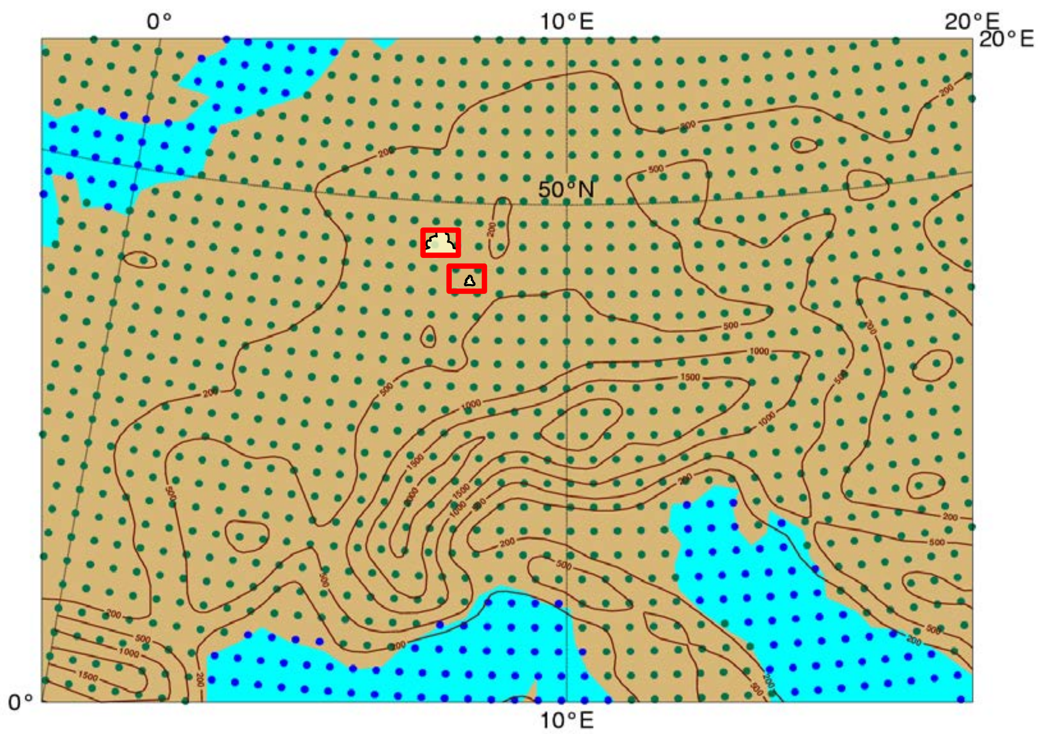


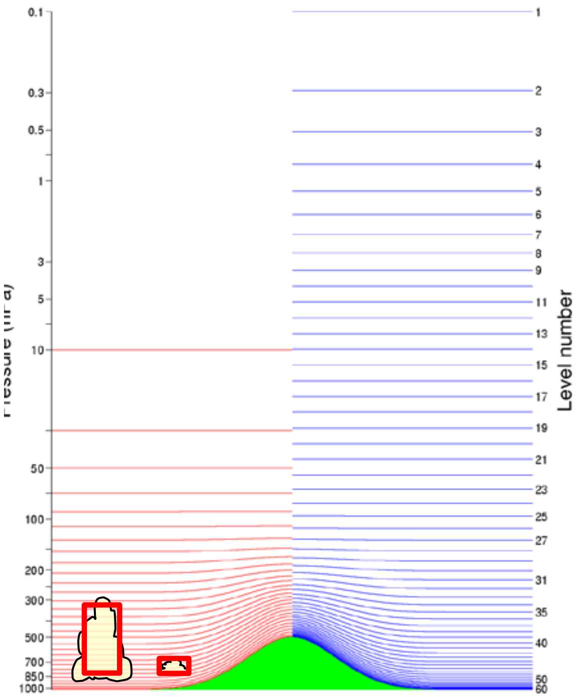
How to represent a cloud in a model?

Horisontal grid spacing
T_L511 ~ 40 km



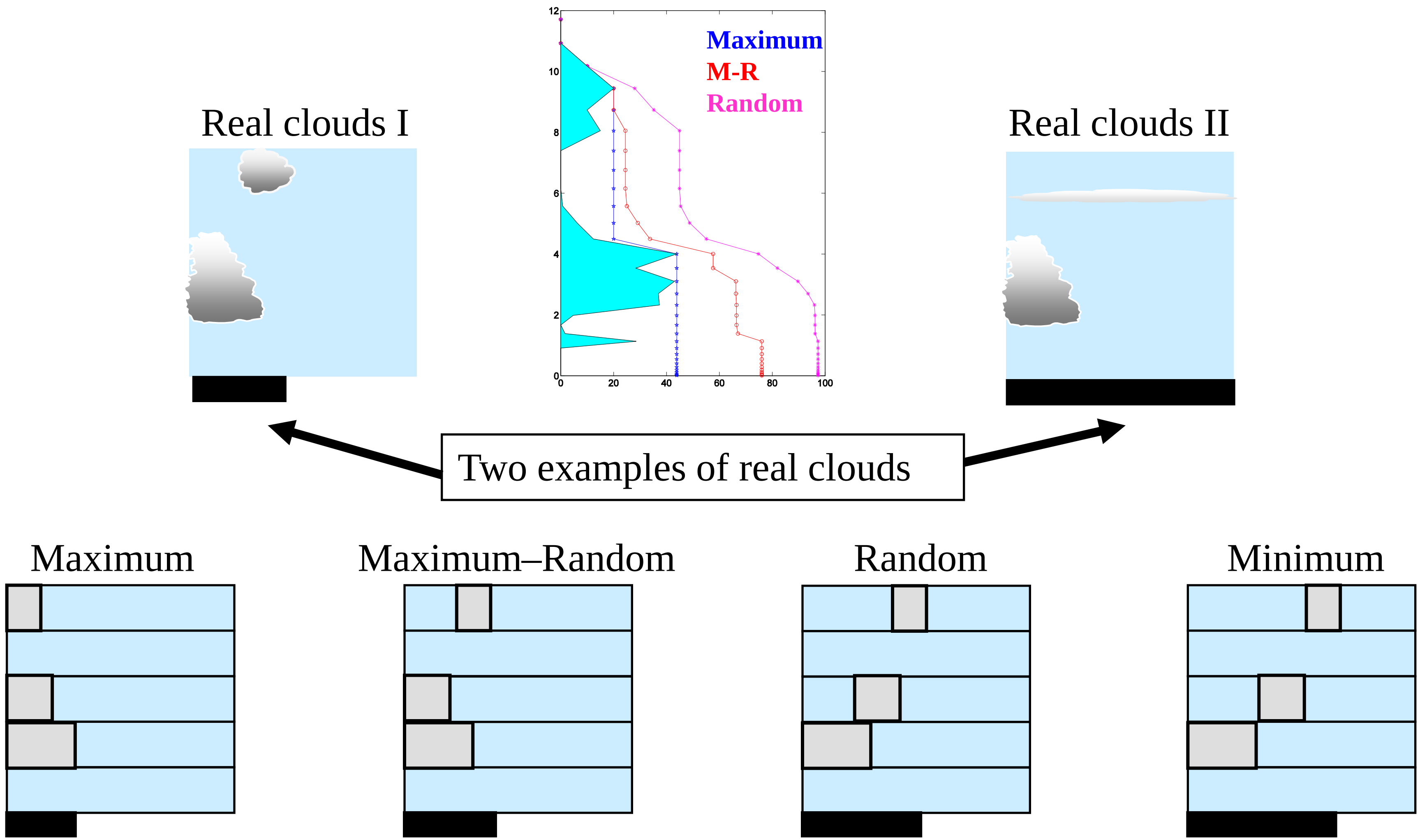
Vertical grid
60 levels



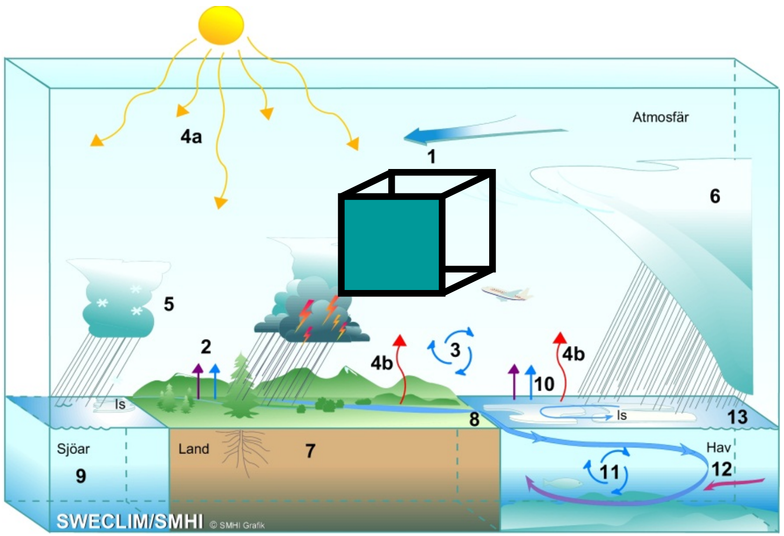


1
5
14
22
30
60

An example of parameterisation: Distribution of clouds



Limitations of a NWP (or GCM)



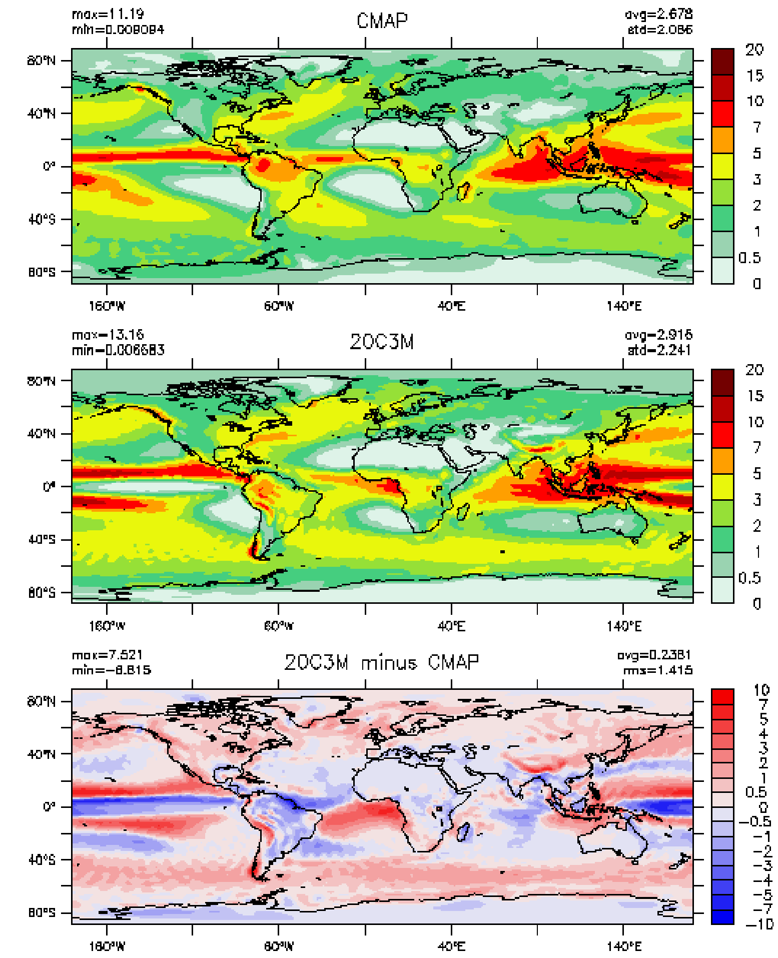
- All processes are not resolved
- Need to be described in an approximative way (e.g. turbulence, clouds and precipitation, …)
- Parametrisations (express small scale phenomenon with large scale variables)
- NWPs (GCMs) are compromises between details in the physical description and computational speed

AOGCM evaluation

Present-day AOGCMs reproduce many features of today's climate, both in terms of means, variability and extremes

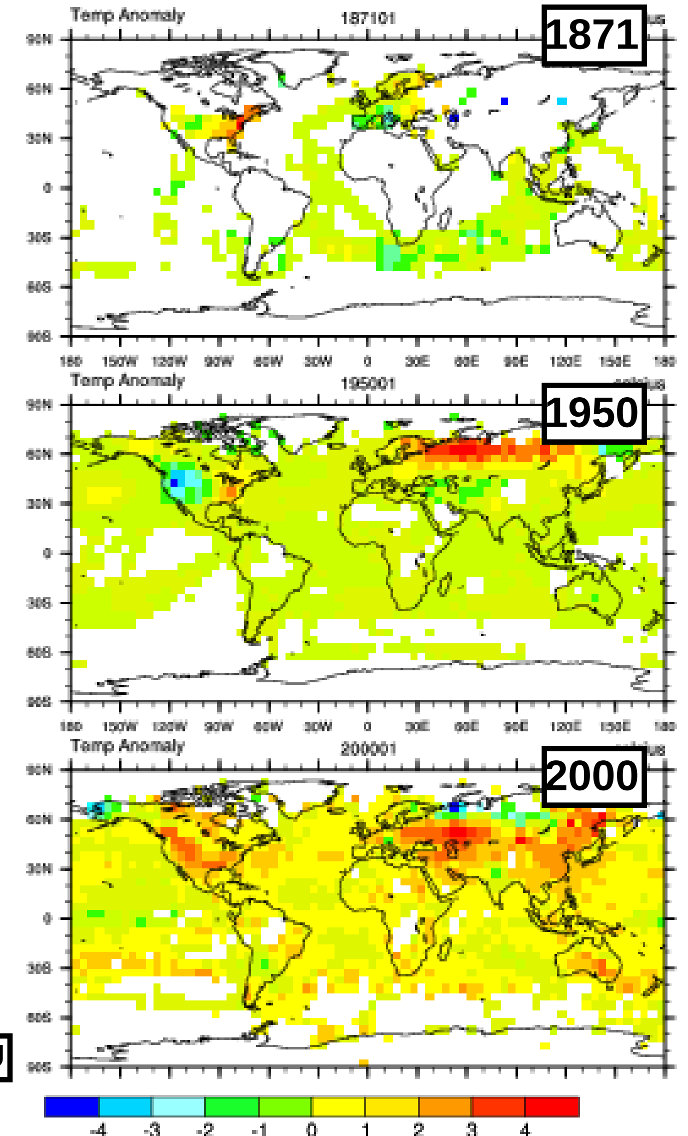
Some weaknesses with present-day AOGCMs are that they have a coarse resolution (>100km), they do not include all processes (e.g. the carbon cycle feedback), they have weaknesses in the understanding of parts of the climate system (in particular clouds are problematic)

Annual mean precipitation: OBS vs. AOGCM



What observational data can we compare model results with?

- Surface based measurements
  - Relatively long time series
  - Issue of homogeneity and spatial coverage
- Radiosondes
  - Limited spatial coverage
  - Time series starts in the 1950's
- Satellite data
  - Global coverage
  - Limited time series (starts in the 1970's)
- Reanalysis products
  - Global coverage
  - Limited in time (1950's)



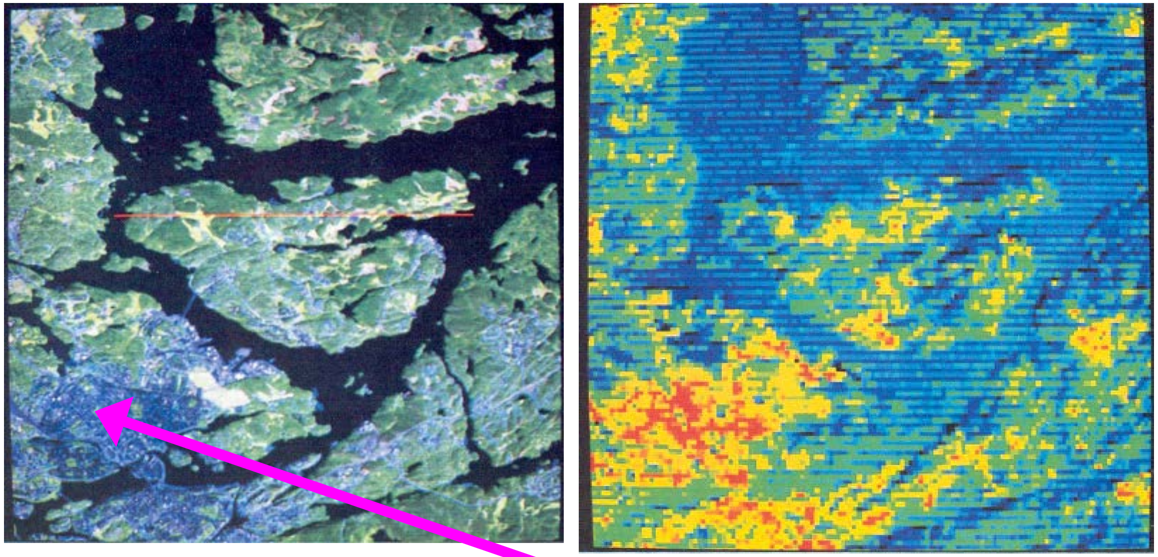
Gridded temperature anomalies from CRU

Homogeneity of observations: Spatial and temporal issues

Example from Stockholm

- Spatial inhomogeneities

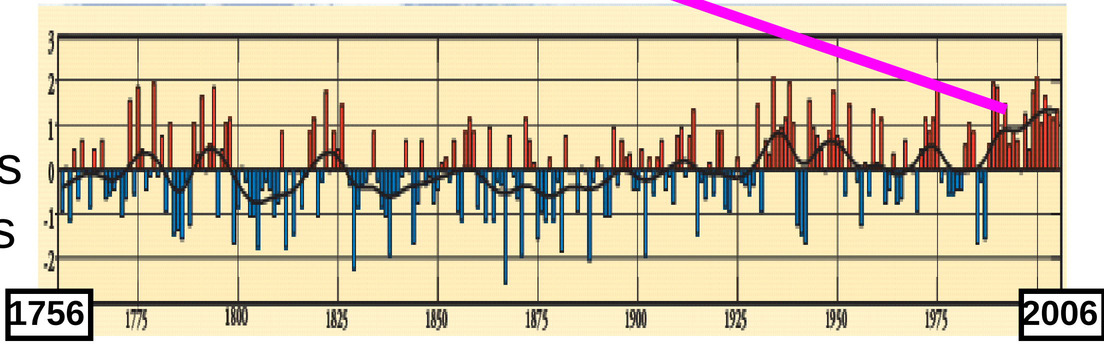
  land / water
  forests / open areas
  rural / urban areas



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.

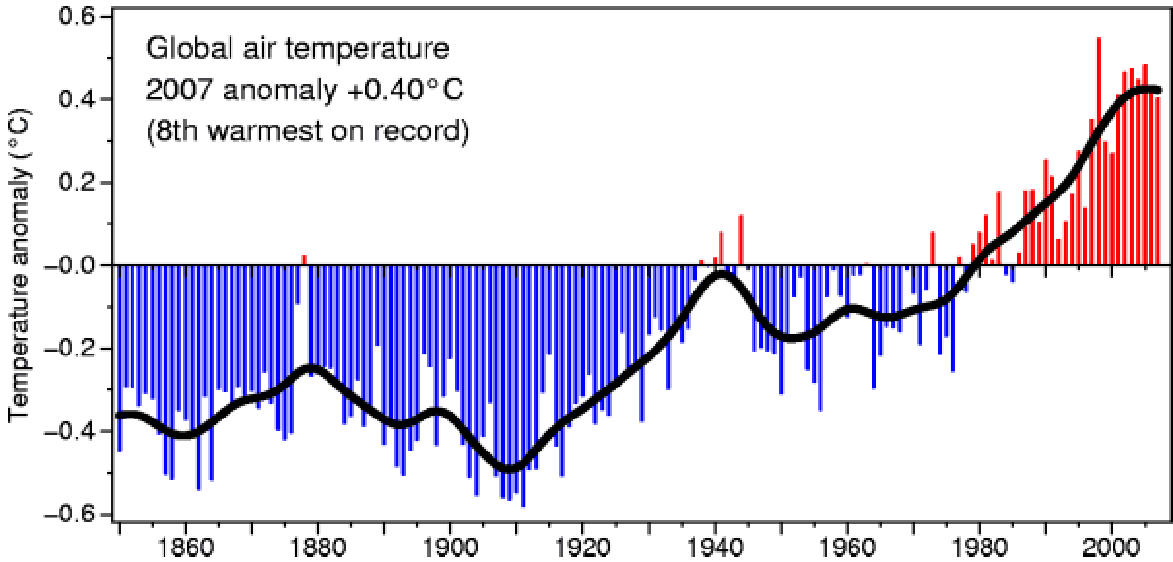
The climate is changing

New records in global mean temperature often broken

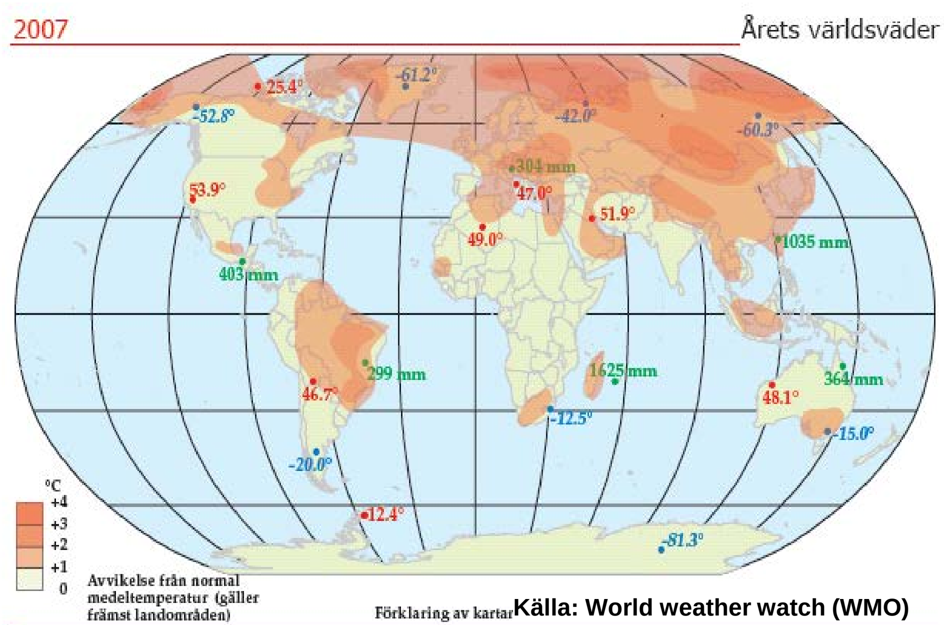
2007 was the 8th warmest year on record, since ca 1860

Exceeded only by 1998, 2005, 2003, 2002, 2004, 2006 and 2001

Source: Climate research Unit, UEA, UK

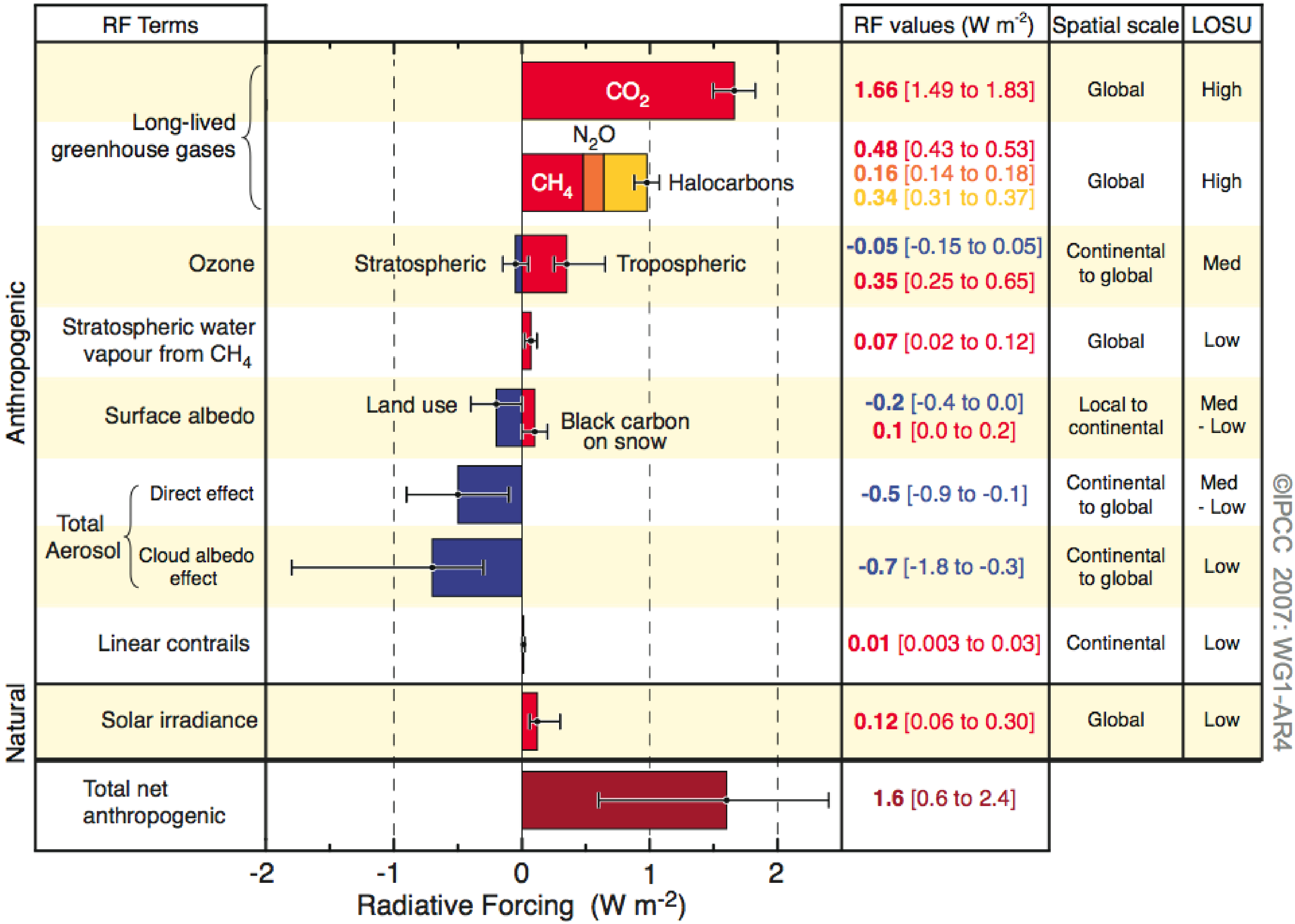


Si



Källa: World weather watch (WMO)

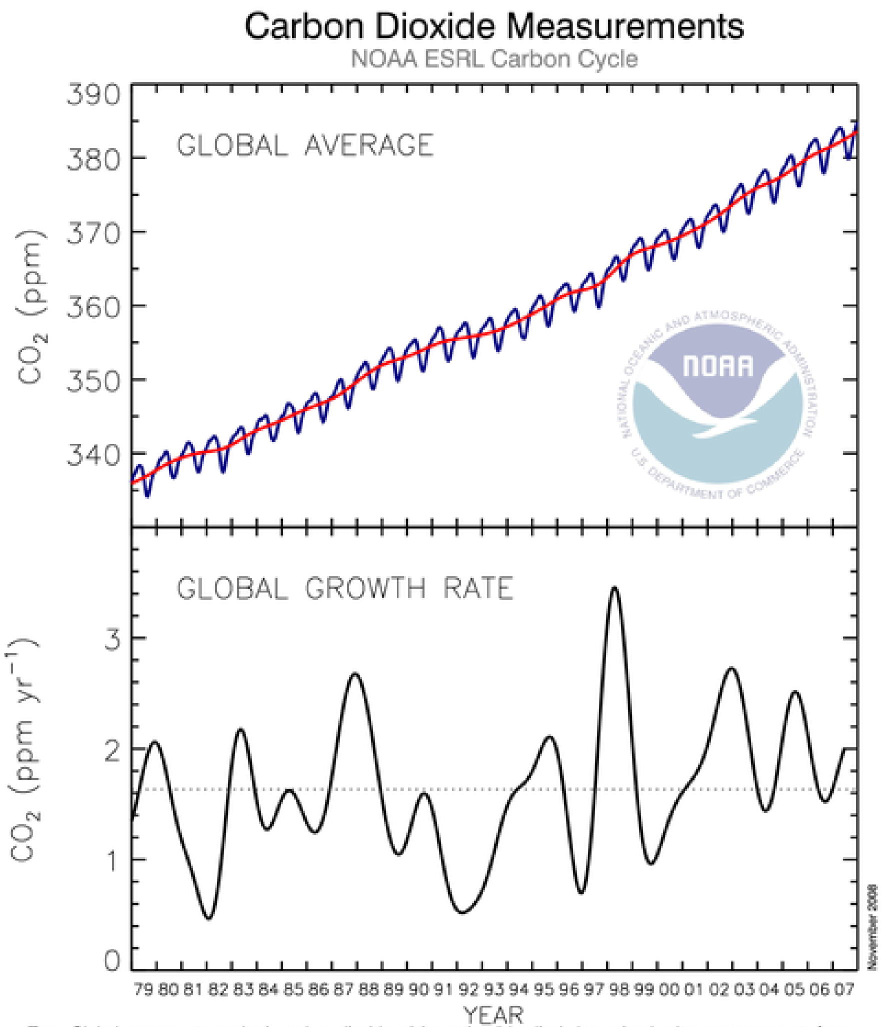
Changing radiative forcing



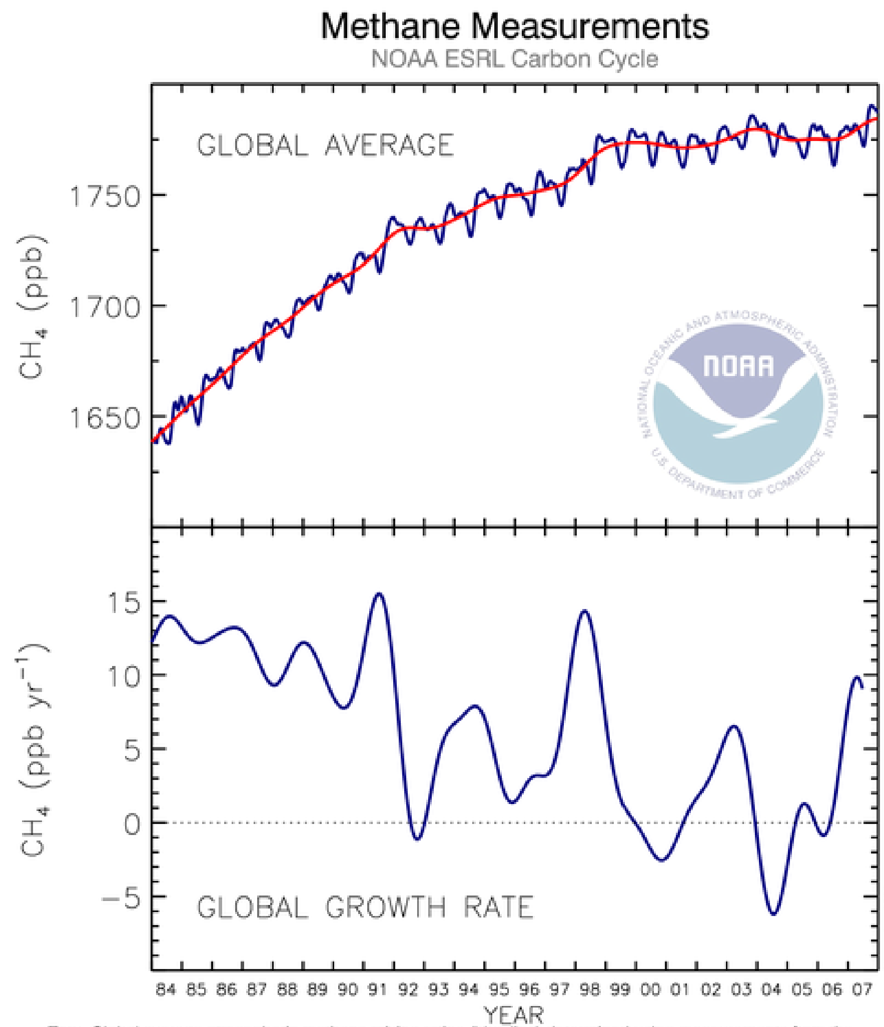
Compare 2005 with 1750

Source: IPCC, 2007

Changing concentrations

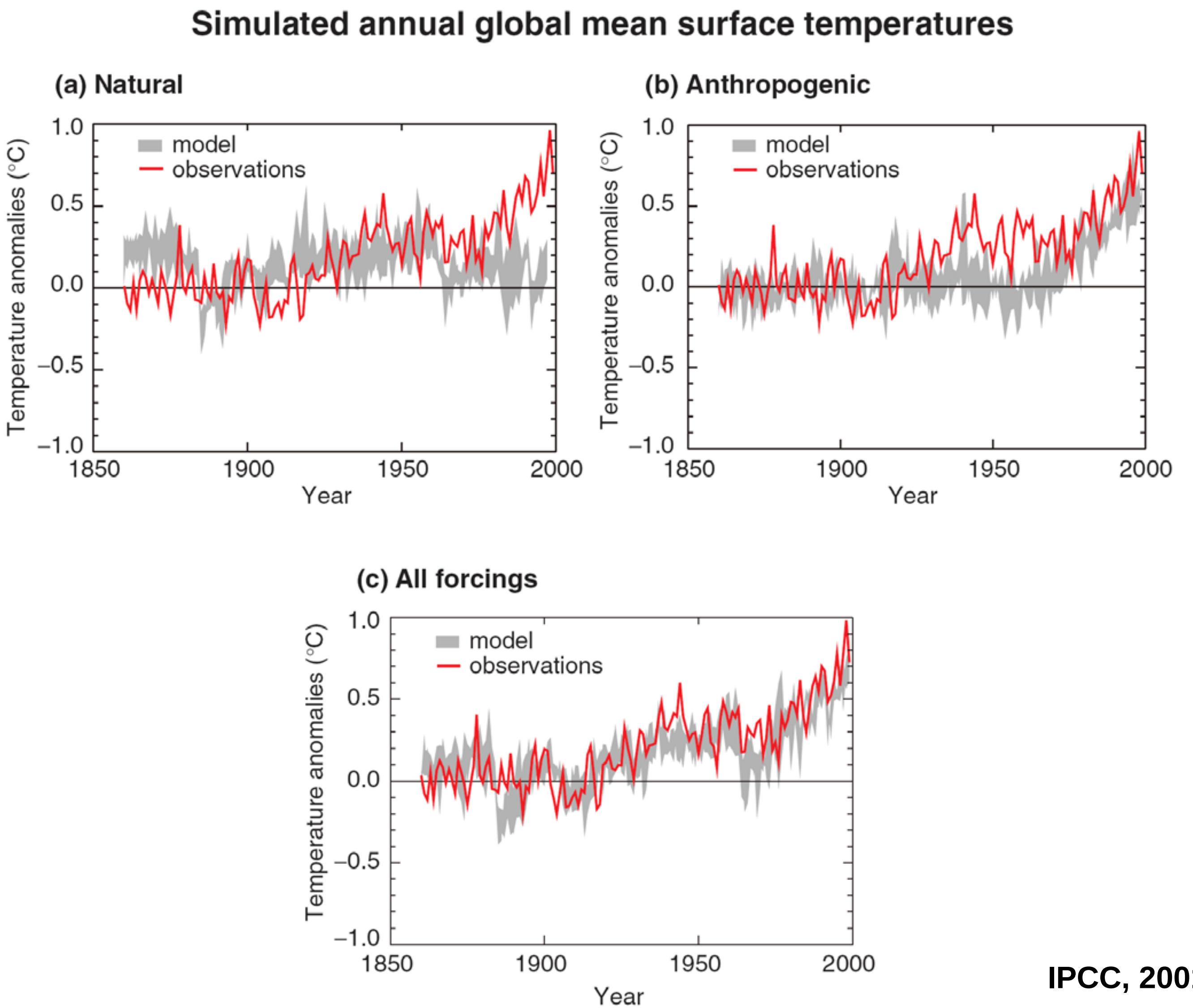


Top: Global average atmospheric carbon dioxide mixing ratios (blue line) determined using measurements from the Carbon Cycle cooperative air sampling network. The red line represents the long-term trend. Bottom: Global average growth rate for carbon dioxide. Contact: Dr. Pieter Tans, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6678, pieter.tans@noaa.gov, http://www.esrl.noaa.gov/gmd/ccgg/.



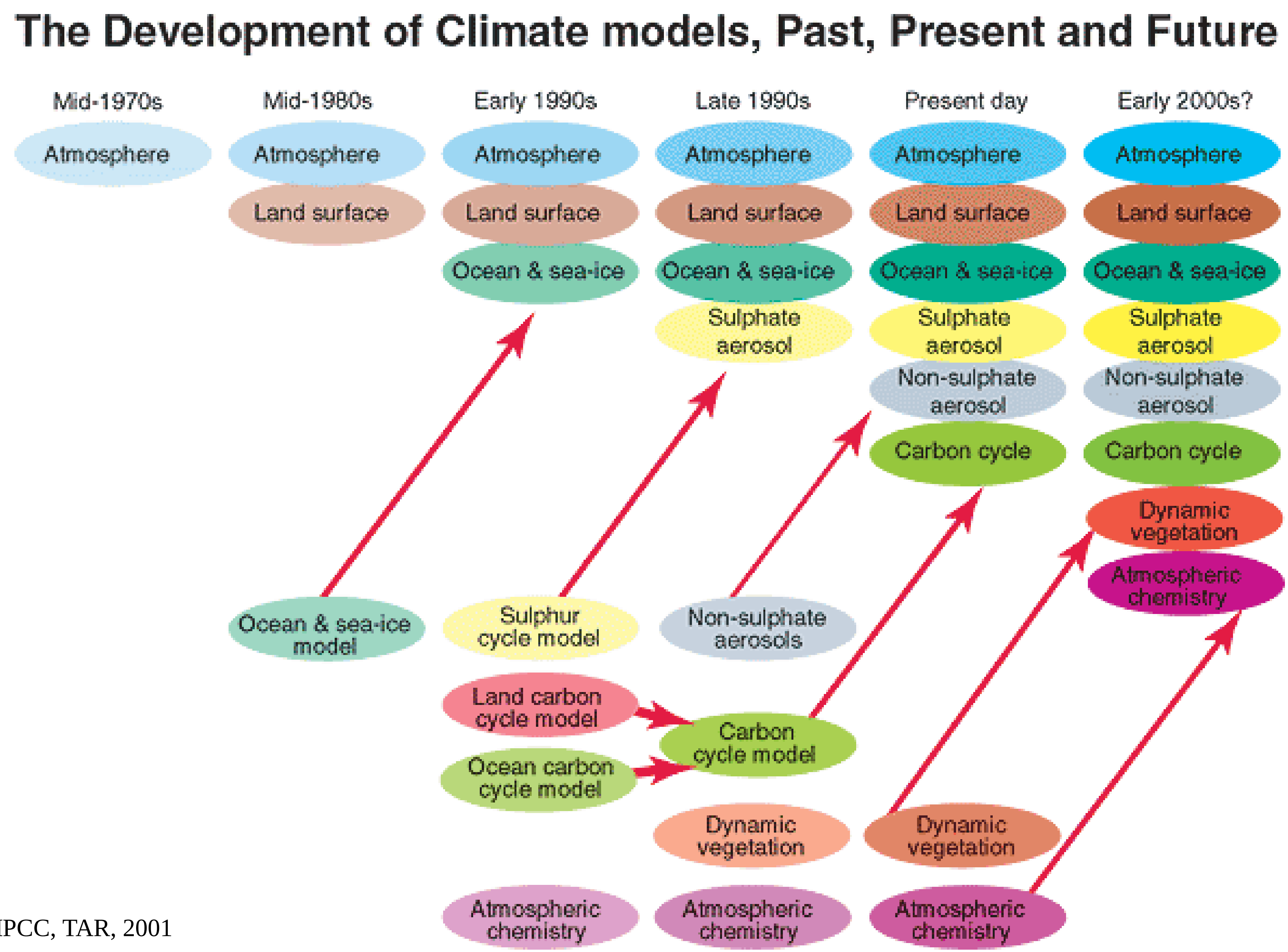
Top: Global average atmospheric methane mixing ratios (blue line) determined using measurements from the Carbon Cycle cooperative air sampling network. The red line represents the long-term trend. Bottom: Global average growth rate for methane. Contact: Dr. Ed Dlugokencky, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6228, ed.dlugokencky@noaa.gov, http://www.esrl.noaa.gov/gmd/ccgg/.

Can GCMs simulate the evolution of climate?



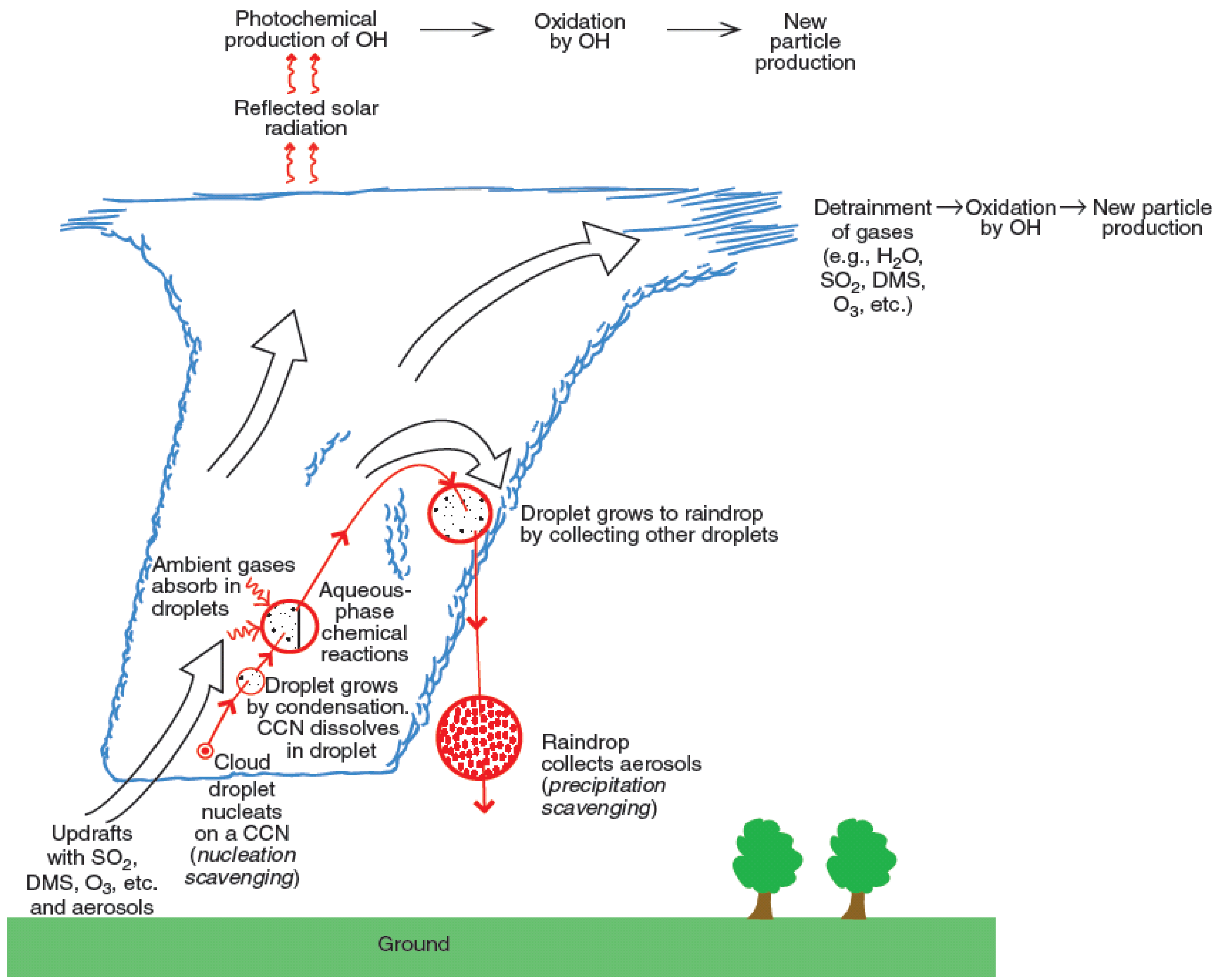
IPCC, 2001

Interacting systems



Source: IPCC, TAR, 2001

Cloud and precipitation processes interacts with atmospheric chemistry



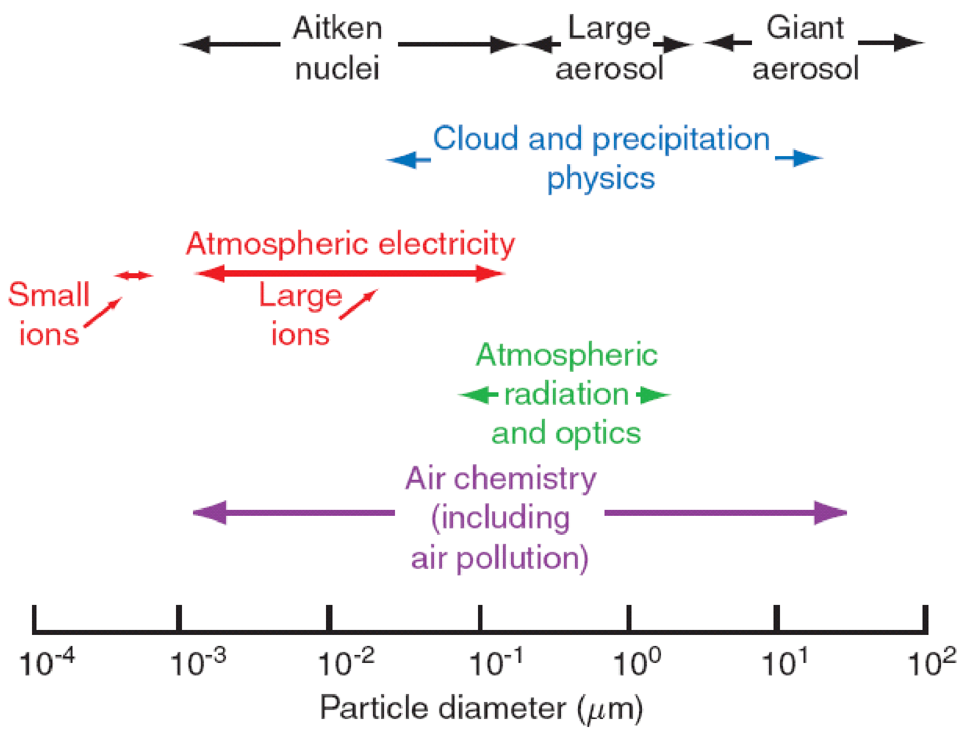
Condensation and formation of cloud droplets

- Condensation takes place when the air gets saturated
- Curvature of droplets leads to high saturation pressure (up to 400% in clean conditions)
- Condensation starts on small particles (aerosols) consisting of various salts that lead to lower saturation pressure (small droplets can form already at 80% RH)
- Cloud properties depend on the condensation nuclei (size, number, properties)
- Droplets increase in size due to condensation and coalescence

SHIP TRACKS OFF FRANCE
(From bands 1,4 and 3 of MODIS on Aqua Satellite)

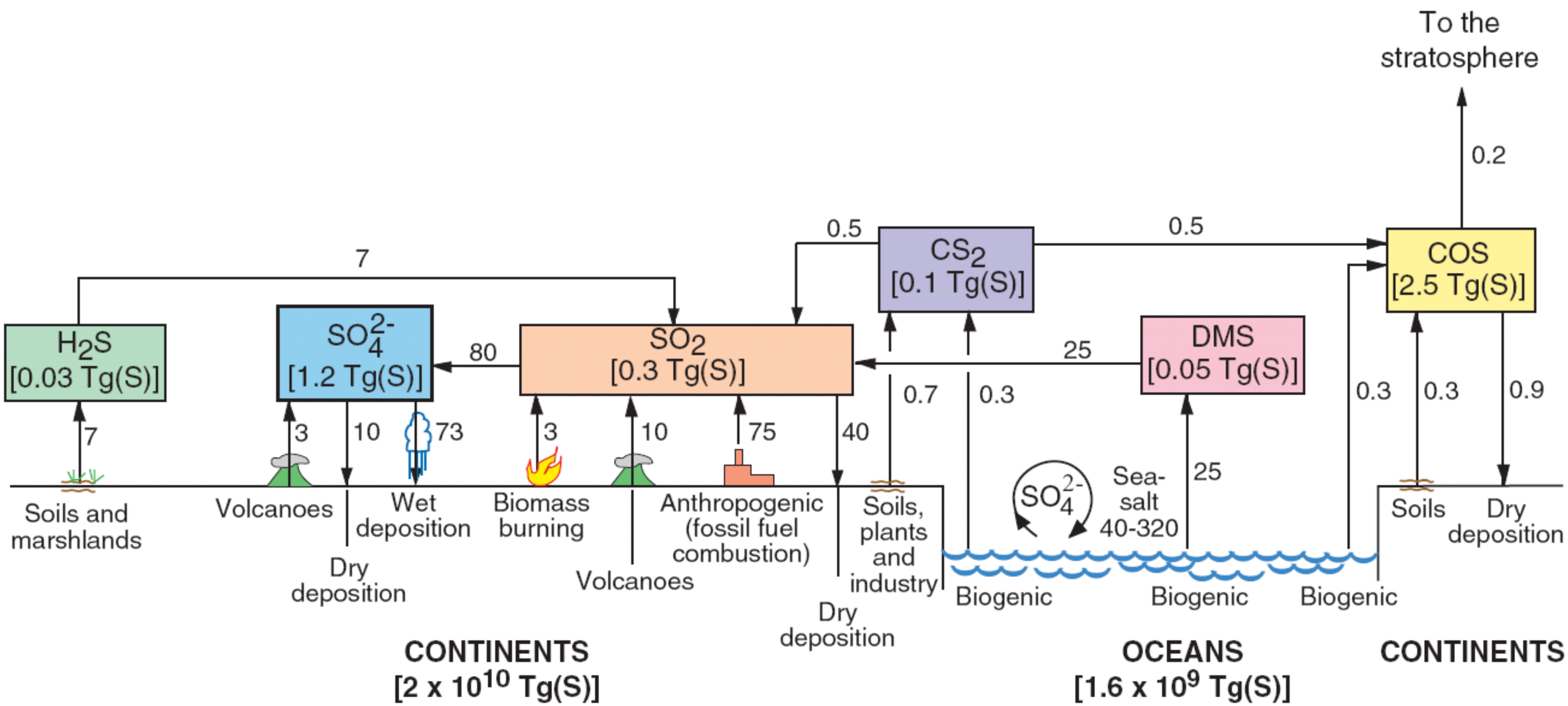
Atmospheric aerosols

- Suspensions of small solid and/or liquid particles with negligible terminal fall speeds
- Important for atmospheric processes



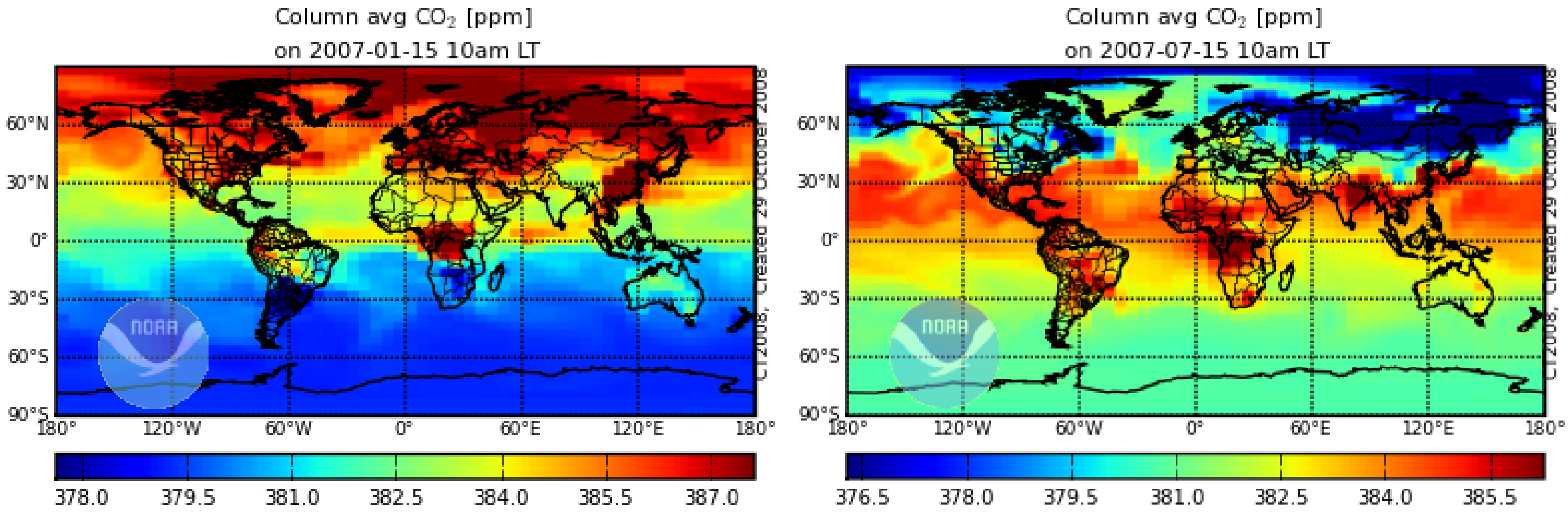
Biogeochemical cycles

- Sources and sinks at the surface, *in situ* formation and destruction determines the content of a compound in the atmosphere
- Large number of processes



Atmospheric motions transports chemical constituents

CO_2 ”weather”



Carbon tracker (NOAA). Information from observational data and meteorological models

End of part 1!

Regional climate simulations and their representation of change in the regional climate

Lectures during the course on

"Impact of climate change on the marine environment with special focus on the role of changing extremes"

25 August 2015

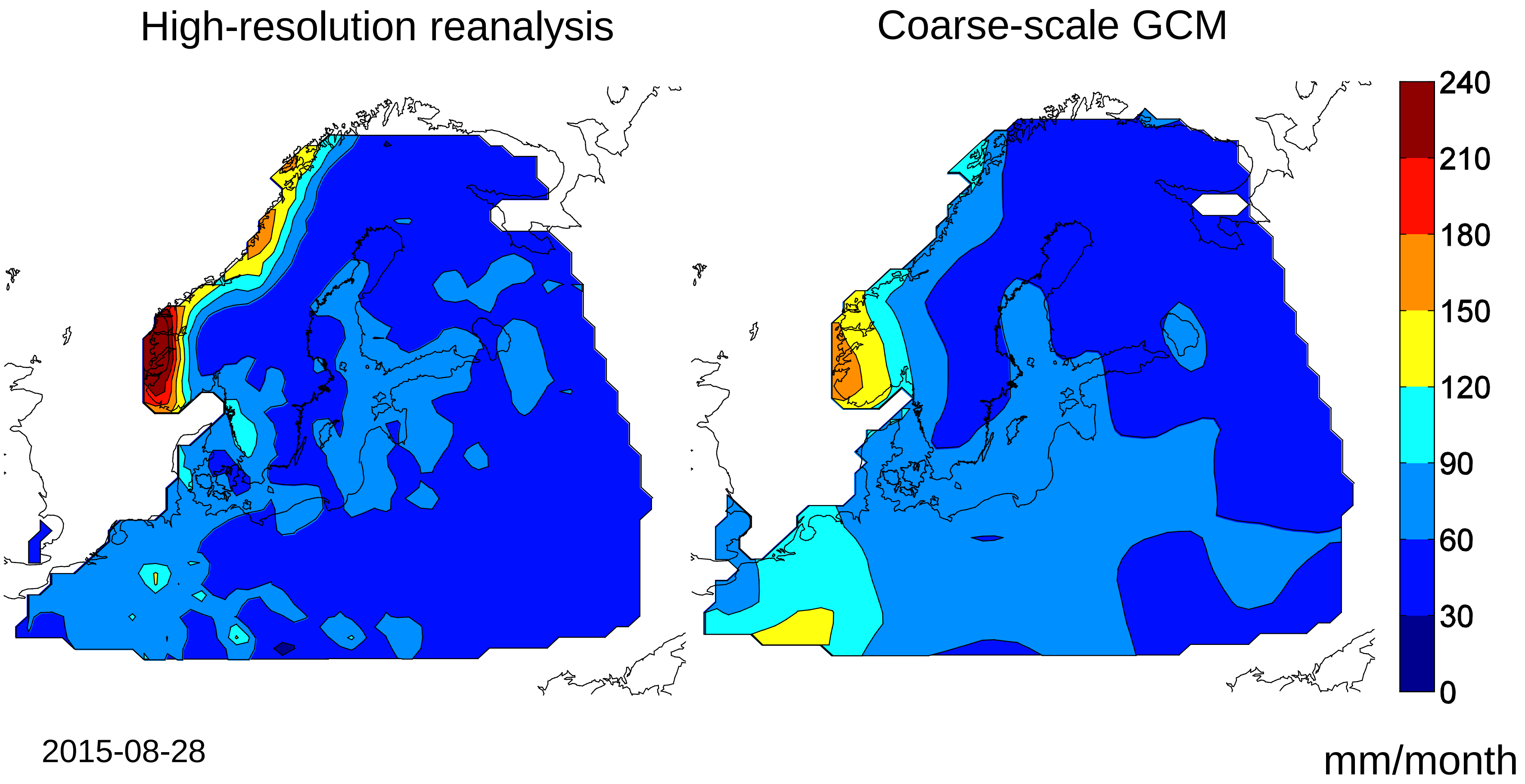
Erik Kjellström, SMHI

011-4958501

(erik.kjellstrom@smhi.se)

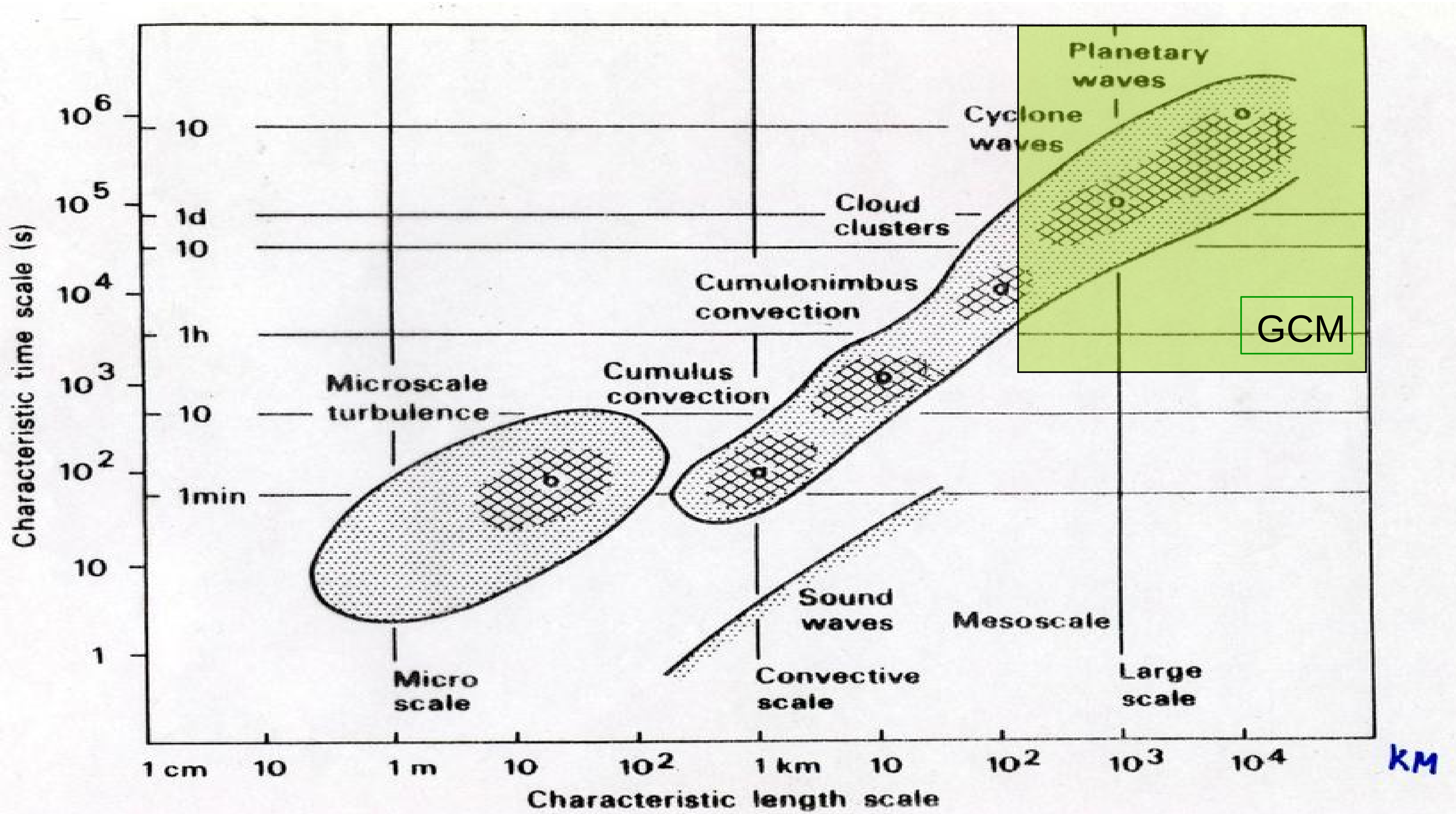
Problems with global climate models (1)

Details in precipitation are not captured: example winter (DJF)



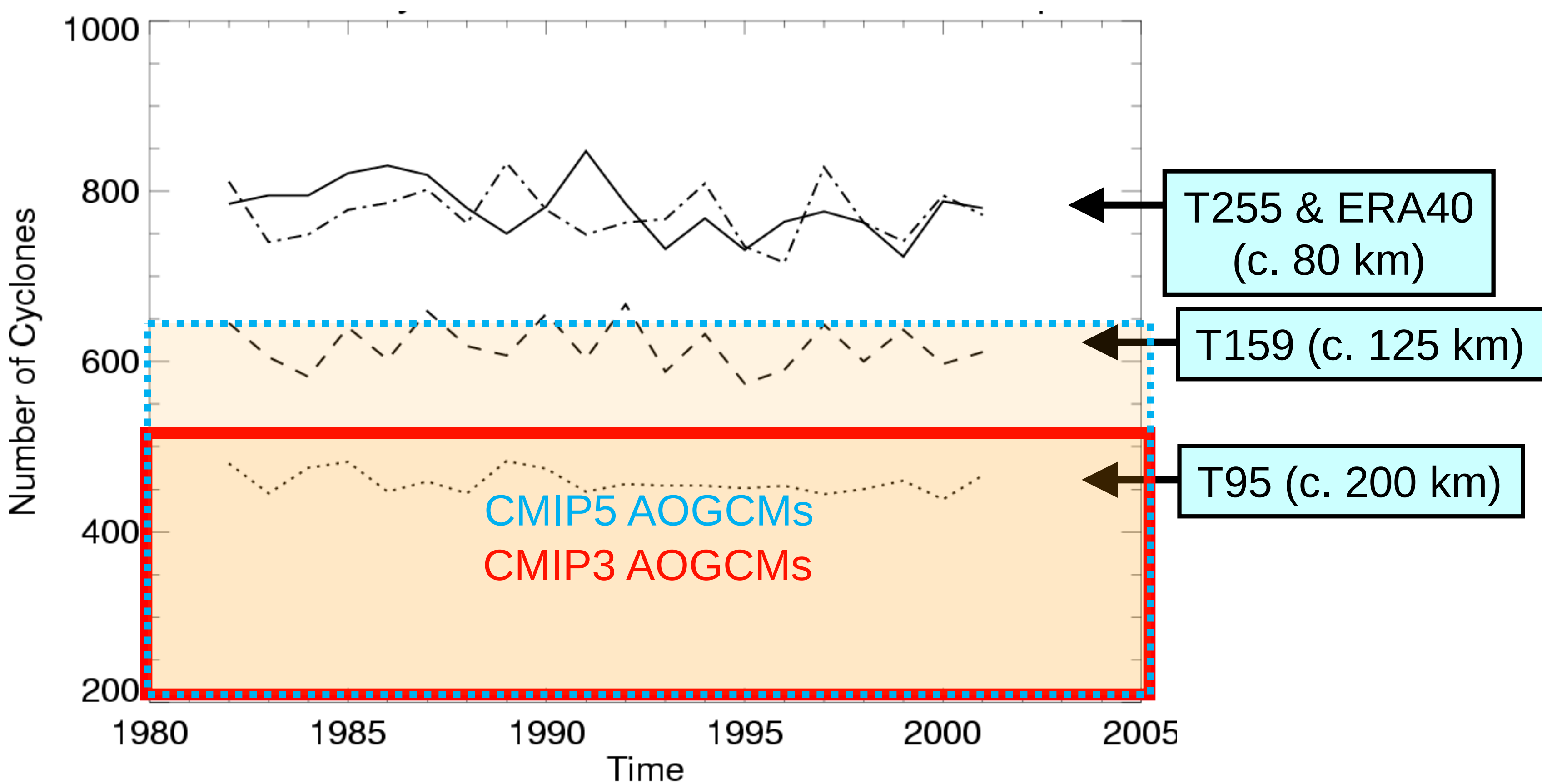
2015-08-28

Spatial and temporal scales in the atmosphere



Problems with global climate models (2)

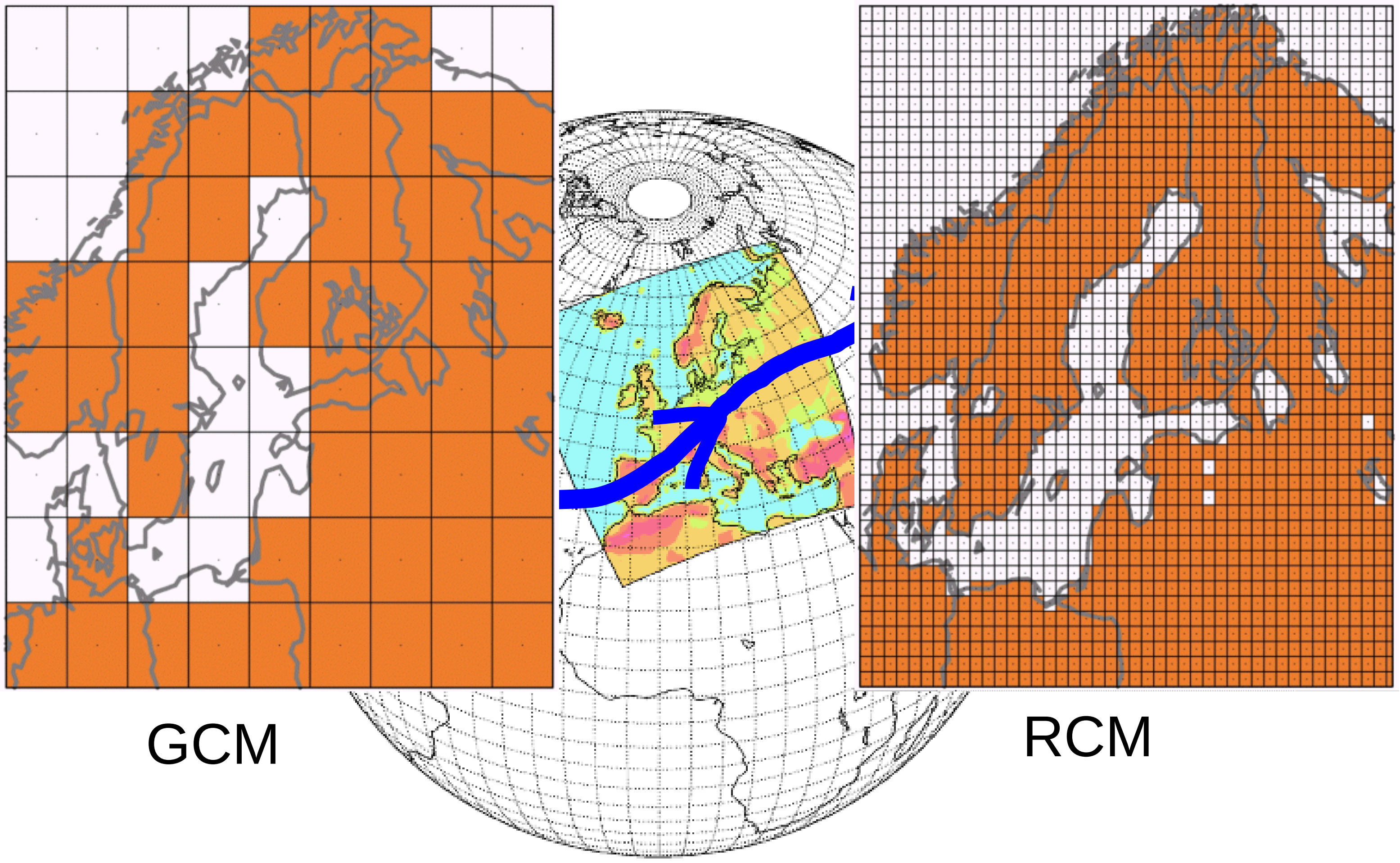
Extra-tropical cyclones over the Northern Hemisphere in winter



2015-08-28

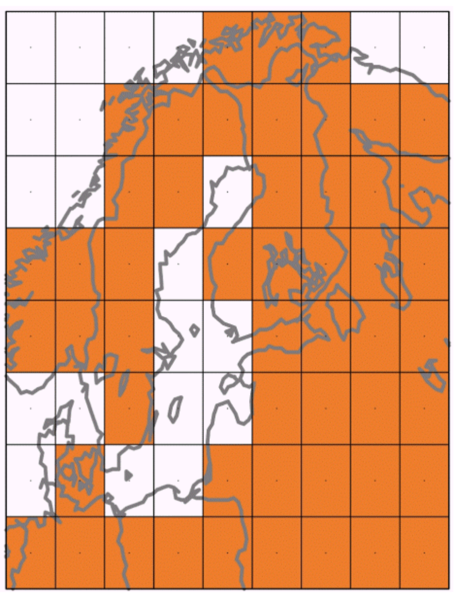
T. Jung (2006)

Regional climate modelling

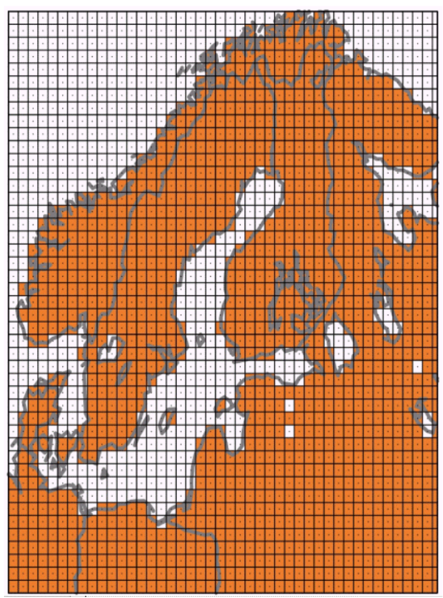


Regional climate models:
Improving global climate scenarios

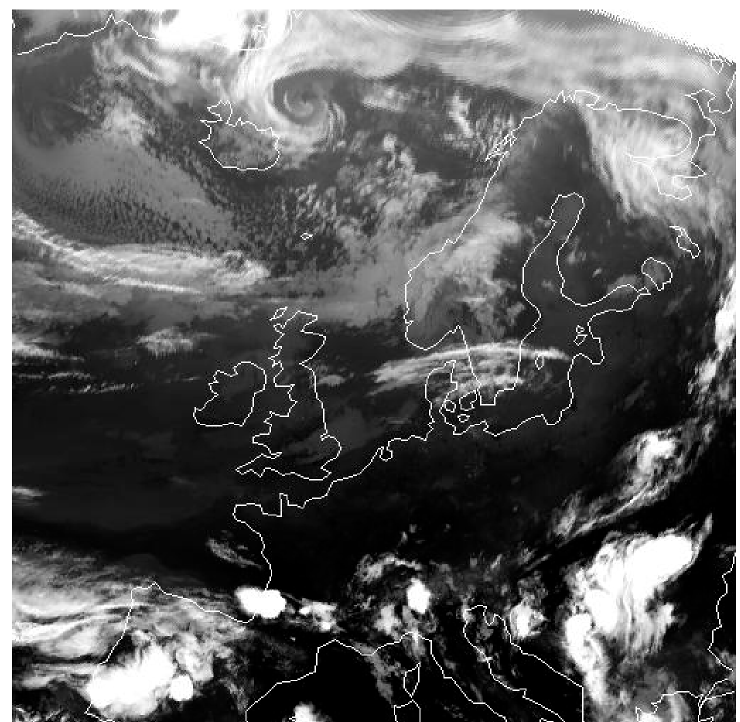
- **Increased resolution → detailed regional forcing**
- **Greater number of explicitly resolved processes**



Global

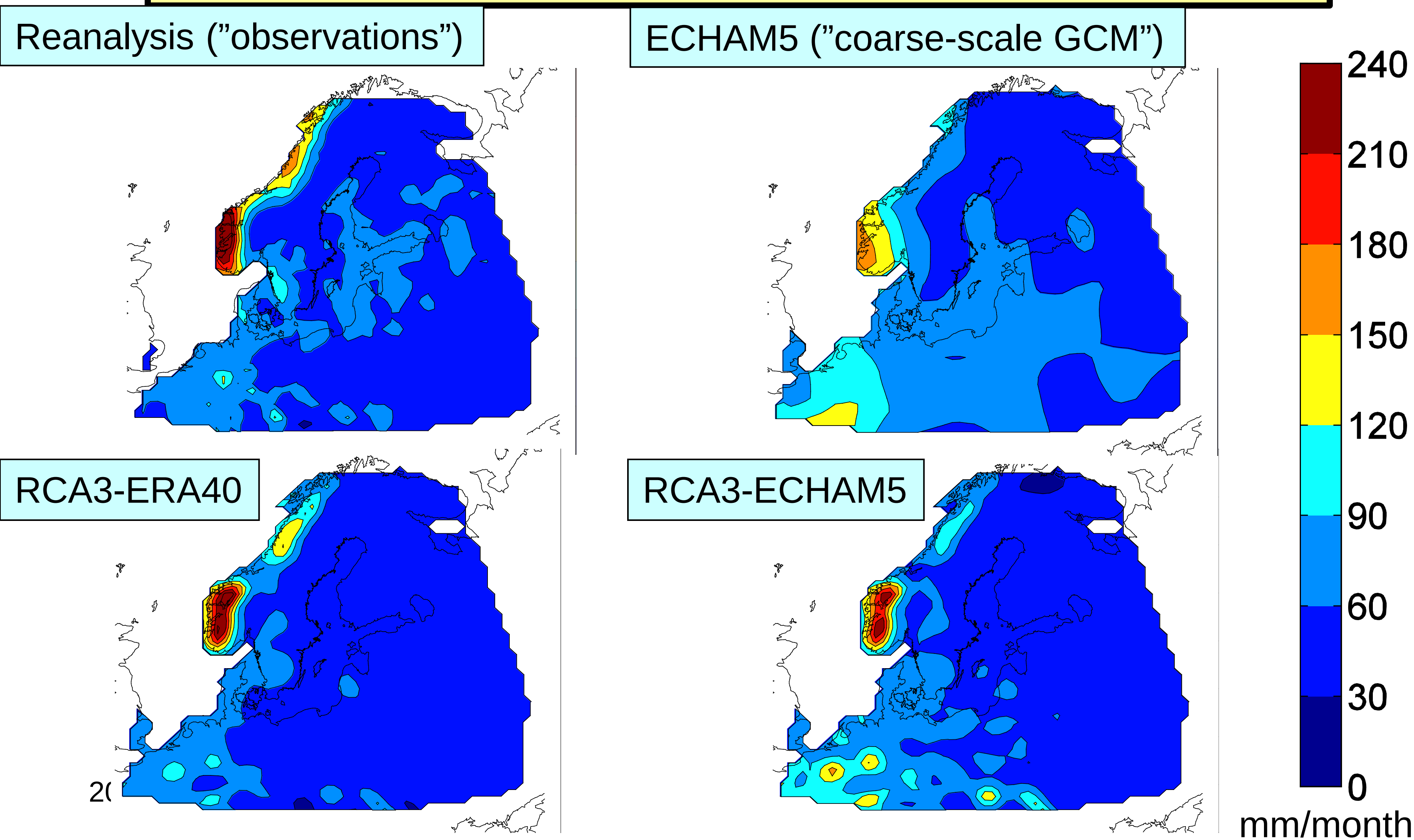


Regional

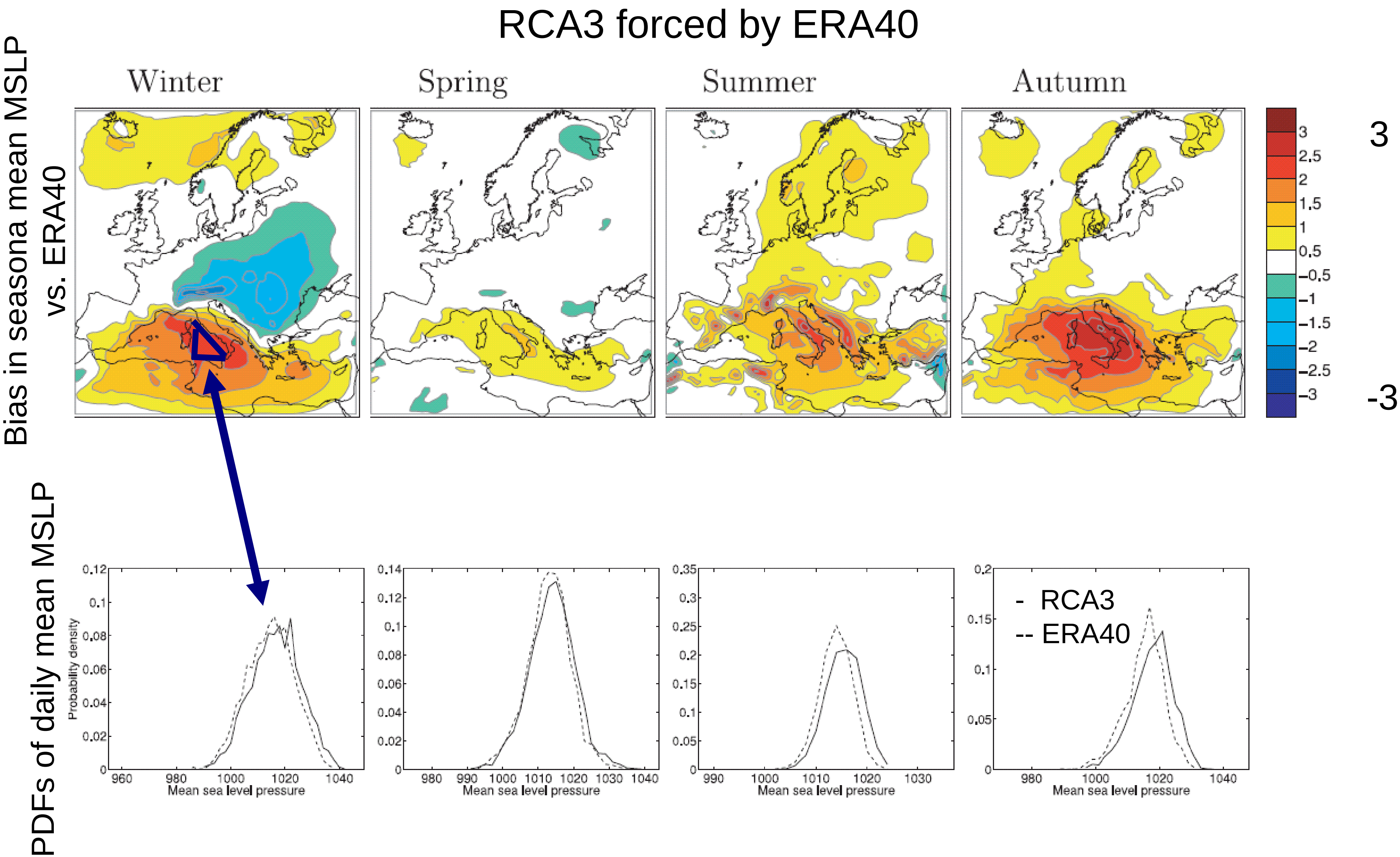


Increased resolution can help

Details in precipitation are improved: example winter (DJF)



Large-scale circulation in RCA3

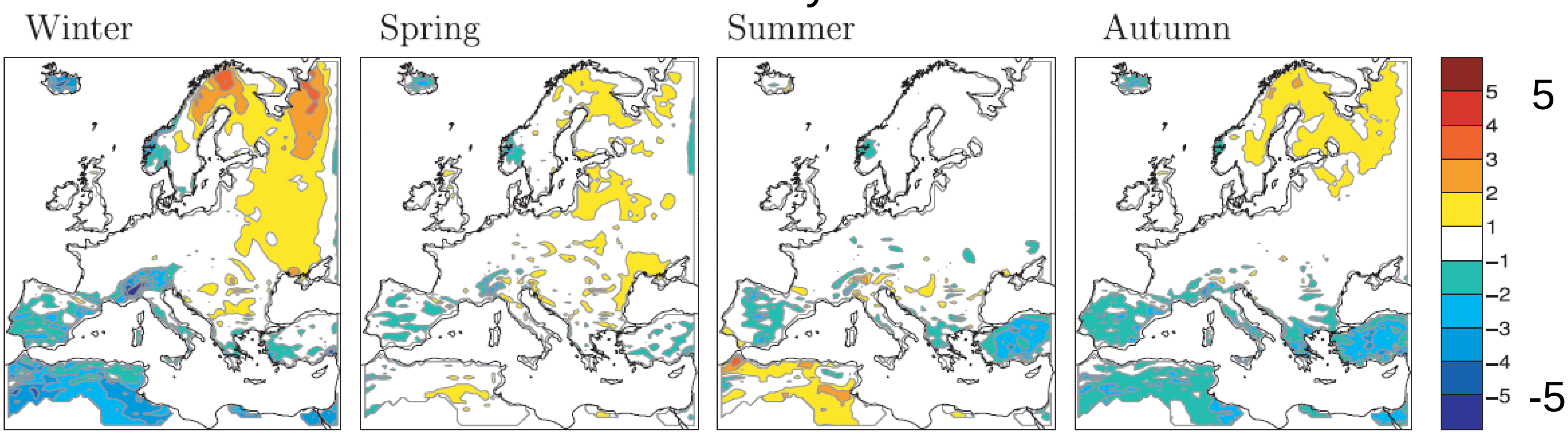


Samuelsson et al., Tellus 2011

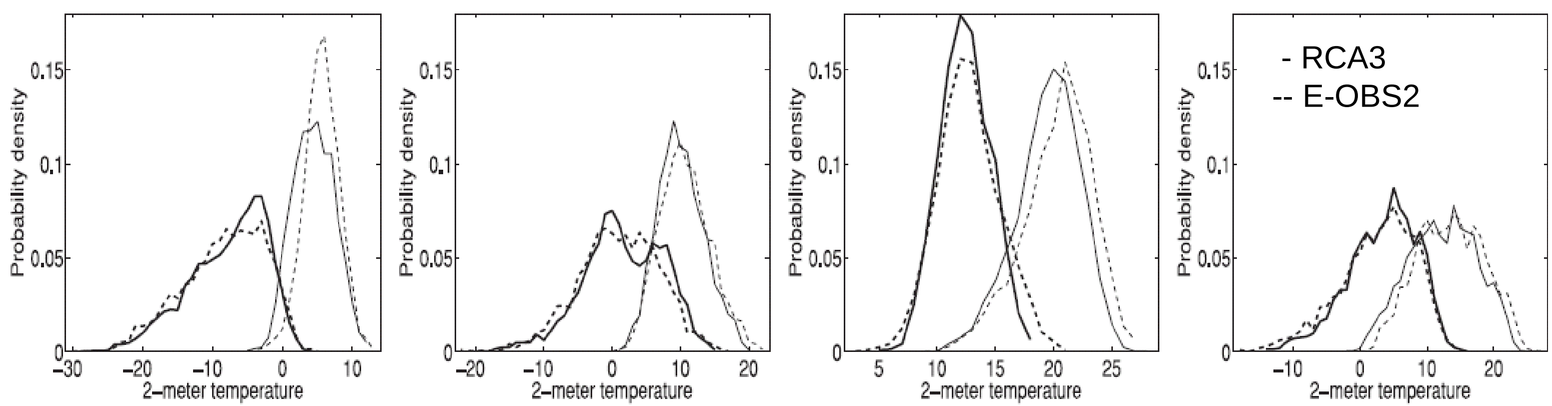
Near-surface temperature in RCA3

RCA3 forced by ERA40

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



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

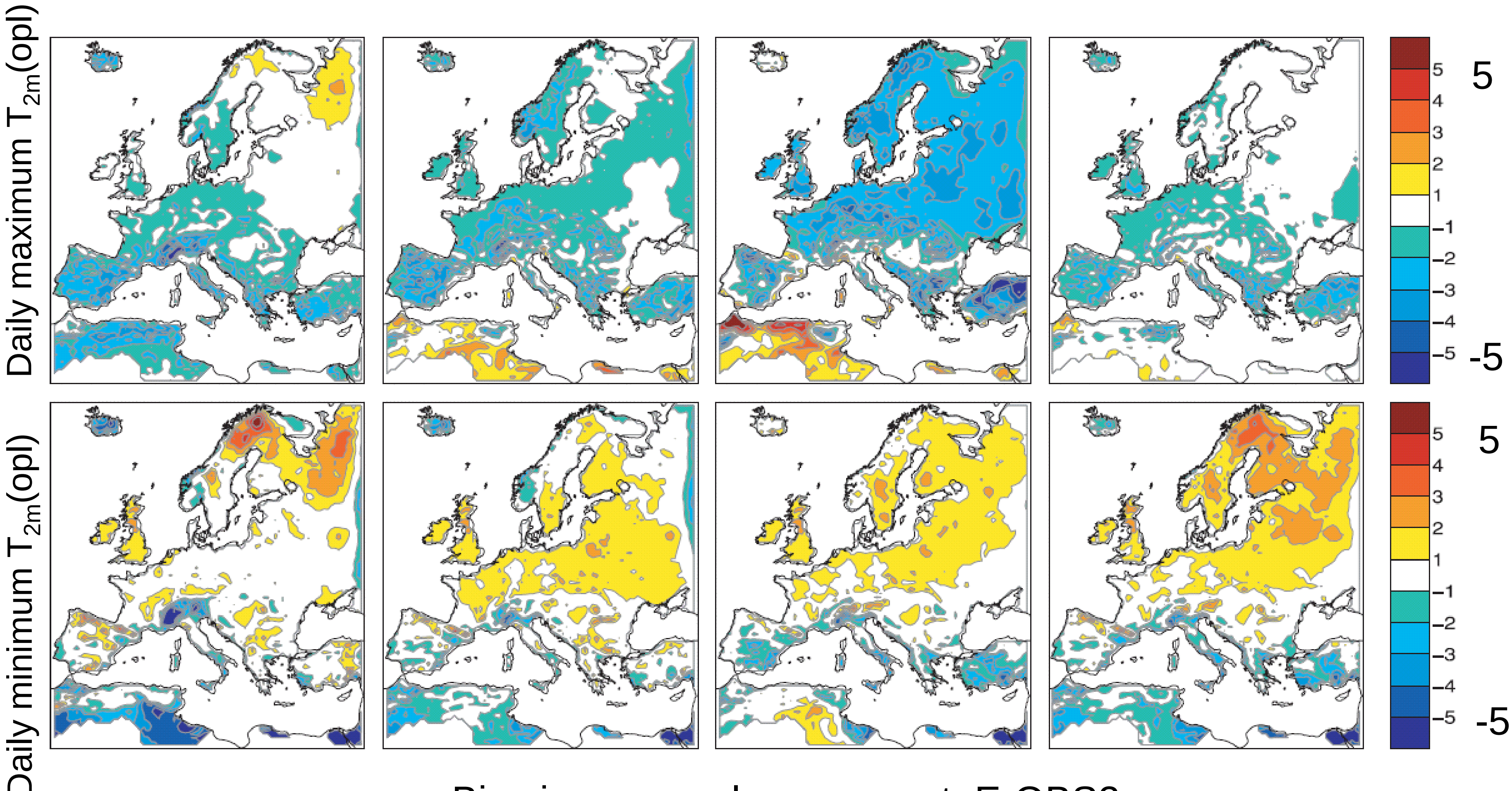


Sweden (thick lines) Iberian Peninsula (thin lines)

Samuelsson et al., Tellus 2011

Near-surface temperature in RCA3

RCA3 forced by ERA40

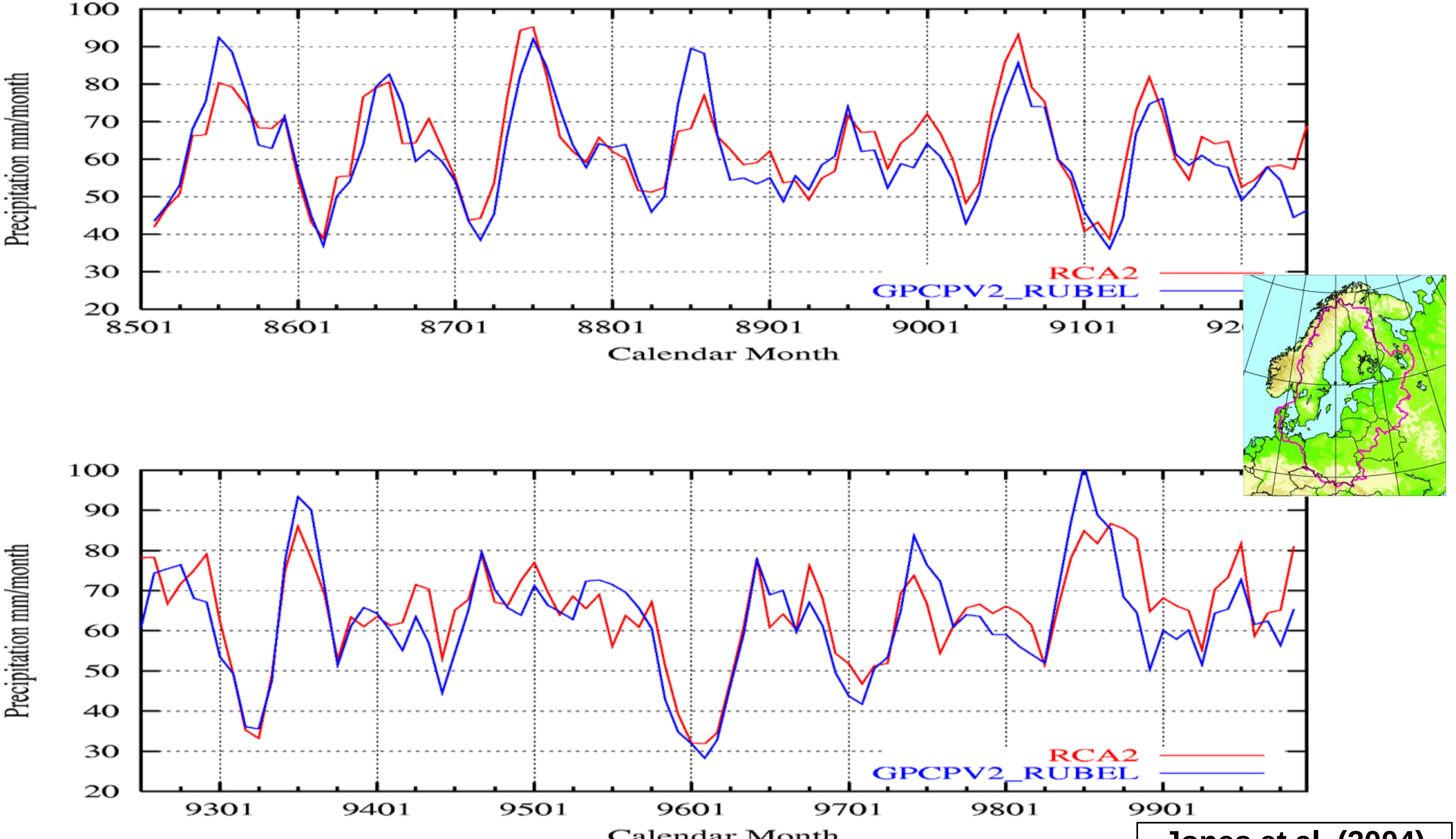


Bias in seasonal means w.r.t. E-OBS2

Samuelsson et al., Tellus 2011

Evaluation on the regional scale

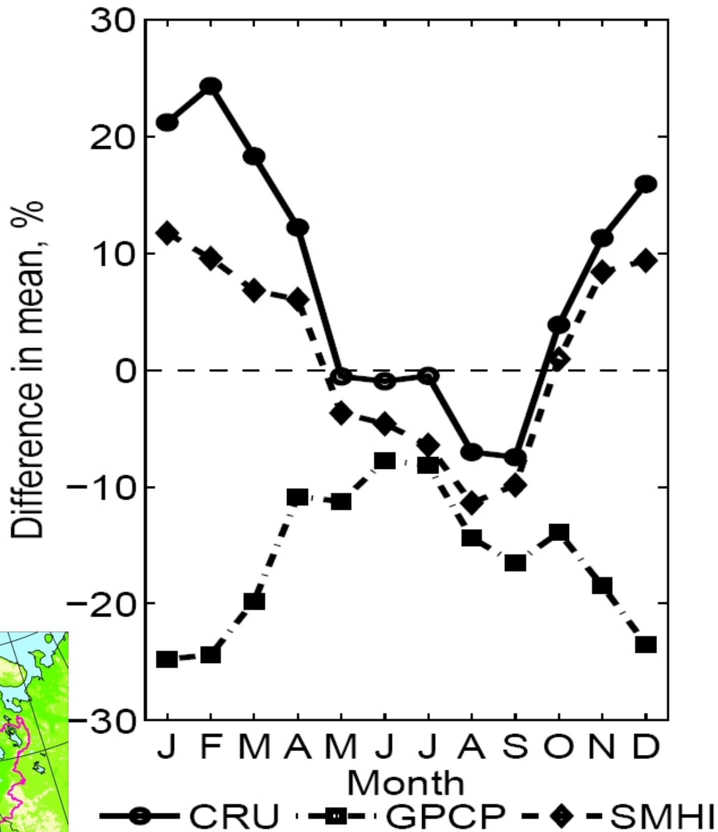
Monthly mean precipitation in the Baltic Sea runoff area



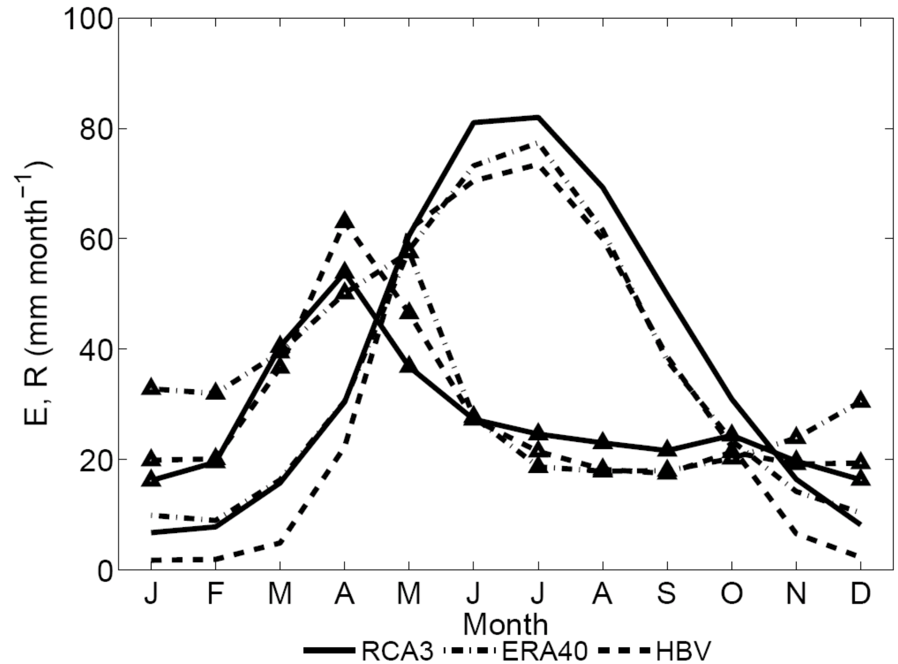
Jones et al. (2004)

Can we trust the observational data?

Three precipitation climatologies (1979-2002) for the Baltic Sea drainage basin compared to reanalysis data (ERA40)



Observational data on evaporation and surface runoff hardly exist at all

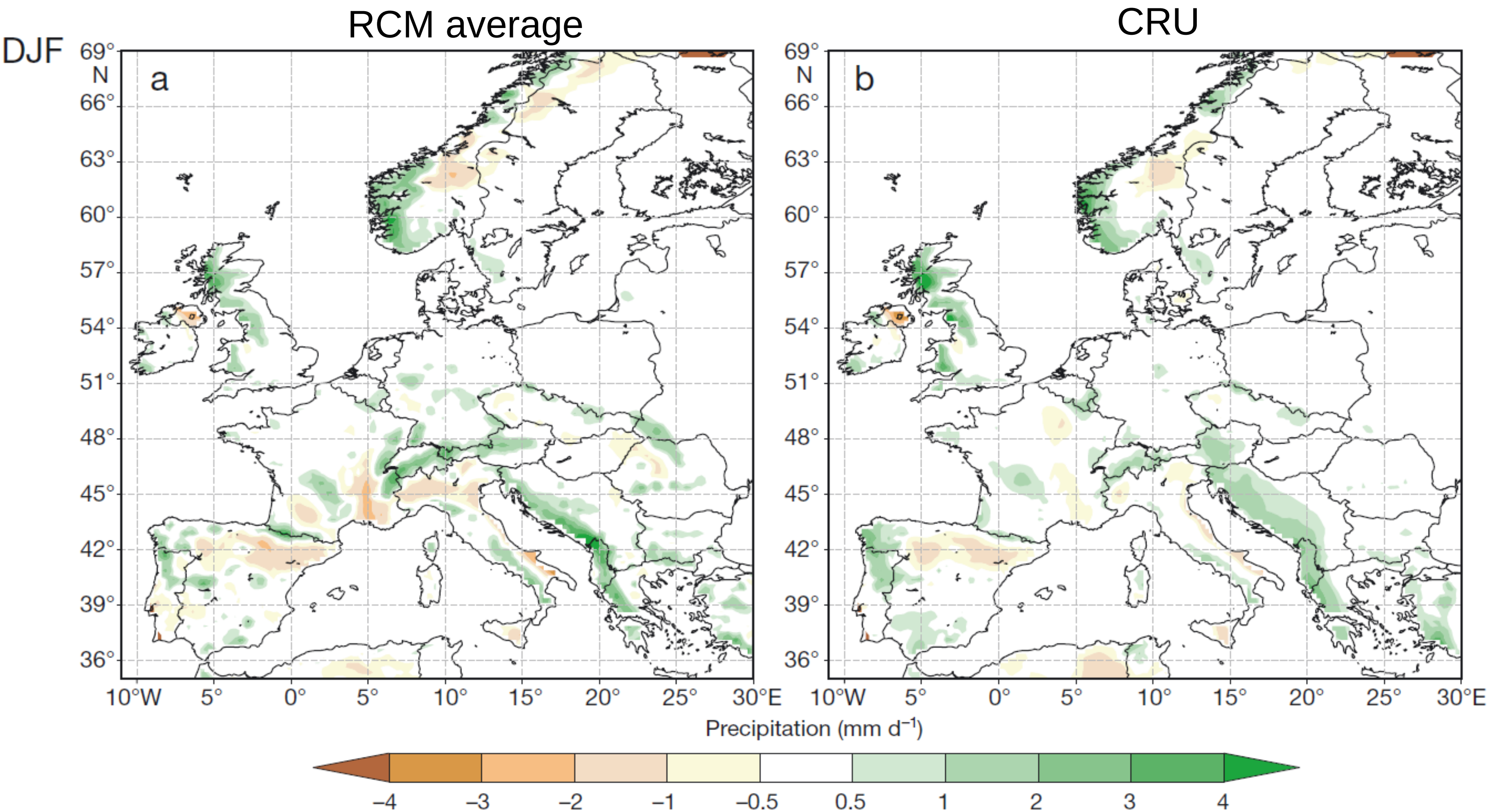


Comparing model to models!

Lind and Kjellström (2009)

Reproduction of ”meso-scale” features in RCMs

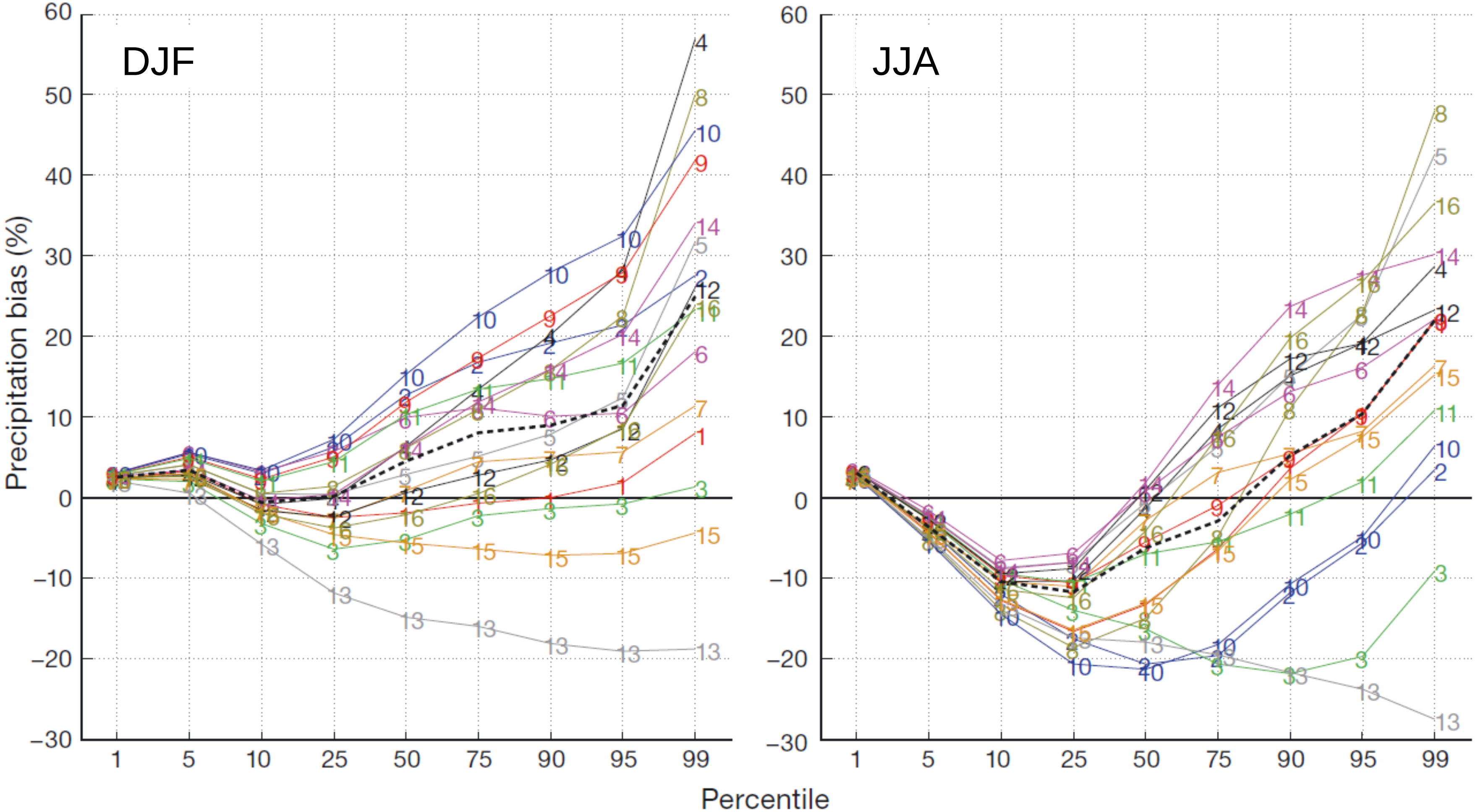
Large-scale (200-250 km) features have been filtered out



Coppola et al., special issue Climate Research, 2010

How good are RCMs at reproducing statistics of daily precipitation?

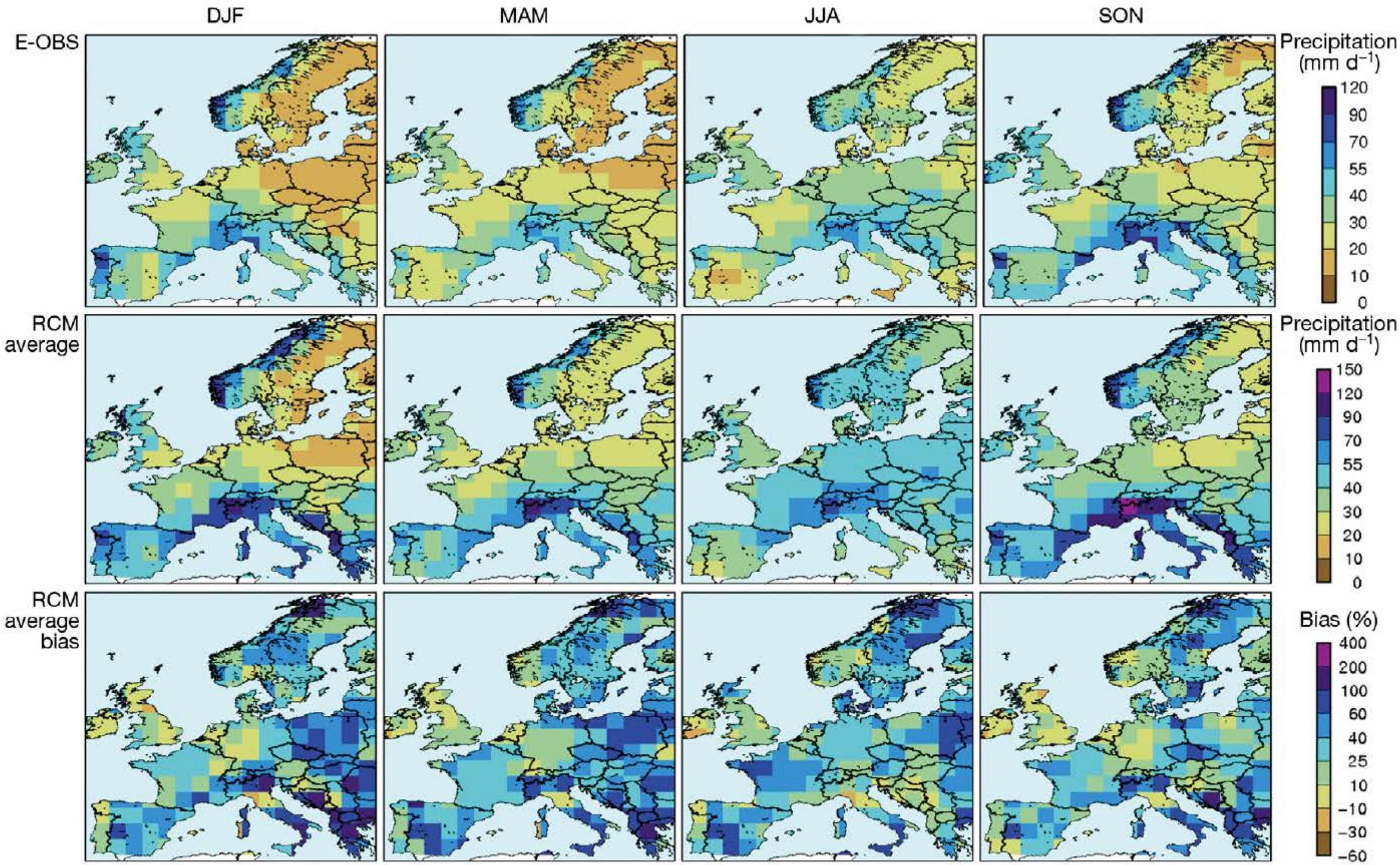
Comparison between RCMs and E-OBS for all European land areas
(dashed line is the ensemble mean)



Kjellström et al., special issue Climate Research, 2010

How good are RCMs at reproducing extremes of daily precipitation?

Comparison between RCMs and E-OBS for P99.9

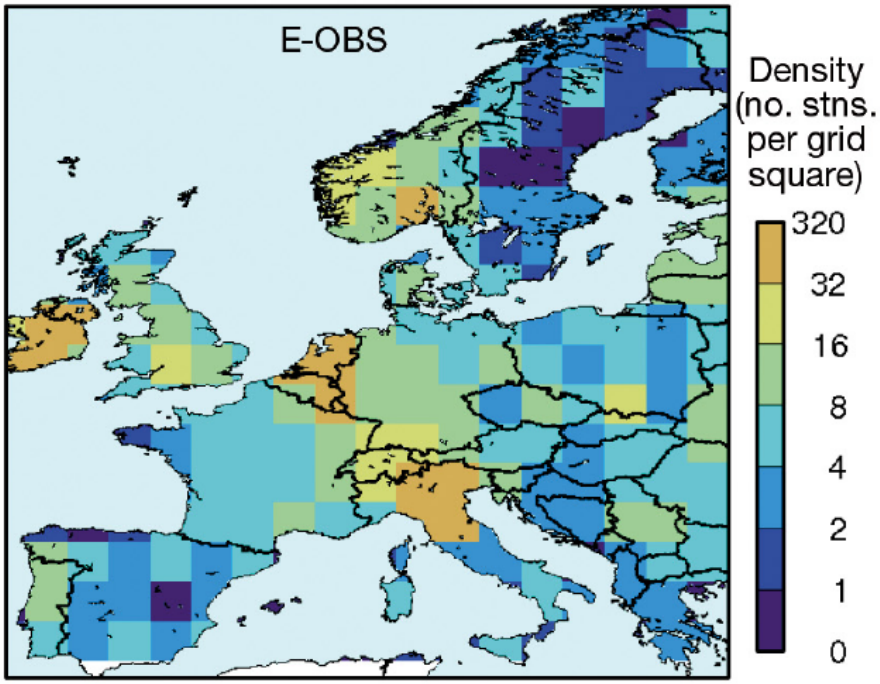


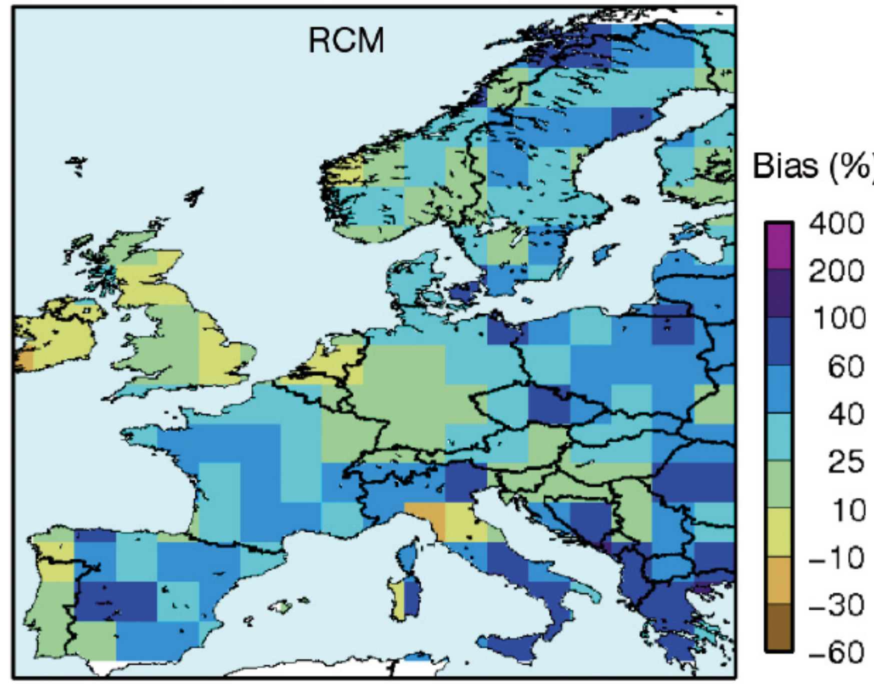
Lenderink, special issue Climate Research, 2010

Are biases a pure model problem?

Station density in E-OBS

Bias in P99.9

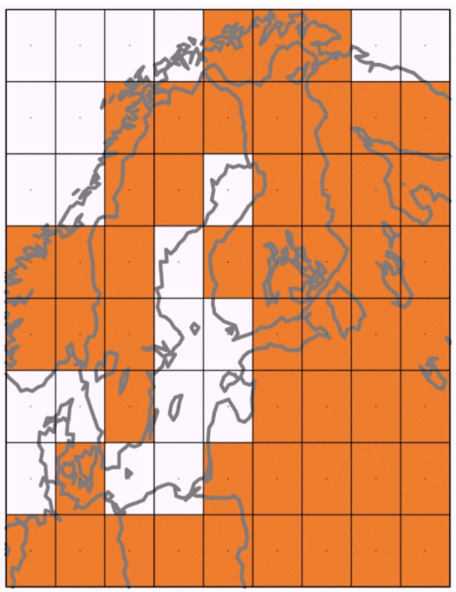


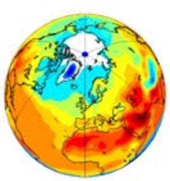


Lenderink, special issue Climate Research, 2010

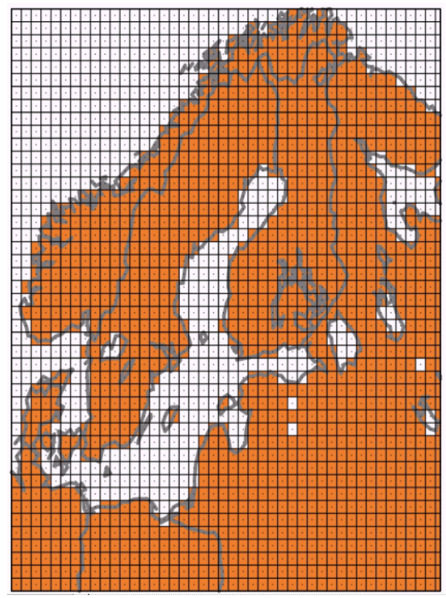
Is model resolution high enough?

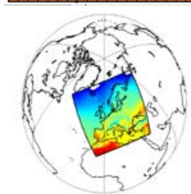
- **Details (i.e. land/sea distr., mountains)**
- **Processes that need explicit description**



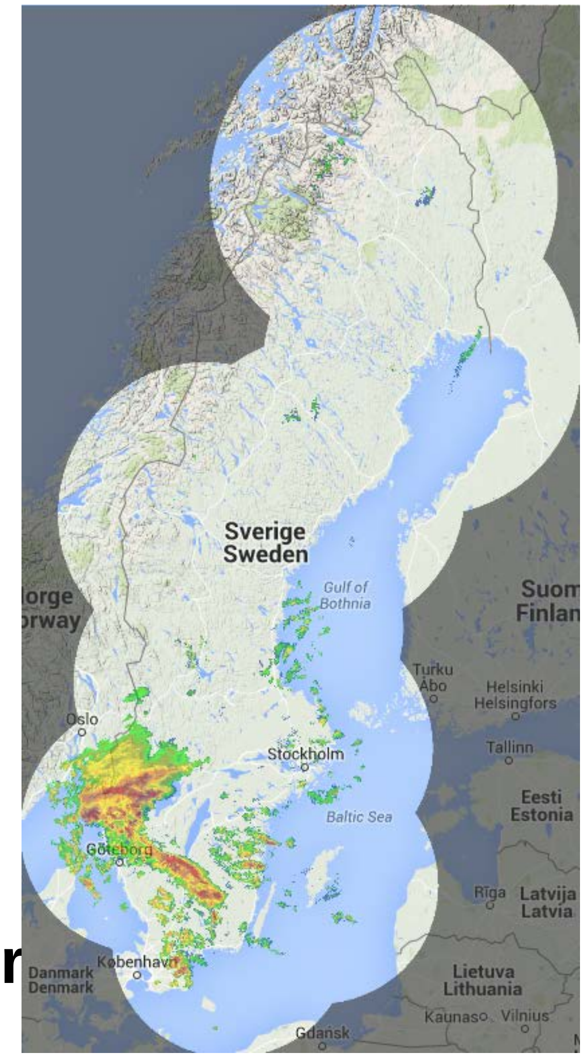


Grid in a GCM





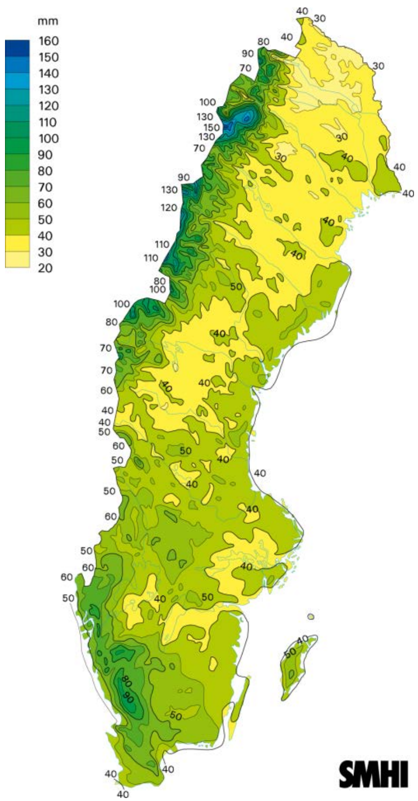
Grid in a RCM



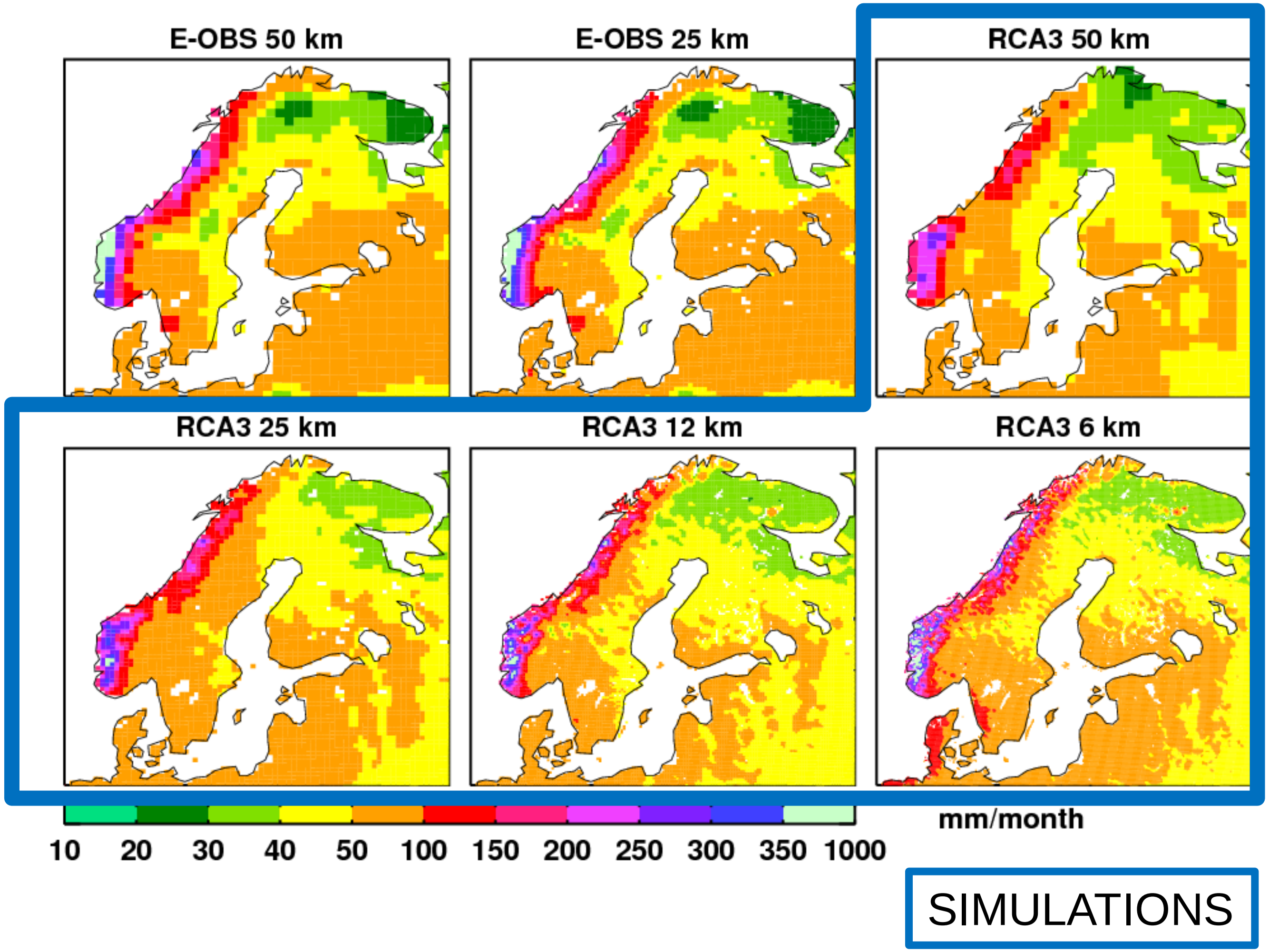
- **Compromise with computational power**

Towards higher resolution

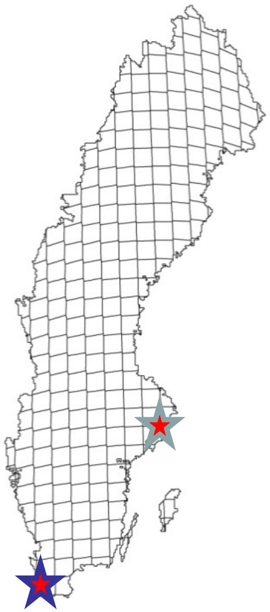
Observed Precipitation January 1961-1990

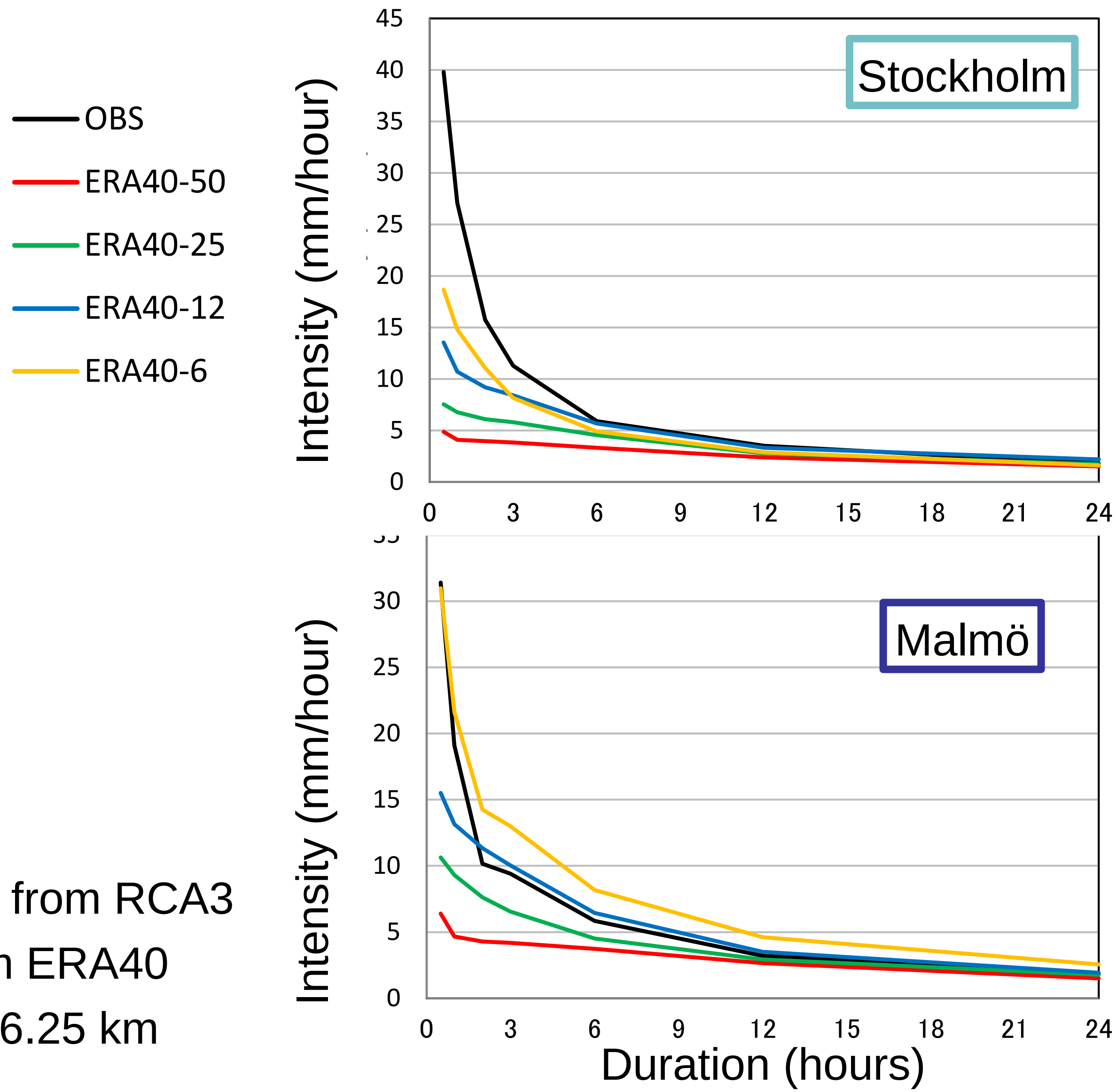


Winter (DJF) precipitation 1987-2007



Intensity and duration





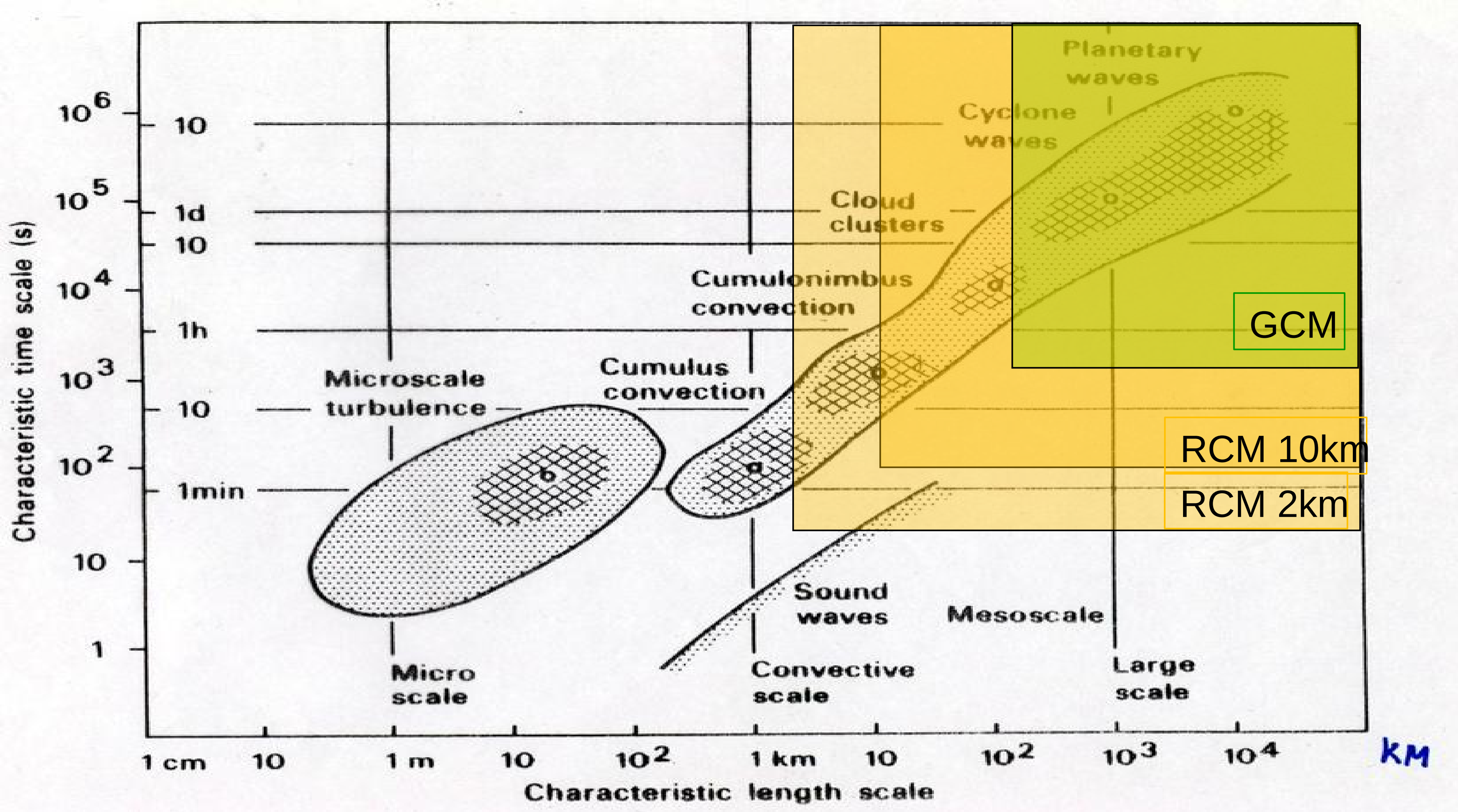
Period: 1995-2010

Observations: 30-min automatic

RCM-data: - 30-min precipitation from RCA3
with LBCs from ERA40
- resol. 50, 25, 12.5, 6.25 km
- 3×3 grid-boxes

From Jonas Olsson, SMI

Spatial and temporal scales in the atmosphere

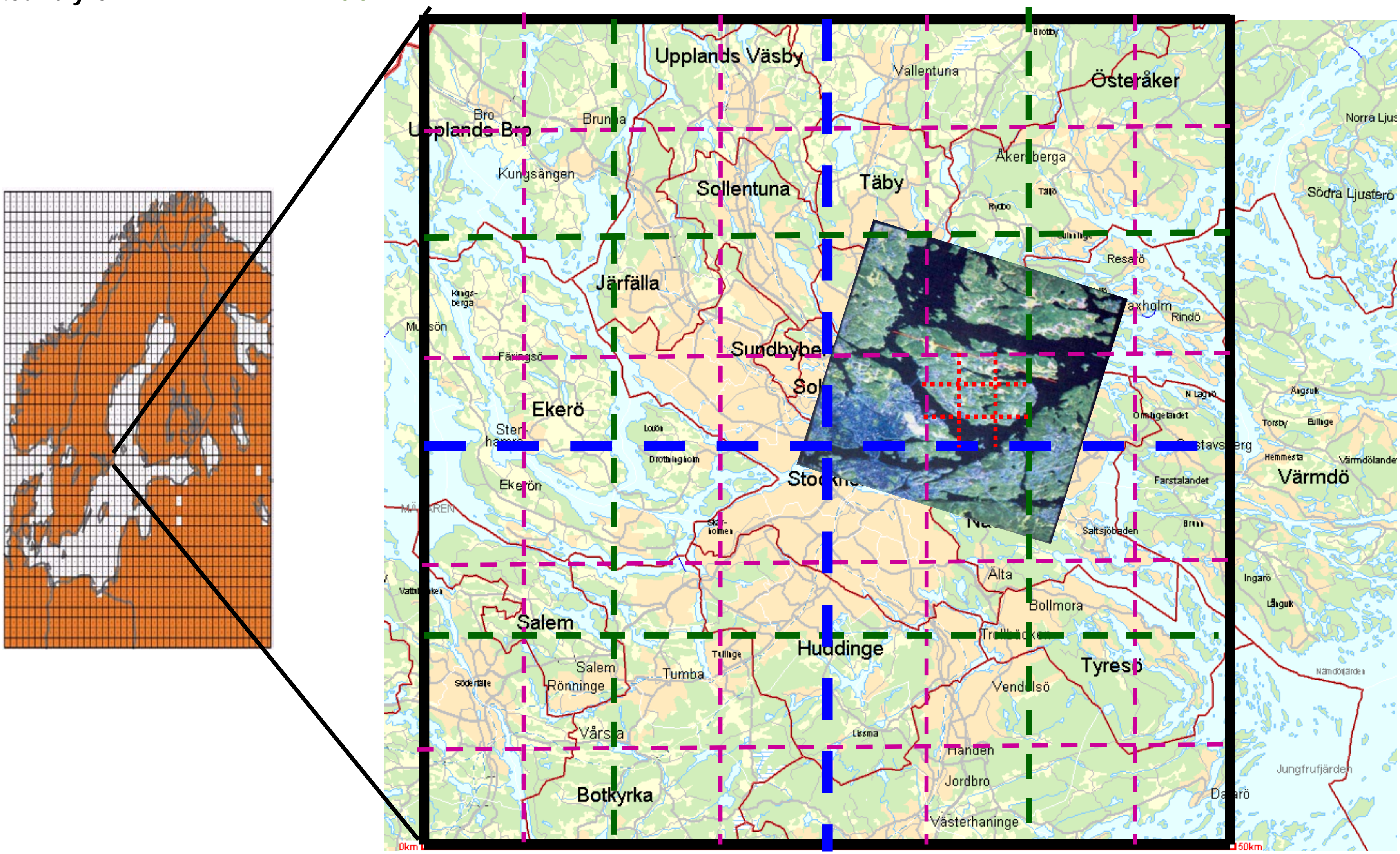


Towards higher spatial resolution

50 km ➔ 25 km ➔ 12 km ➔ 6 km ➔ 2 km

standard last 10 yrs | **ENSEMBLES** | **EURO-CORDEX** | **experiment al** | **future**

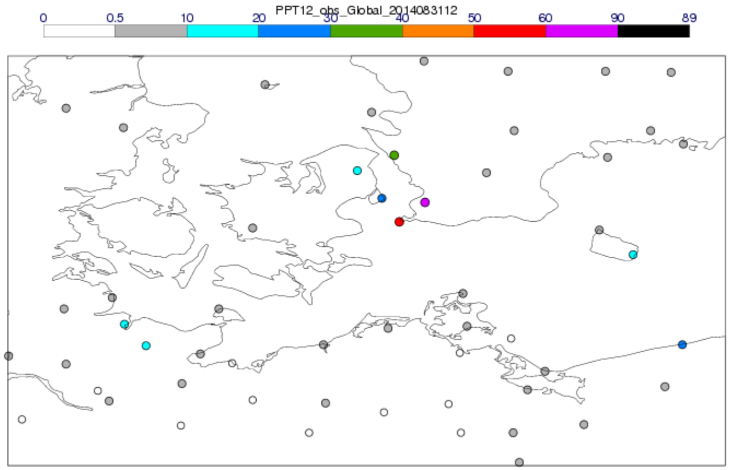
each step requires ~8 times more computer resources



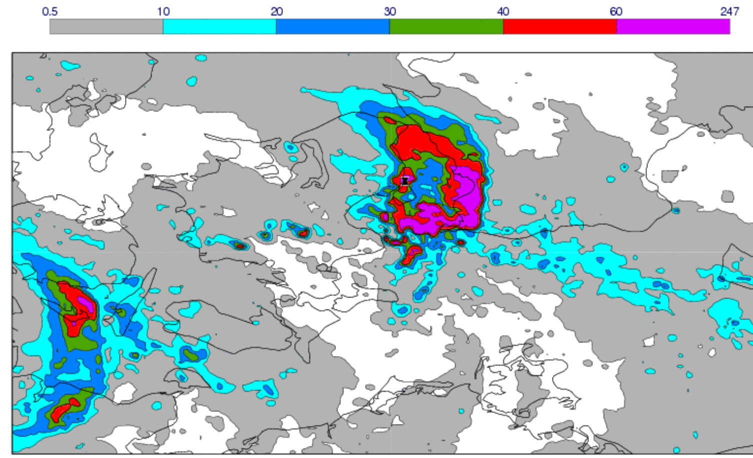
"Modellutveckling: mot lokal skala"

“Malmöregnet” 31/8 2014 (0200-1400)

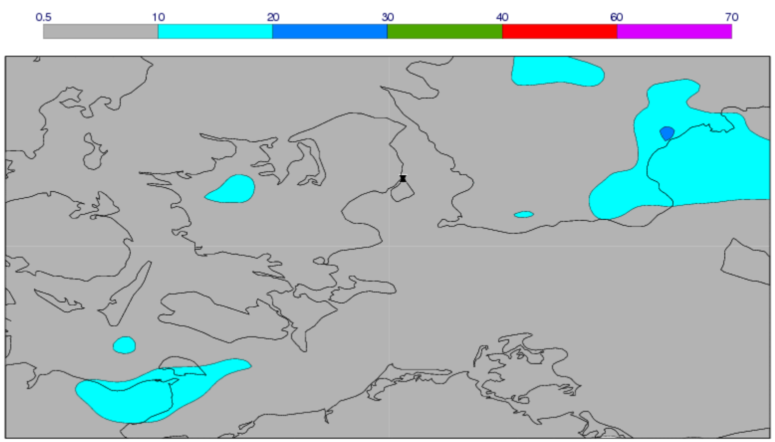
Observed precipitation



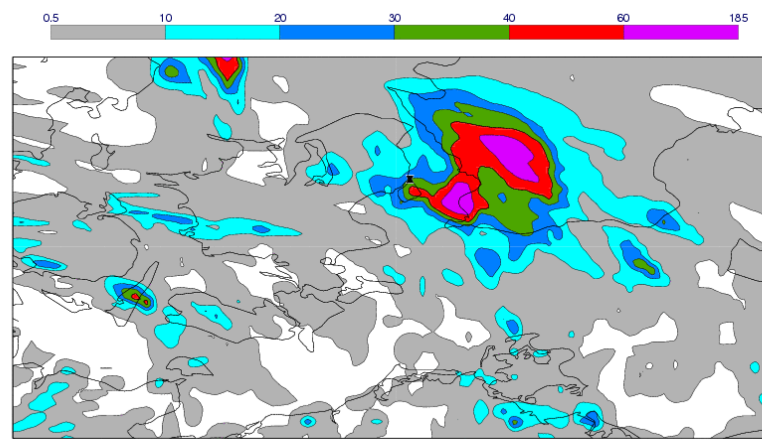
Precipitation from weather radar



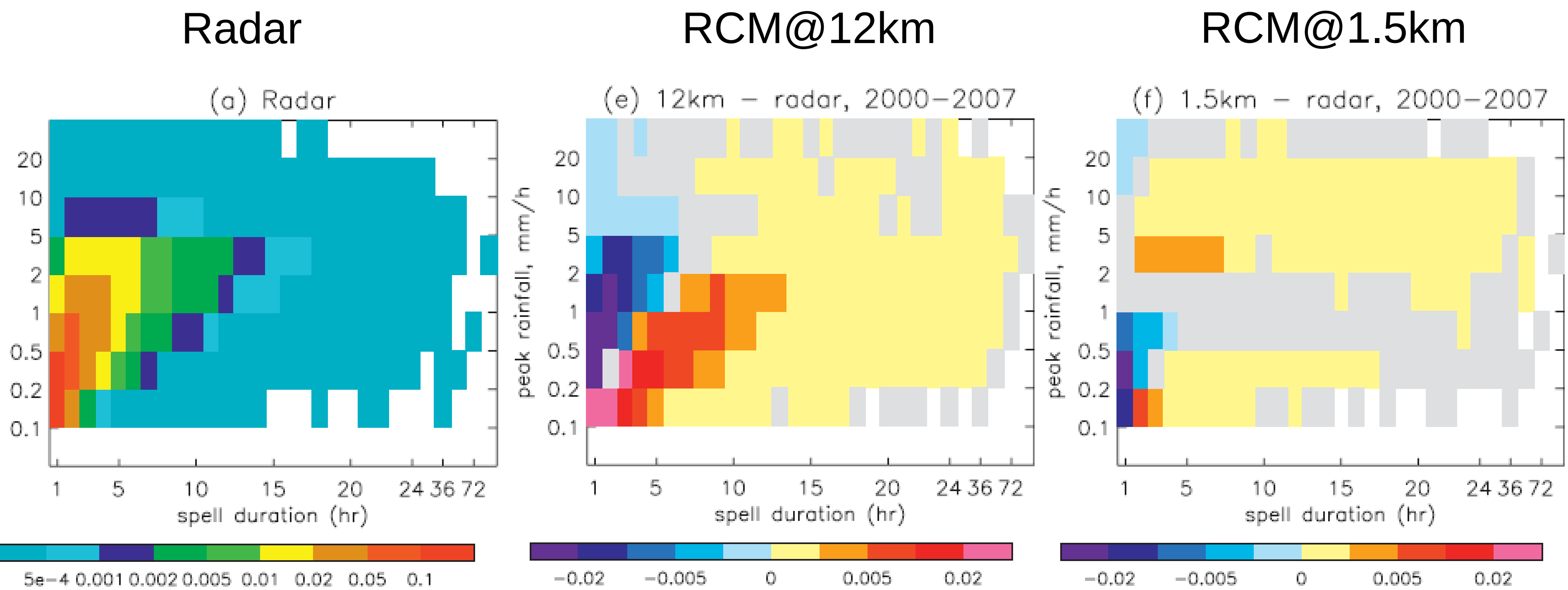
Fcst from global NWP
(16 km resolution)



Fcst from the SMHI regional NWP
(2.5 km resolution)



Precipitation in southern Britain (1)



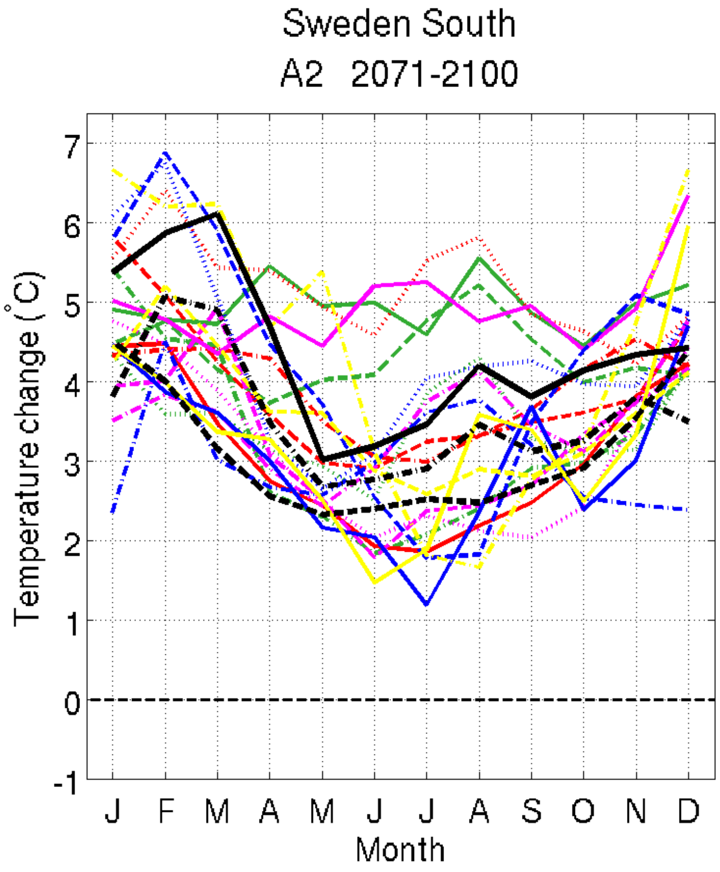
- High-resolution RCMs better capture intense precipitation
- In particular for convective precipitation

Kendon et al., J Clim, 2012

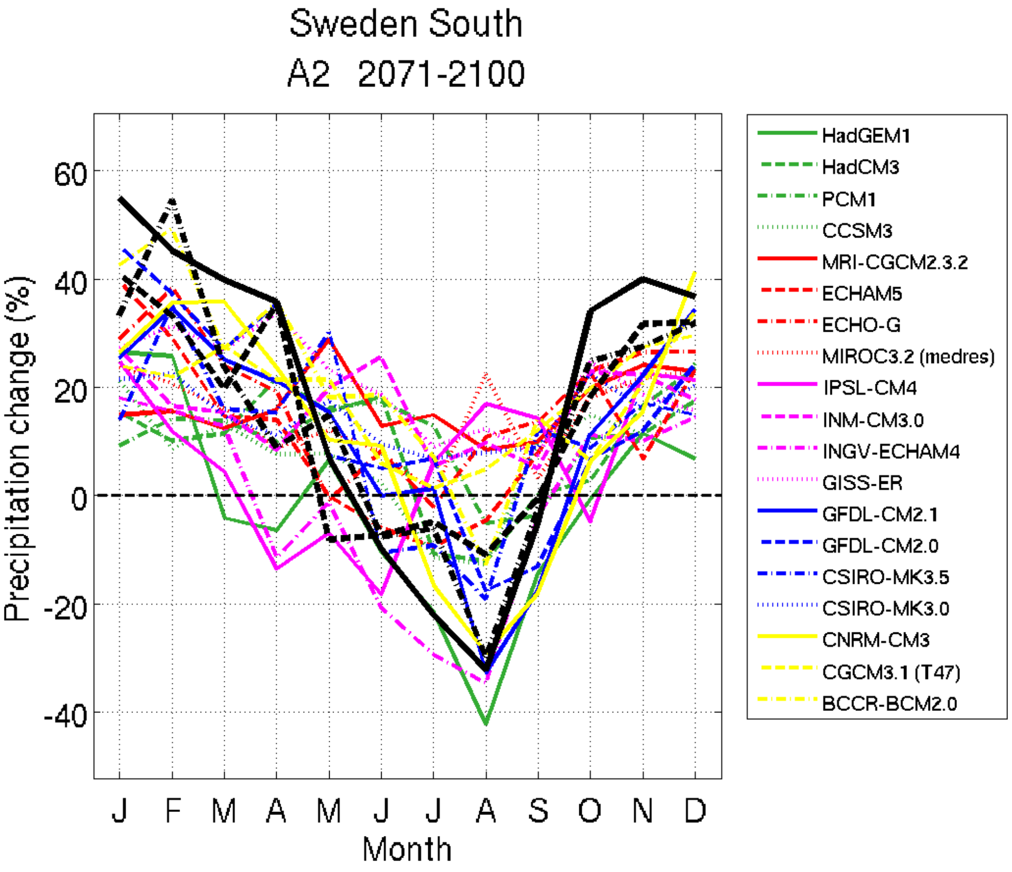
Use of RCMs for climate change studies

Different signals from different GCMs

Example for southern Sweden (2071-2100 vs 1961-1900)



Temperature



Precipitation

Multiple simulations

SMHI

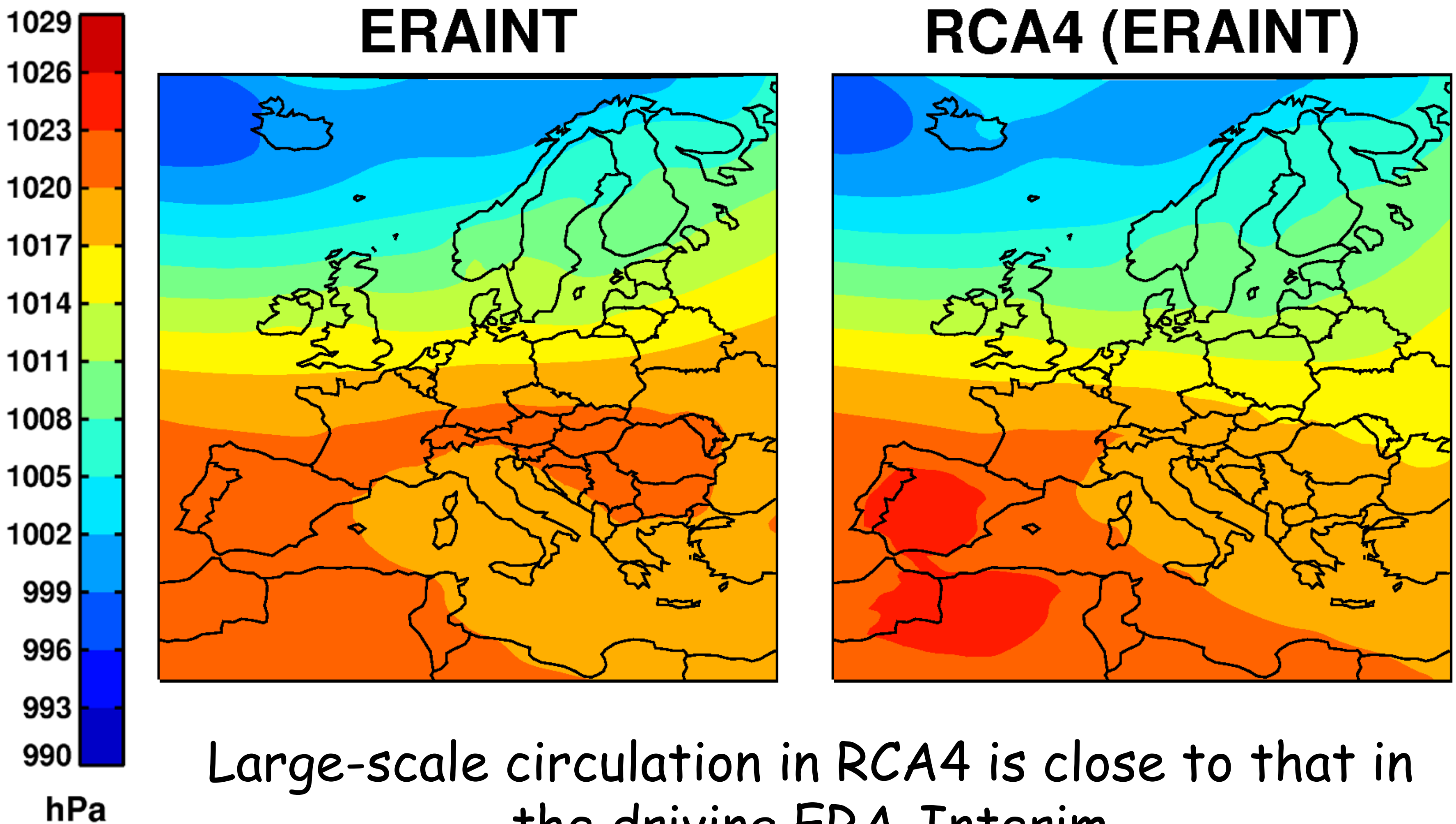
RCA4 set up on the Euro-CORDEX domain at 0.44° (~50 km) and 0.11° (~12.5 km) horizontal resolution. ERA-Interim and GCM driven simulations

RCA4 nested in (GCM name)	RCP2.6	RCP4.5	RCP8.5
CanESM2		X	X
CNRM-CM5		X X	X X
EC-EARTH	X X	X X	X X
GFDL-ESM2M		X	X
HadGEM2-ES		X X	X X
IPSL-CM5A-MR		X	X X
MIROC5		X	X
MPI-ESM-LR		X	X X
NorESM1-M		X	X
	1 (1)	9 (3)	9 (5)

Historical simulations

Large-scale circulation (DJF)

SMHI

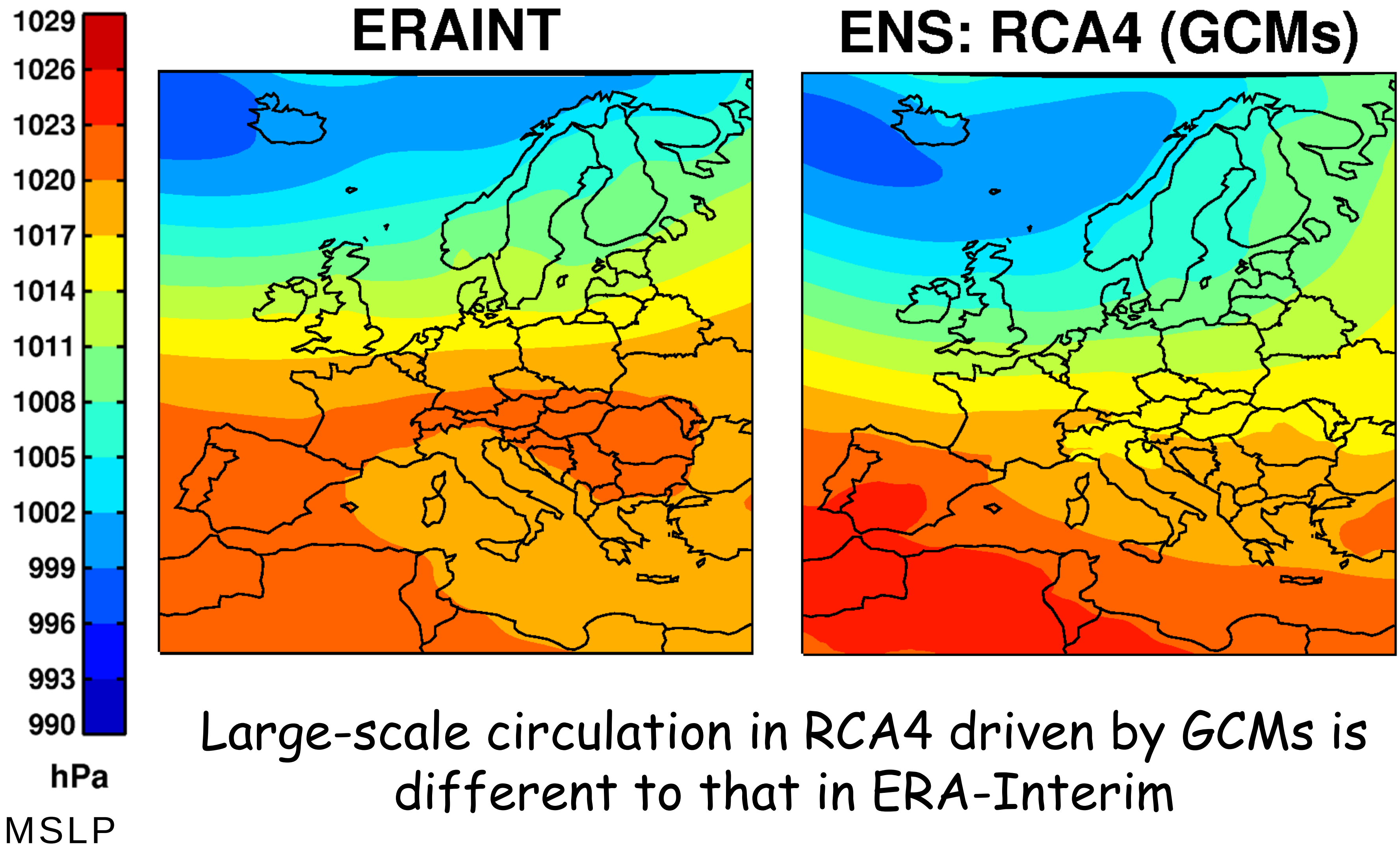


MSLP

Large-scale circulation in RCA4 is close to that in the driving ERA-Interim

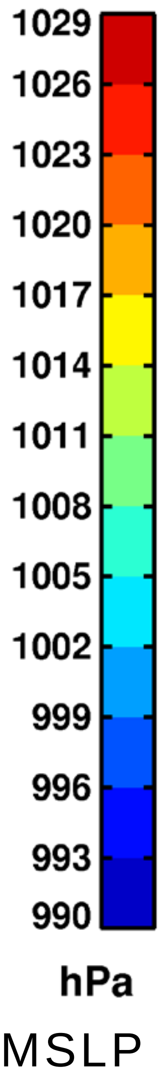
Large-scale circulation (DJF)

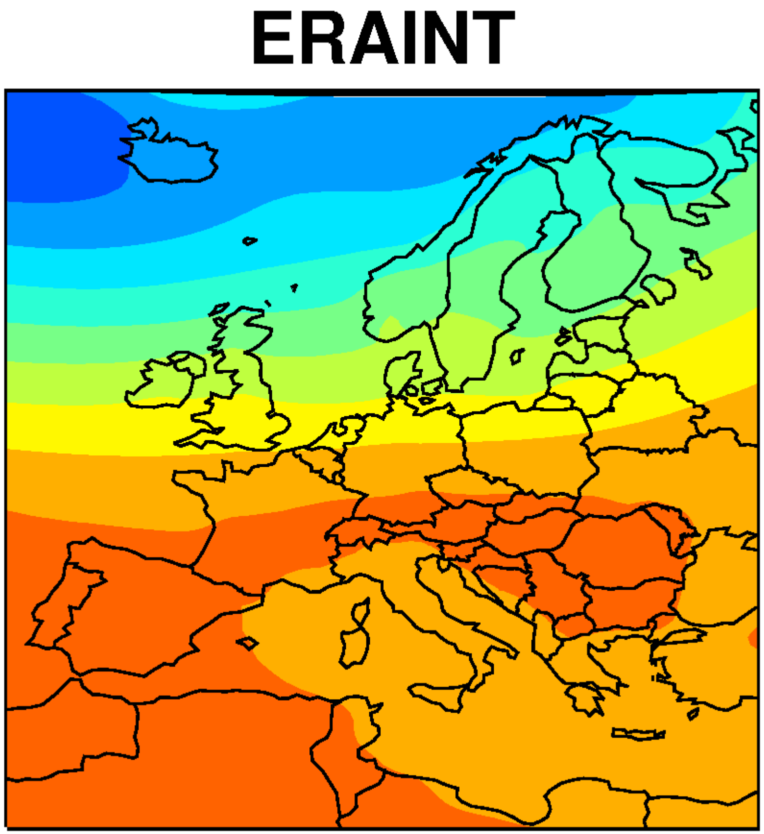
SMHI

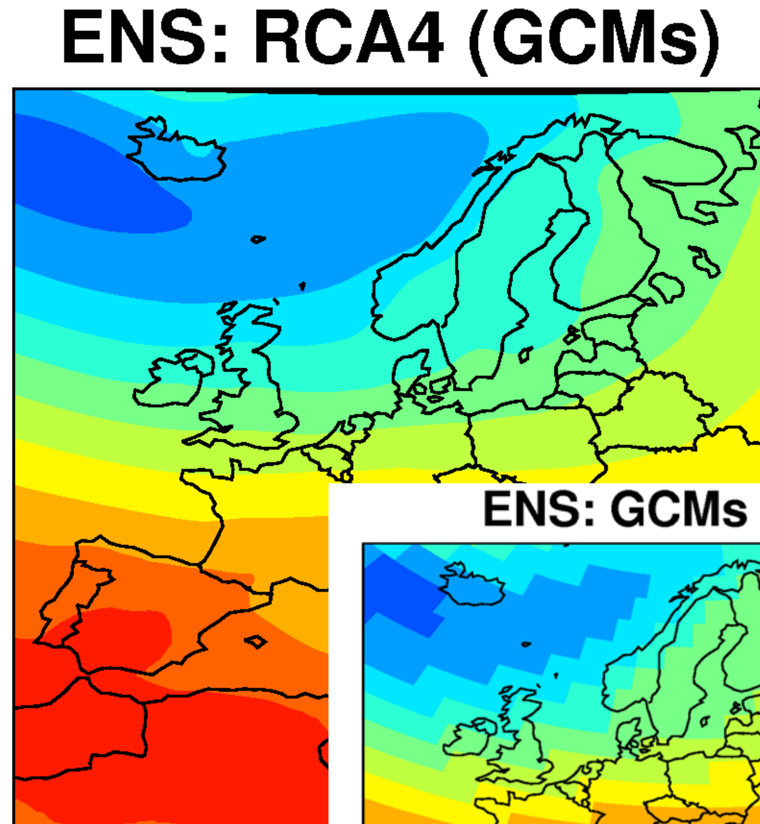


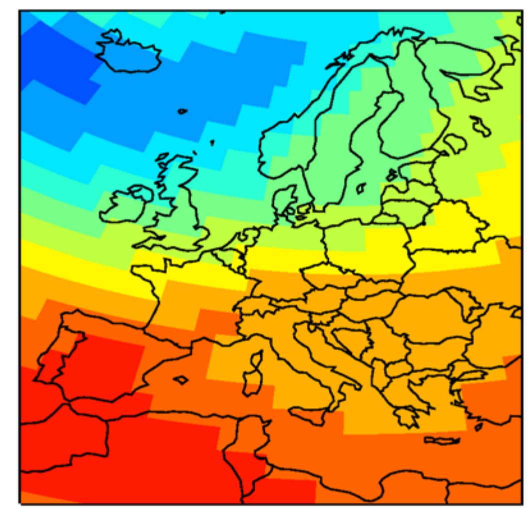
Large-scale circulation in RCA4 driven by GCMs is different to that in ERA-Interim

Large-scale circulation (DJF)



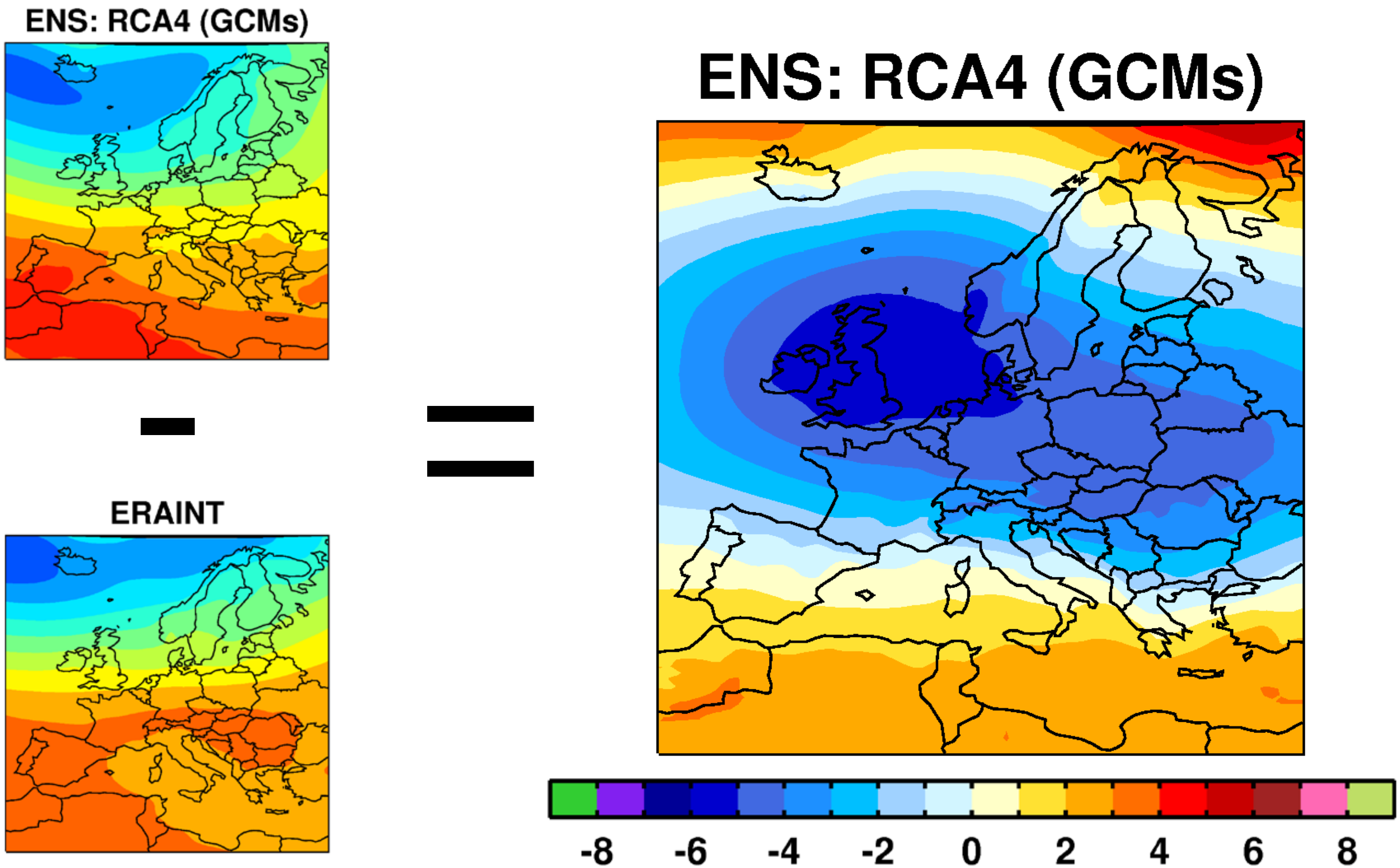






Biases originate from underlying GCMs

Large-scale circulation (DJF)

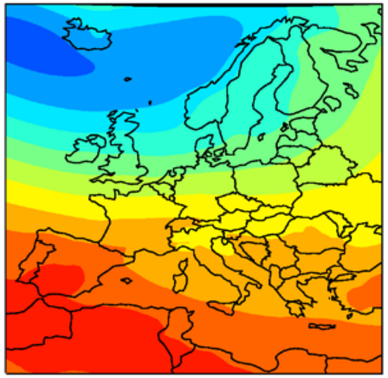


Pronounced anomalies in RCA4 driven by GCMs over Europe

MSLP

Large-scale circulation (DJF)

ENS: RCA4 (GCMs)



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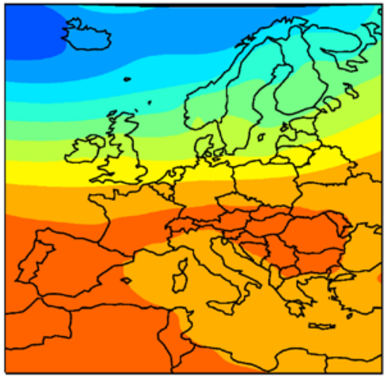
ERAINT



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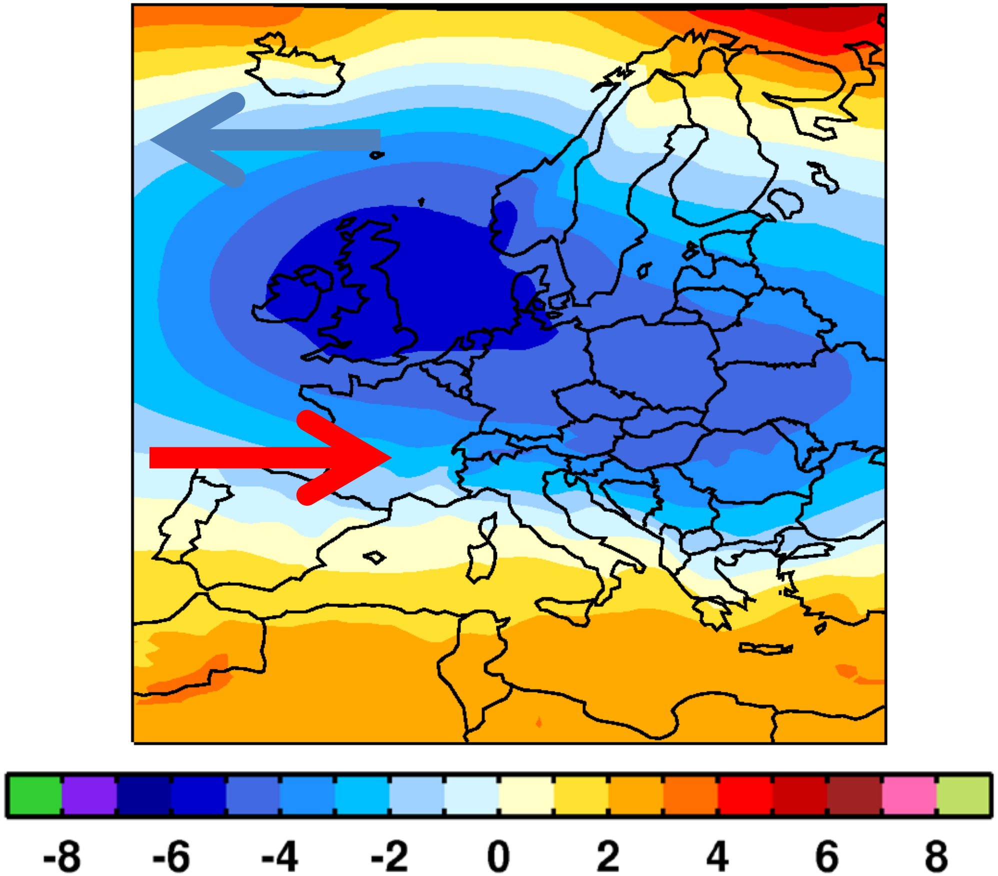
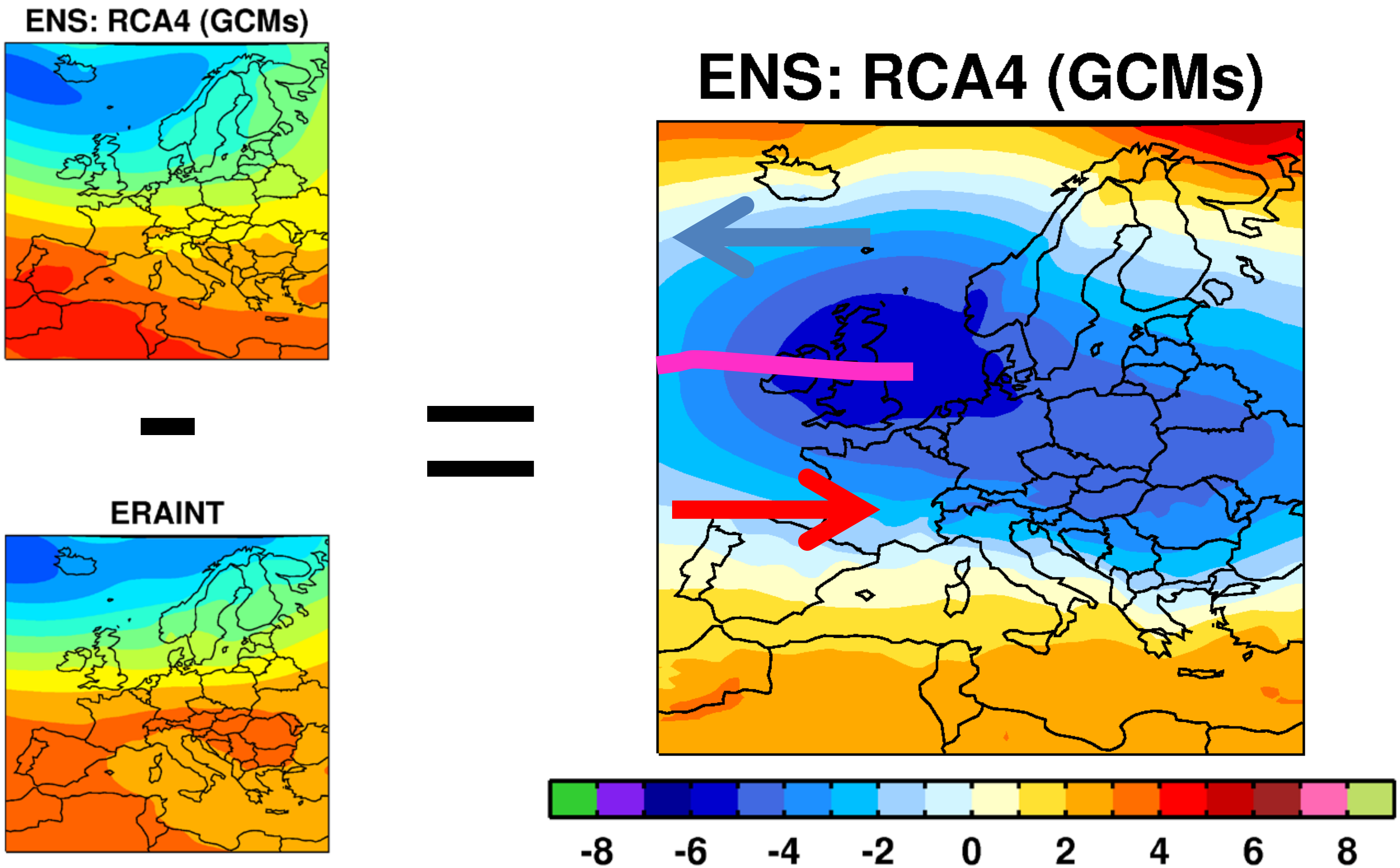
ENS: RCA4 (GCMs)



Too strong and too weak westerlies over the North Atlantic

MSLP

Large-scale circulation (DJF)

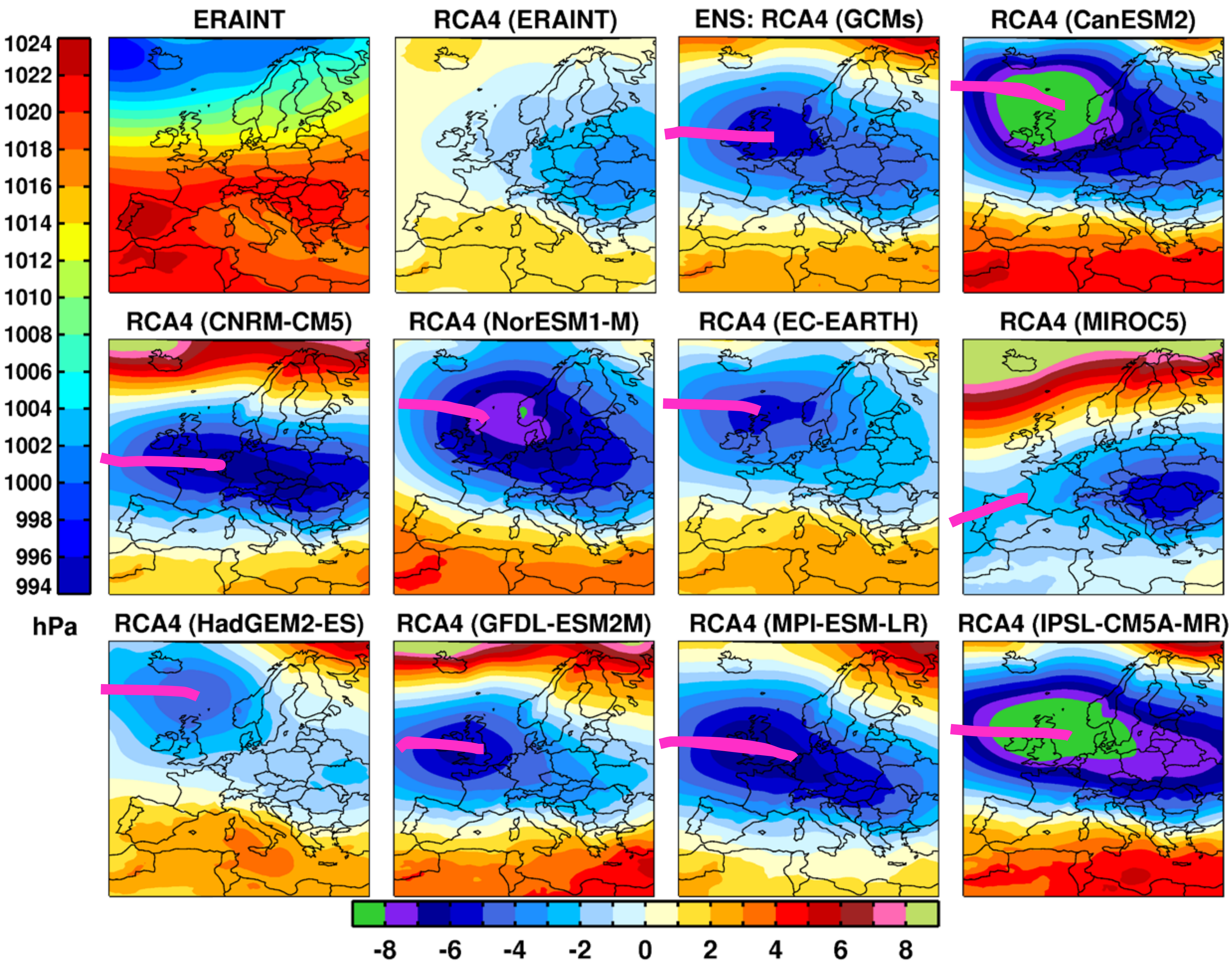


Too strong and too weak westerlies over the North Atlantic

MSLP

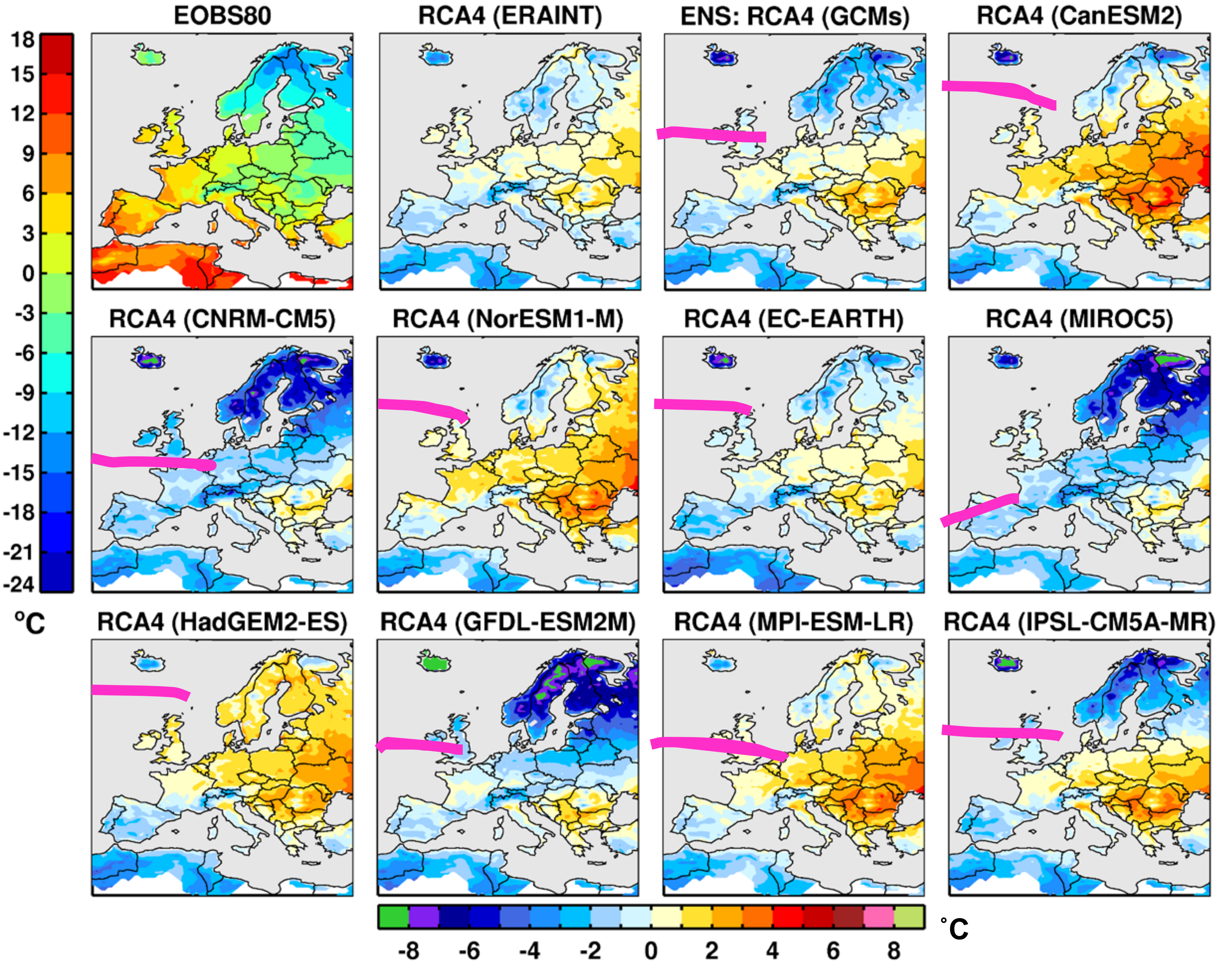
Large-scale circulation (DJF)

SMHI



2m temperature (DJF)

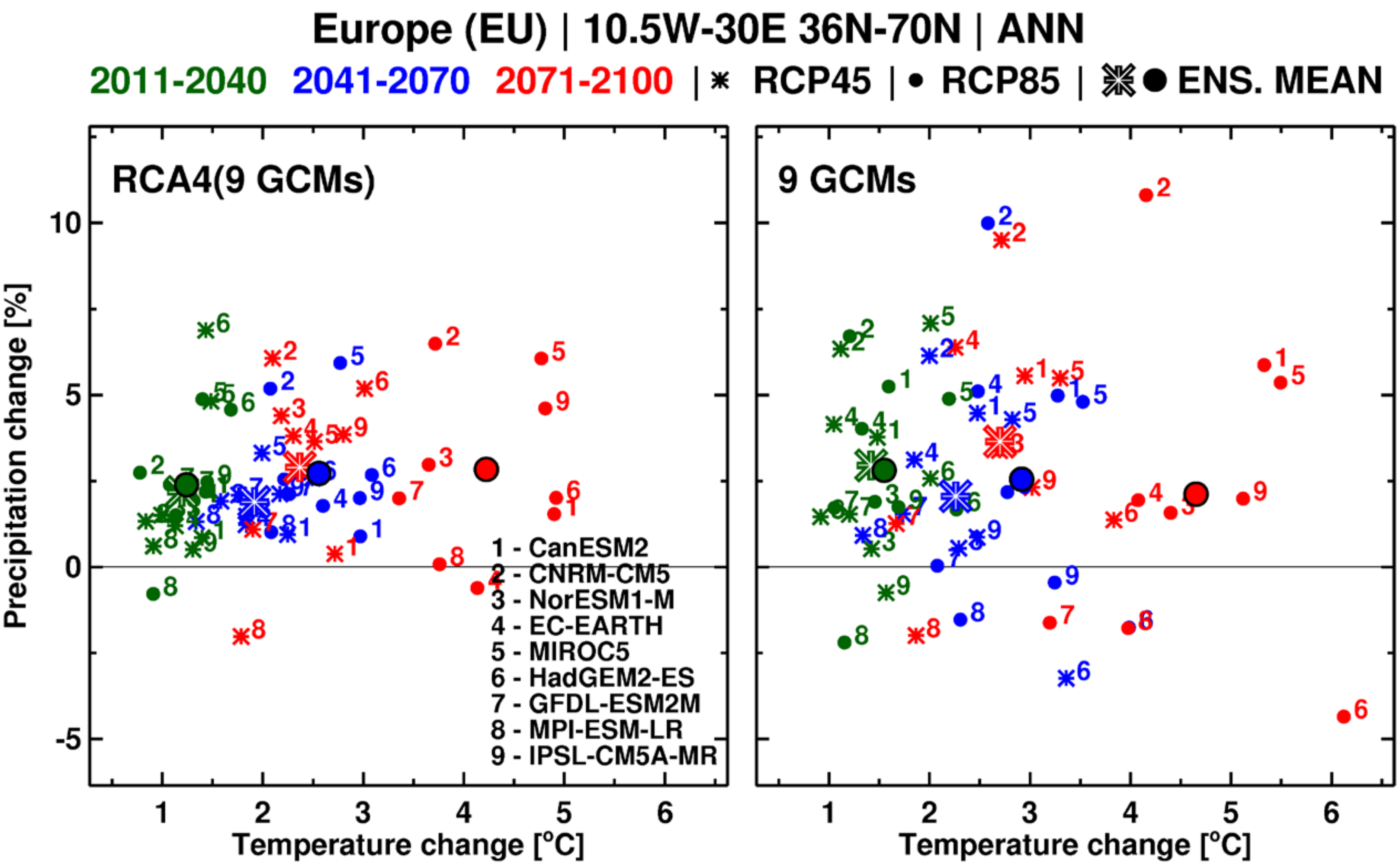
SMHI



Climate change simulations

Future changes

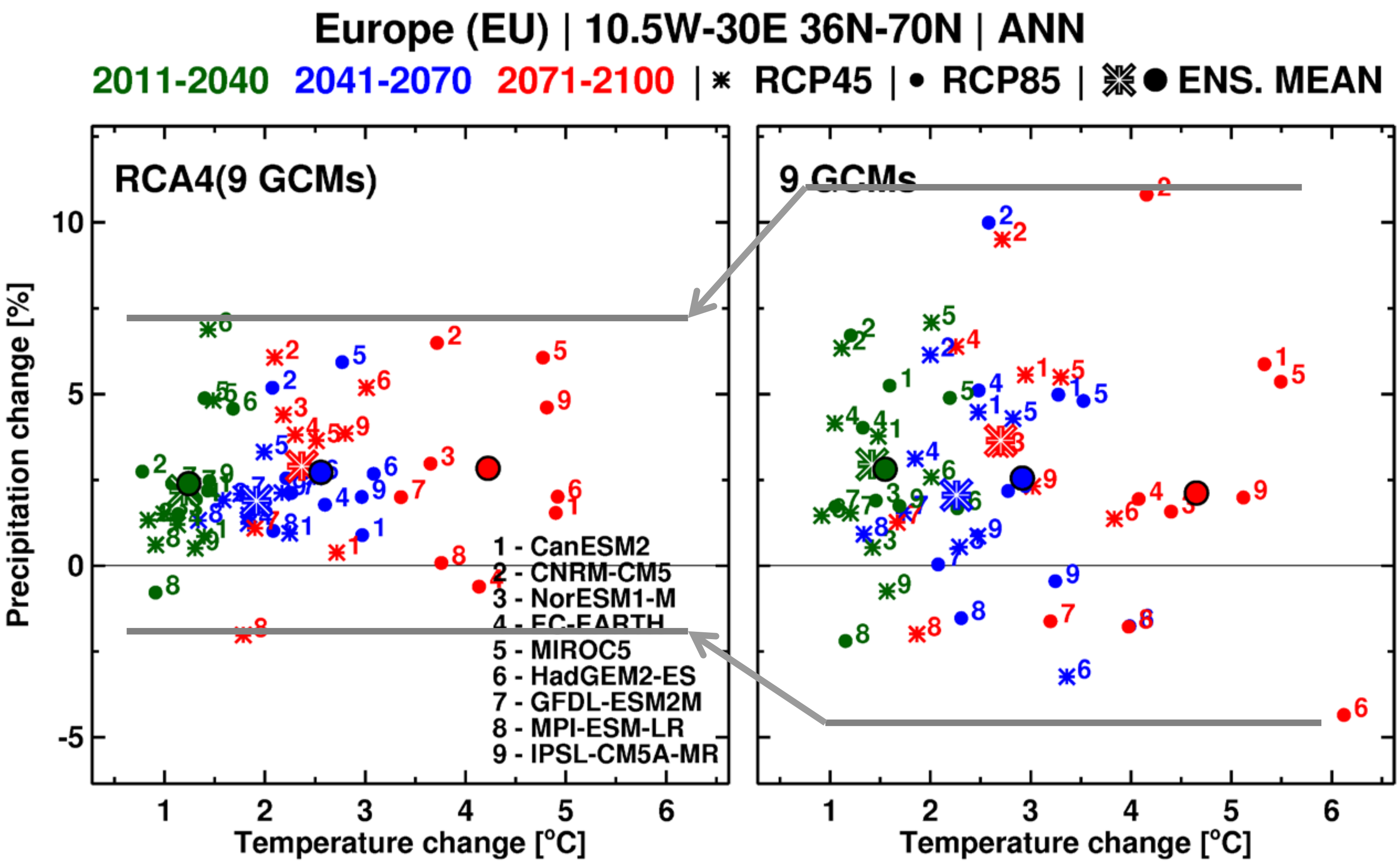
Change in precipitation versus temperature for all land points in Europe



Future changes

SMHI

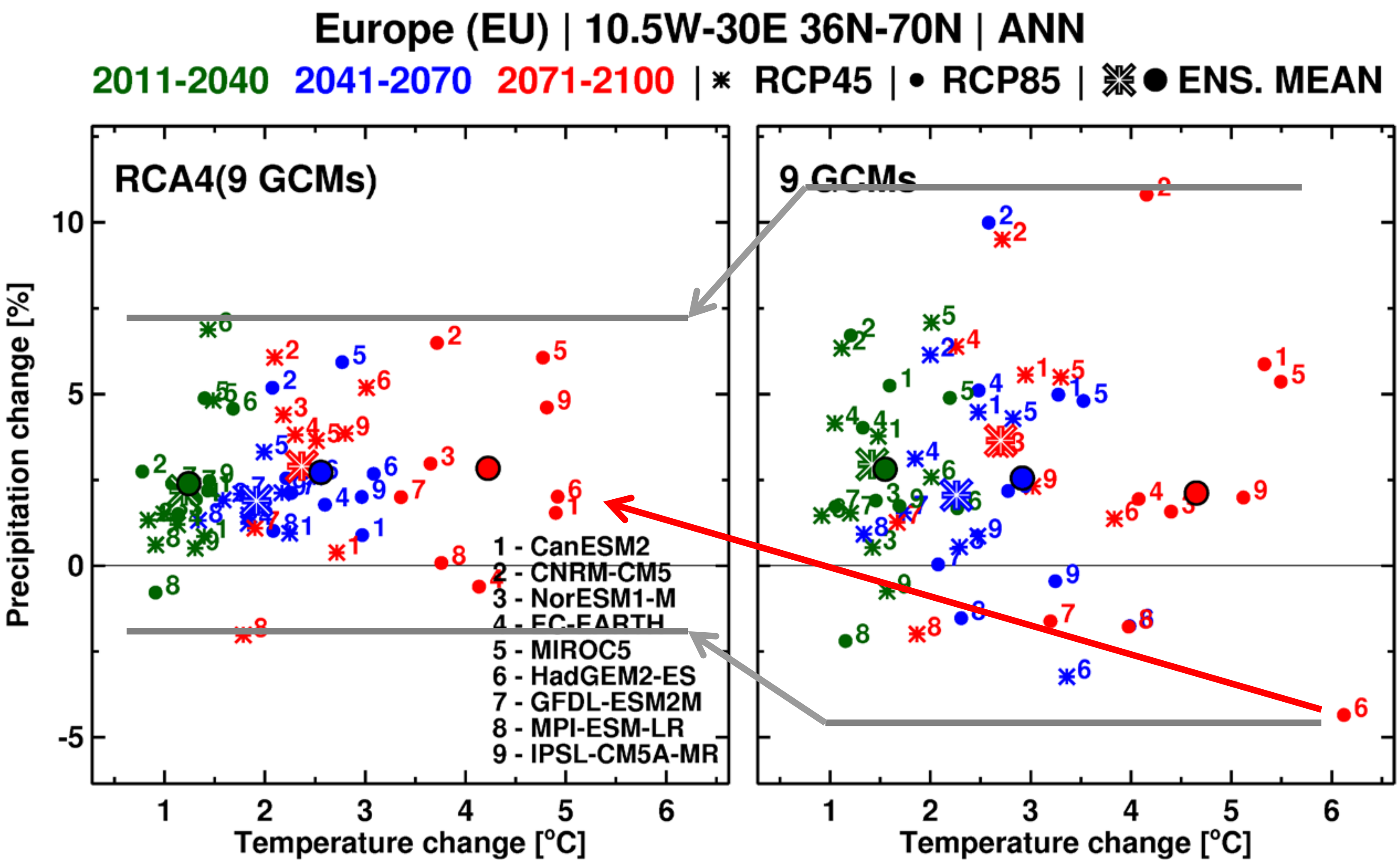
Change in precipitation versus temperature for all land points in Europe



Future changes

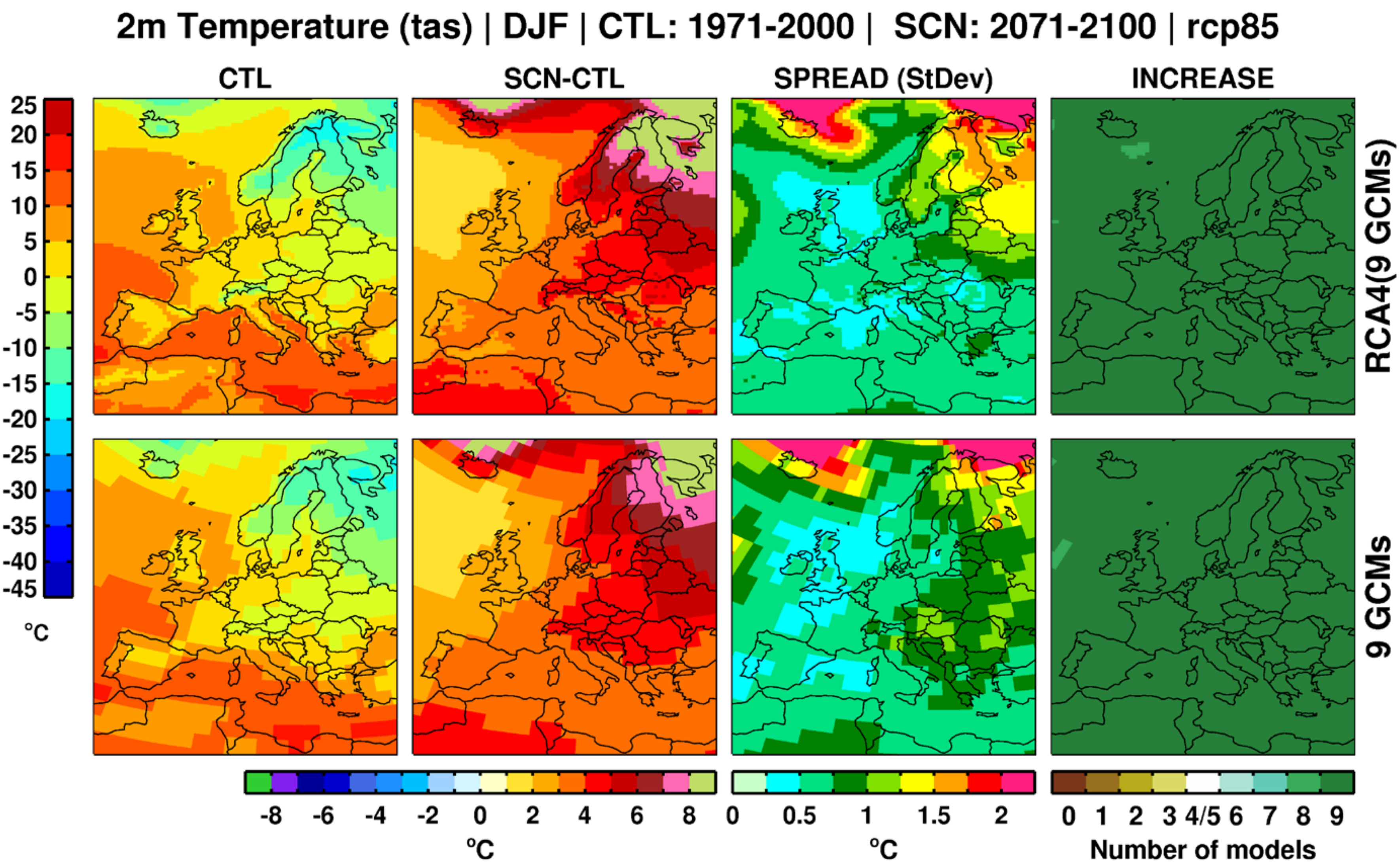
SMHI

Change in precipitation versus temperature for all land points in Europe

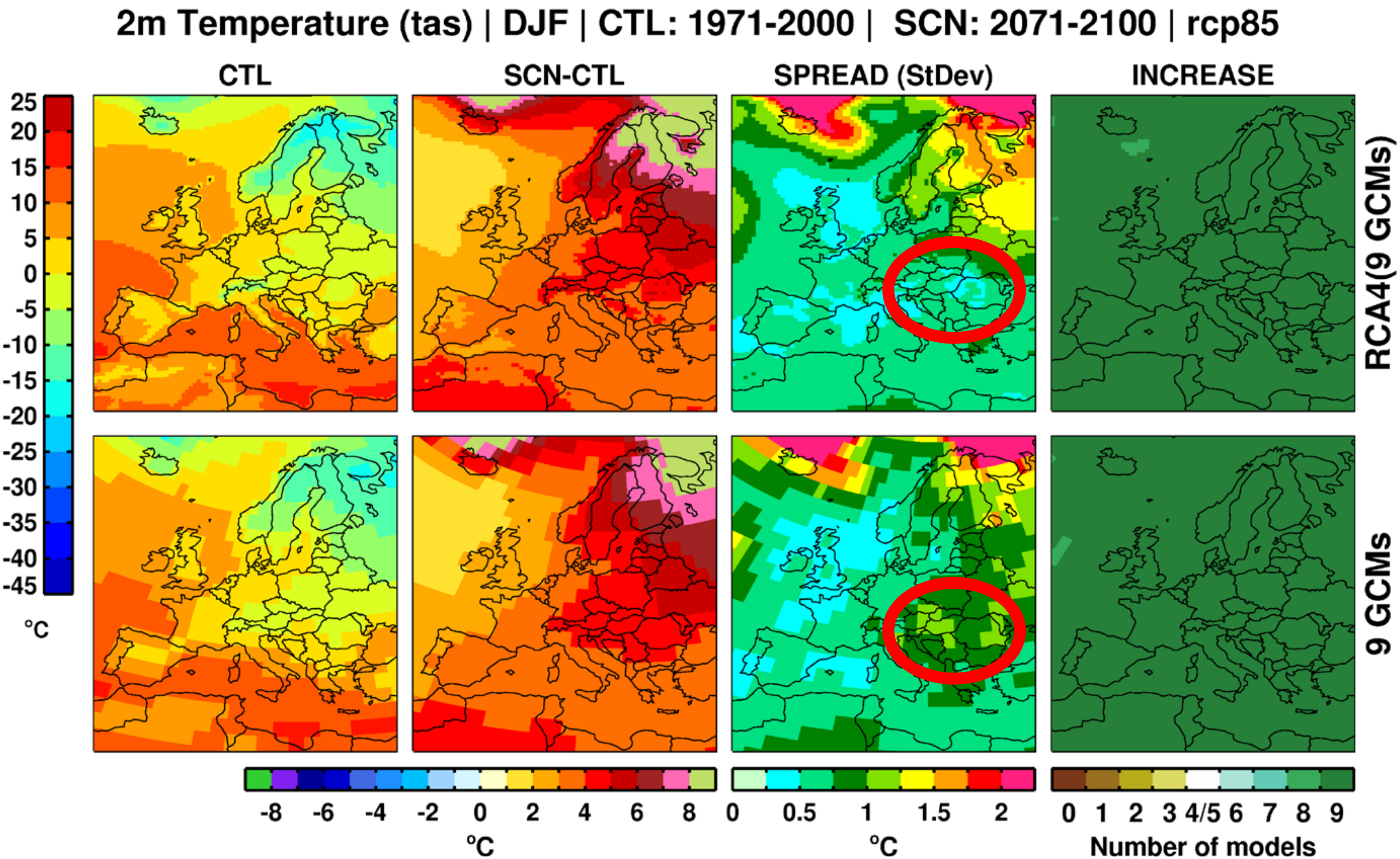


RCA4 reduces the spread and somtimes changes the order between scenarios

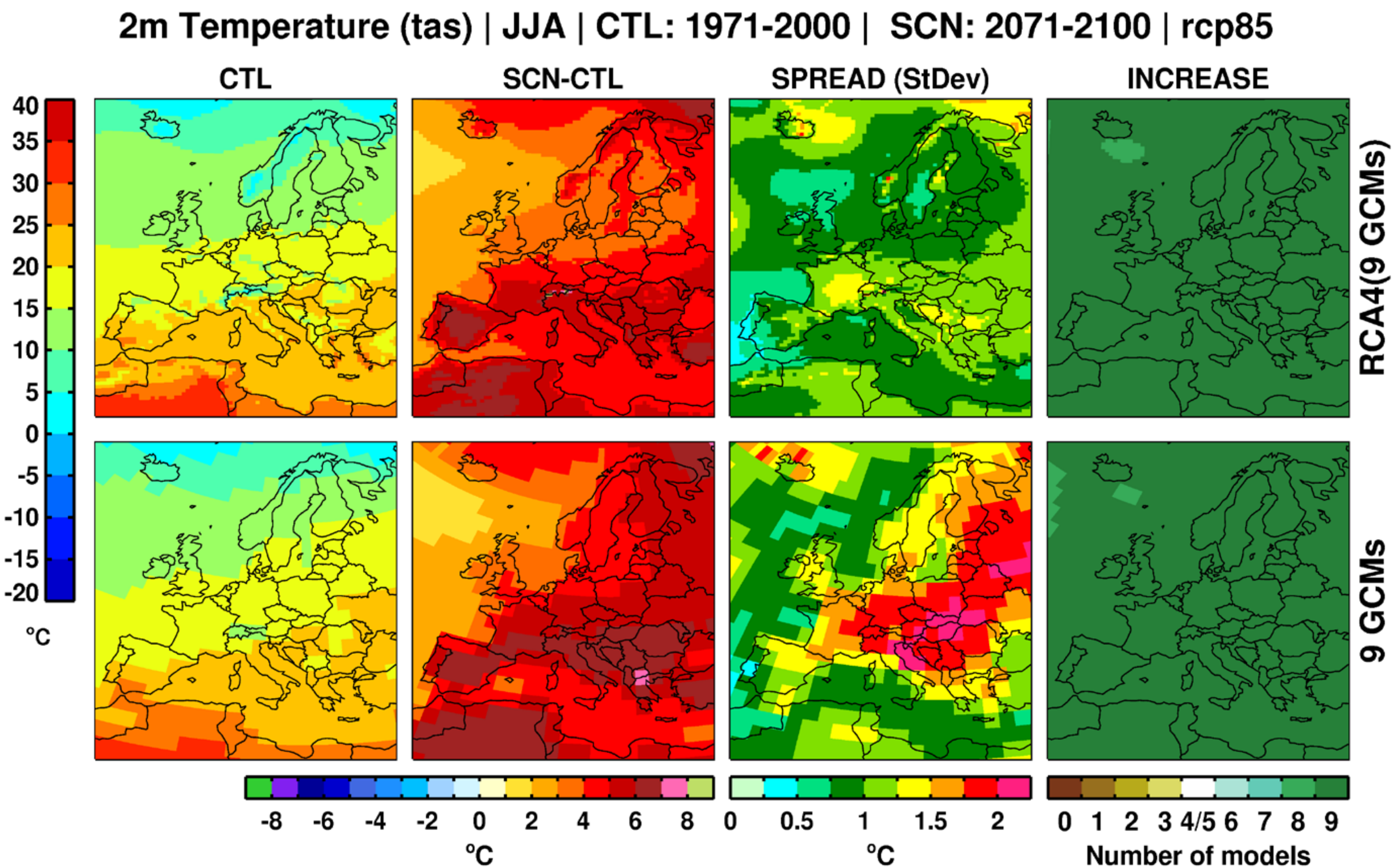
Changes in winter (DJF) temperatures



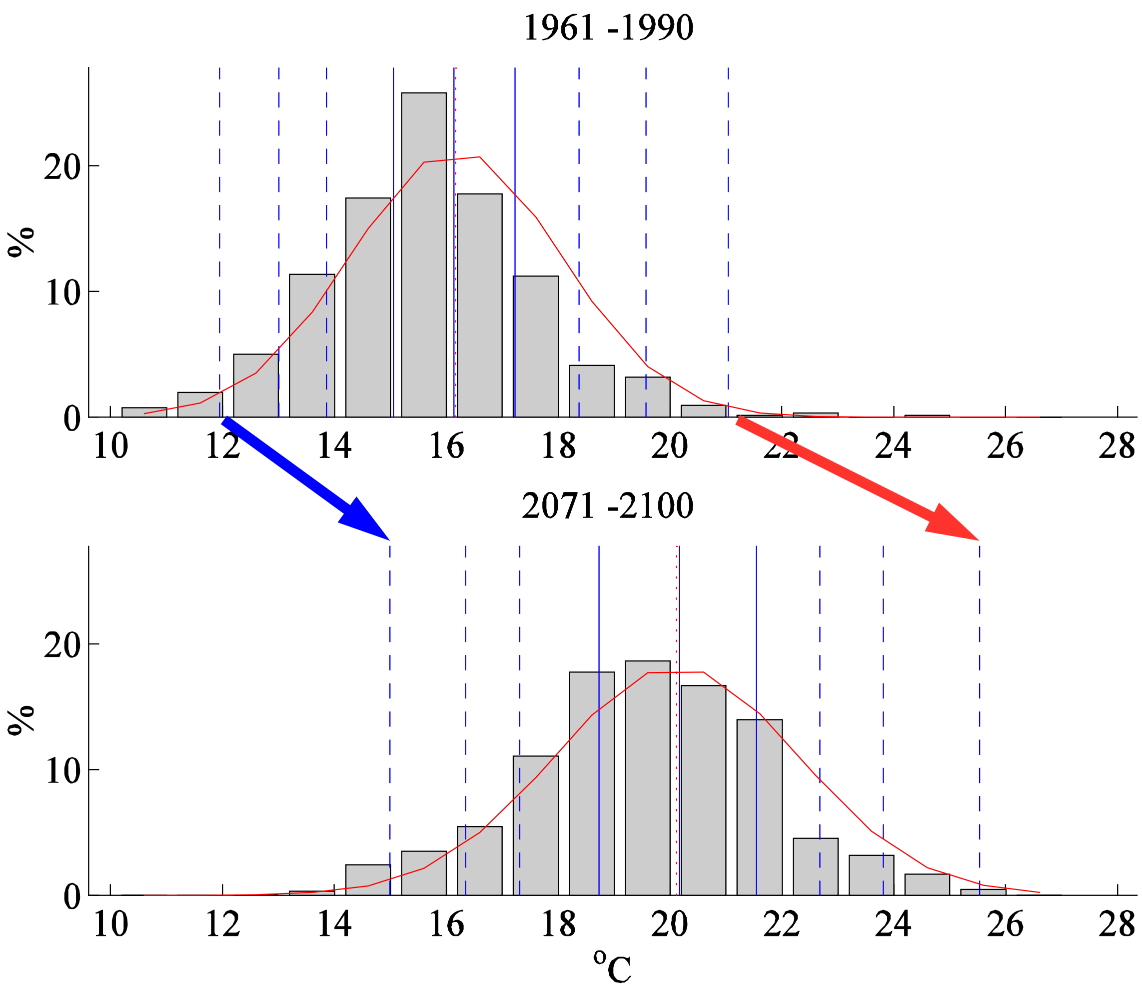
Changes in winter temperatures



Changes in summer temperatures



Simulated summertime (JJA) temperature climate in Stockholm

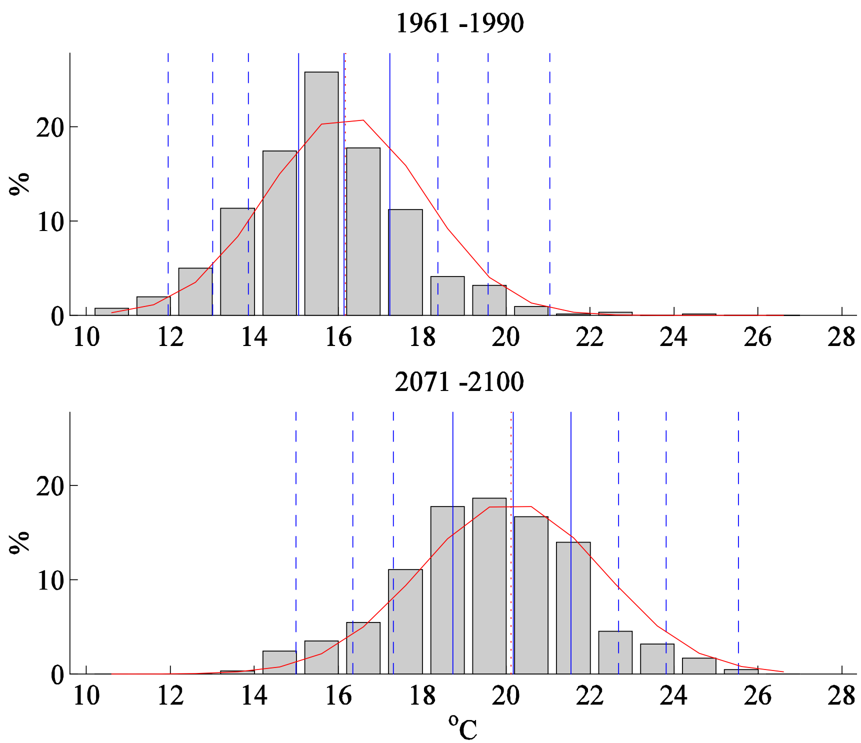


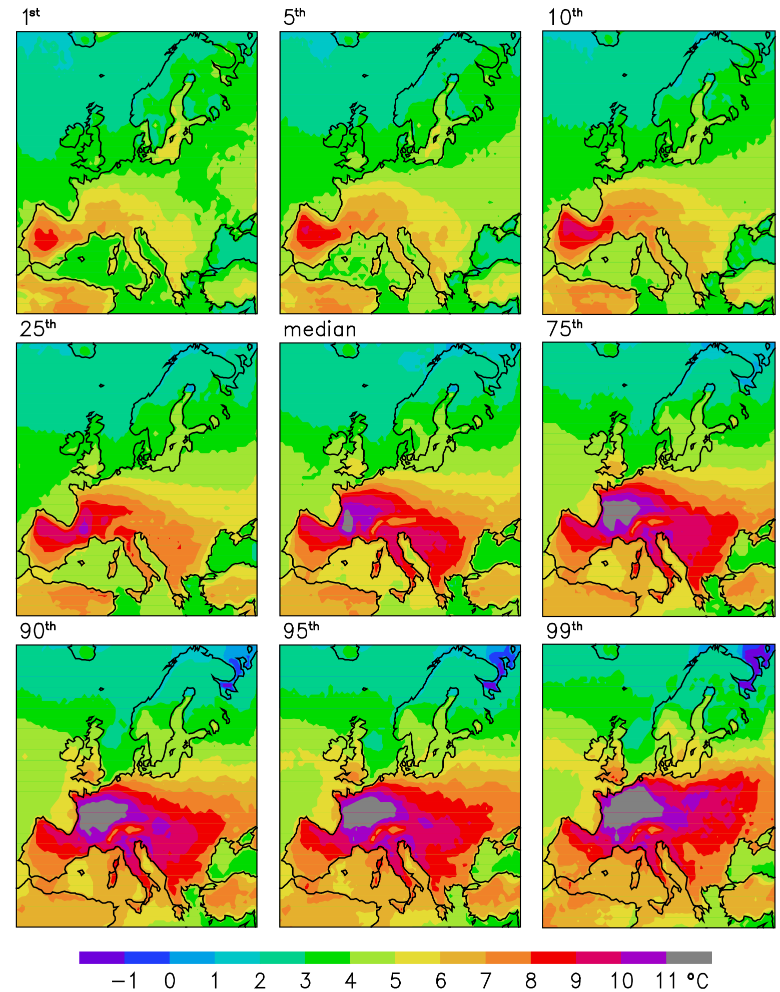
Percentiles for 1, 5, 10, 25, 50 (median), 75, 90, 95 and 99% are shown

Temperature climate during summer (JJA)

In Stockholm … … and in Europe

Difference between 2071-2100 and 1961-1990



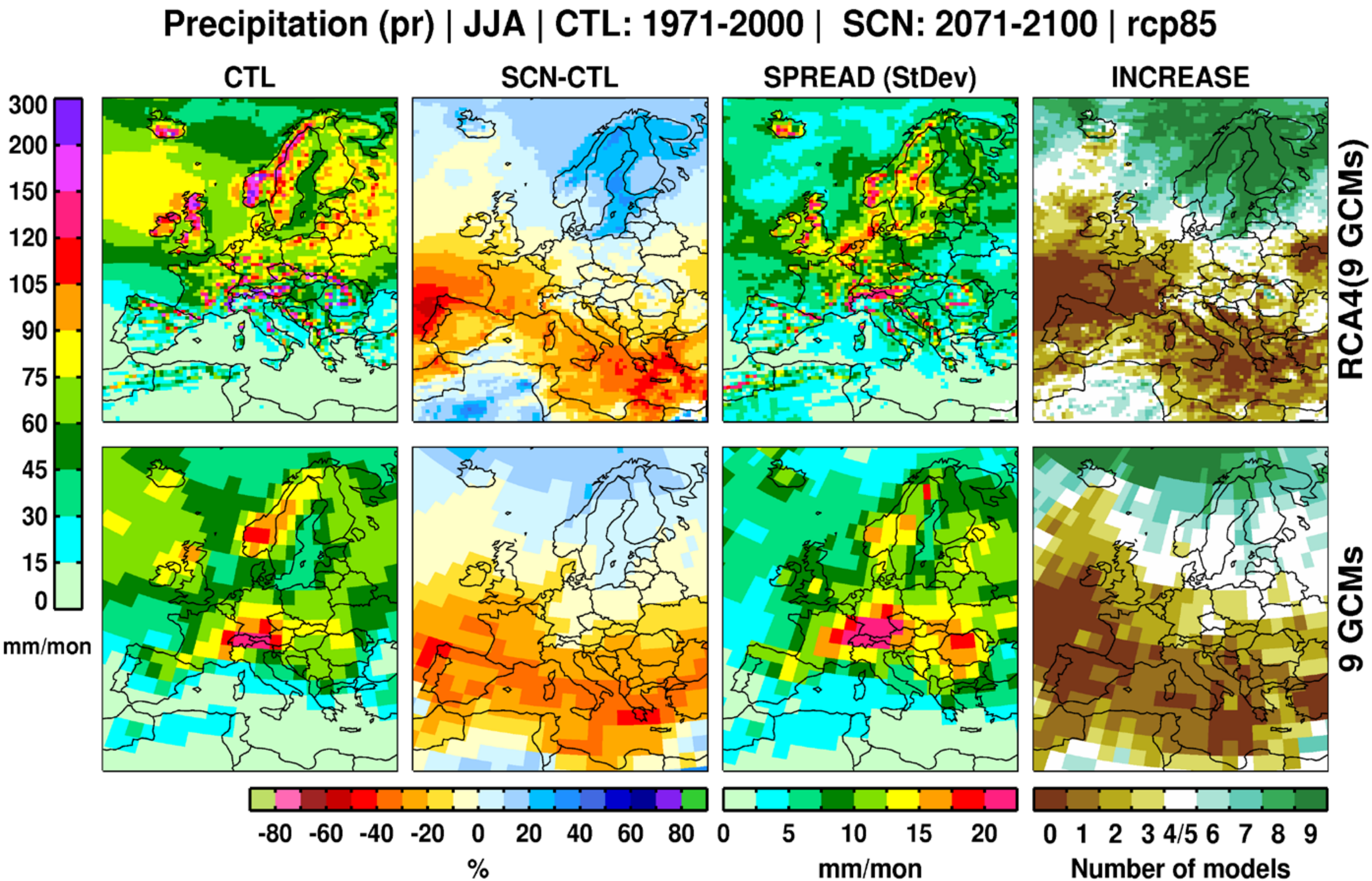


Percentiles for 1, 5,10, 25, 50 (median), 75, 90, 95 and 99% are shown in the figure

Kjellström, E., 2004. Recent and future signatures of climate change in Europe. *Ambio*, 33(4-5), 193-198.

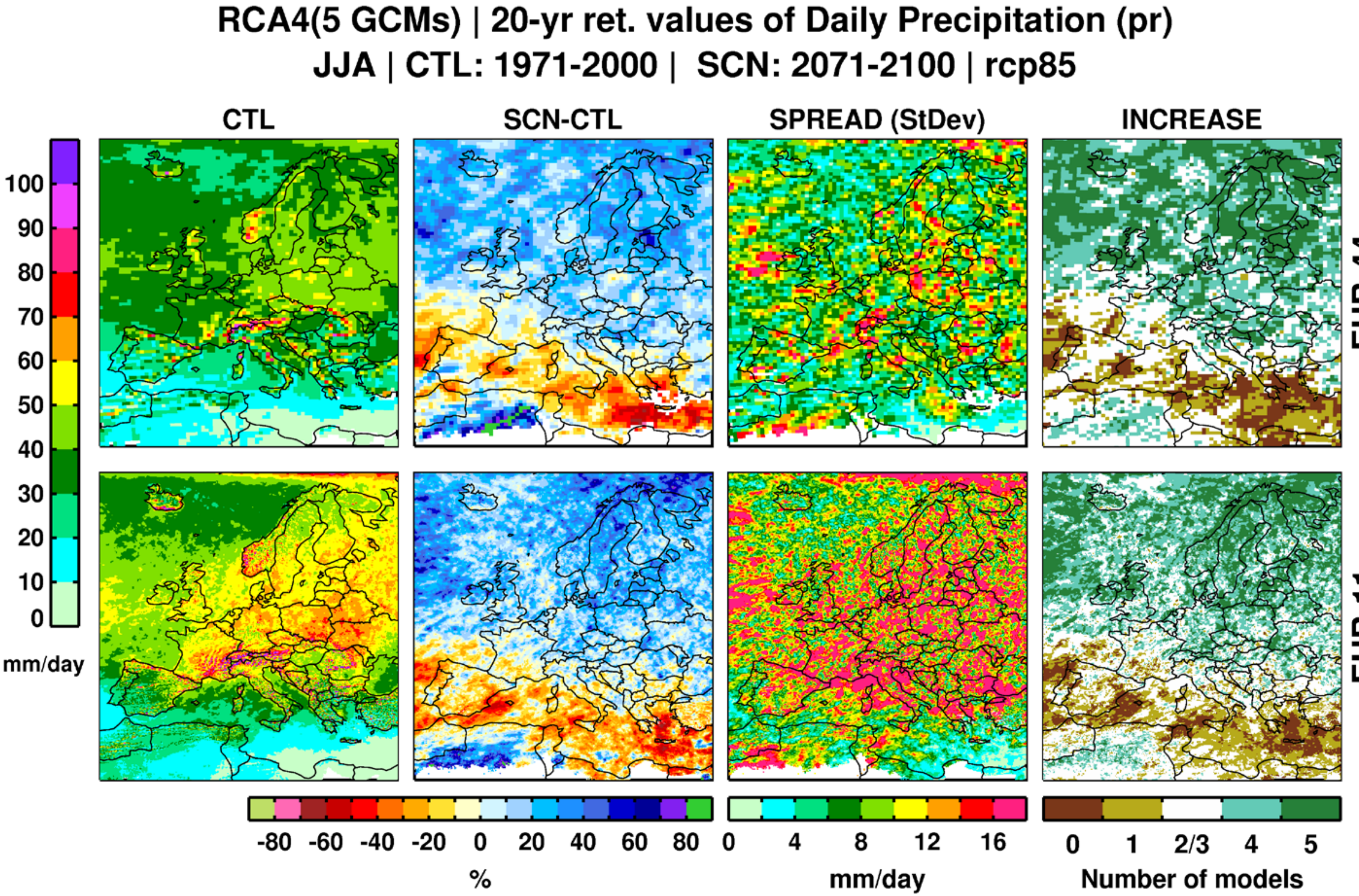
Changes in JJA mean precipitation

SMHI

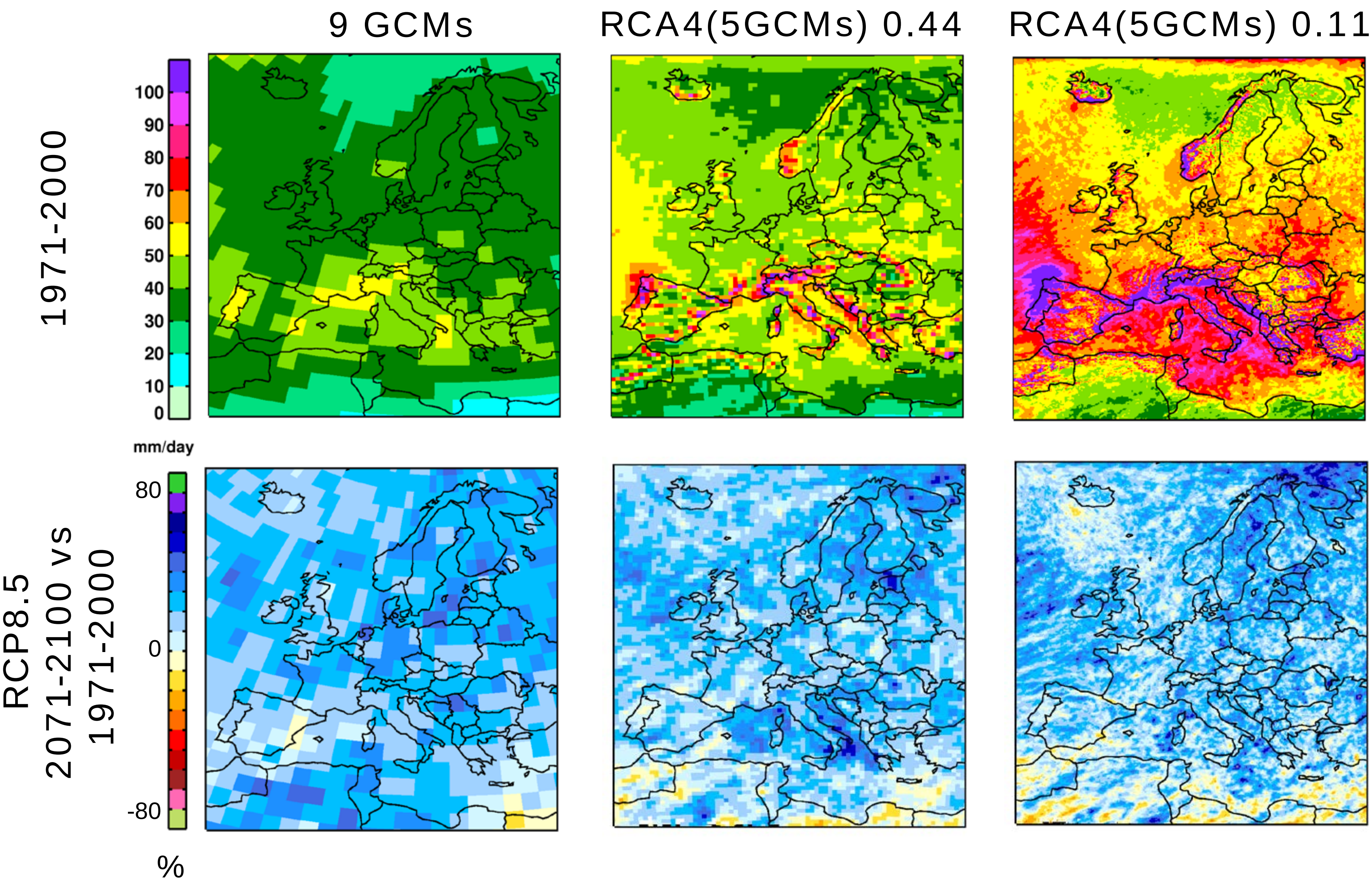


Changes in JJA extreme precipitation

SMHI



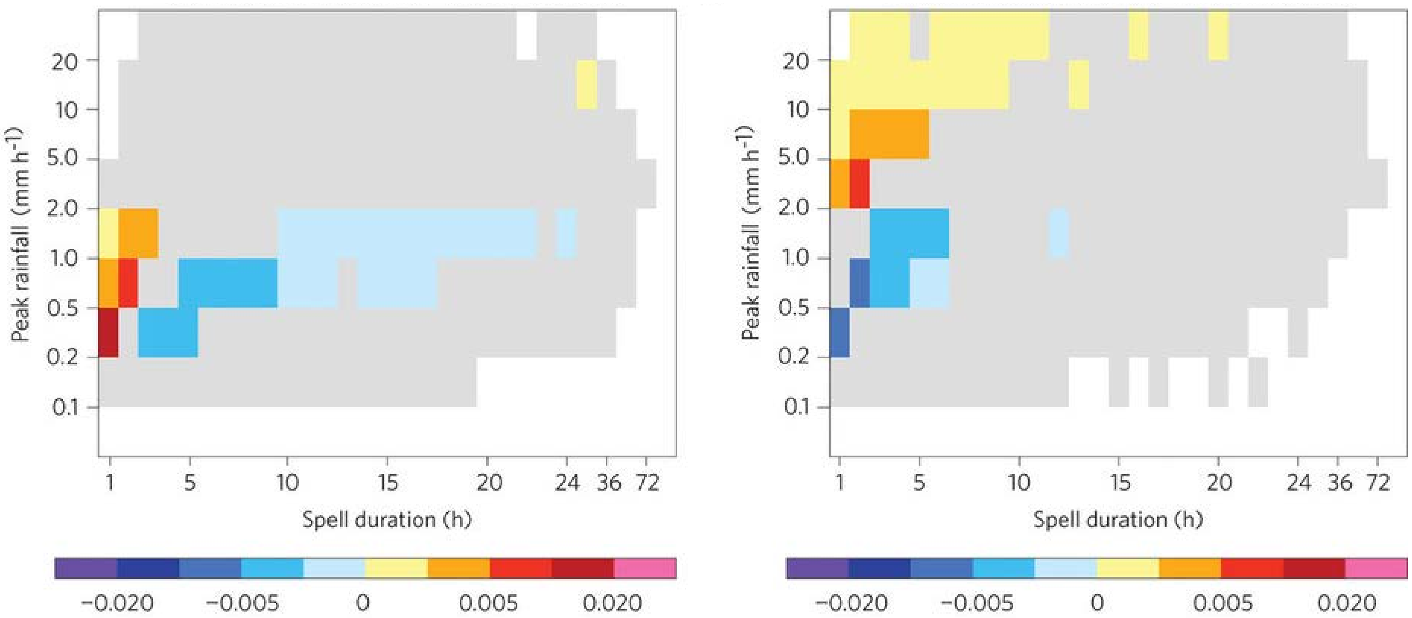
Extreme precipitation (20-yr return level)



Precipitation in southern Britain (2)

Climate change (end of 21st C compared to end of 20th C under SRES A2)

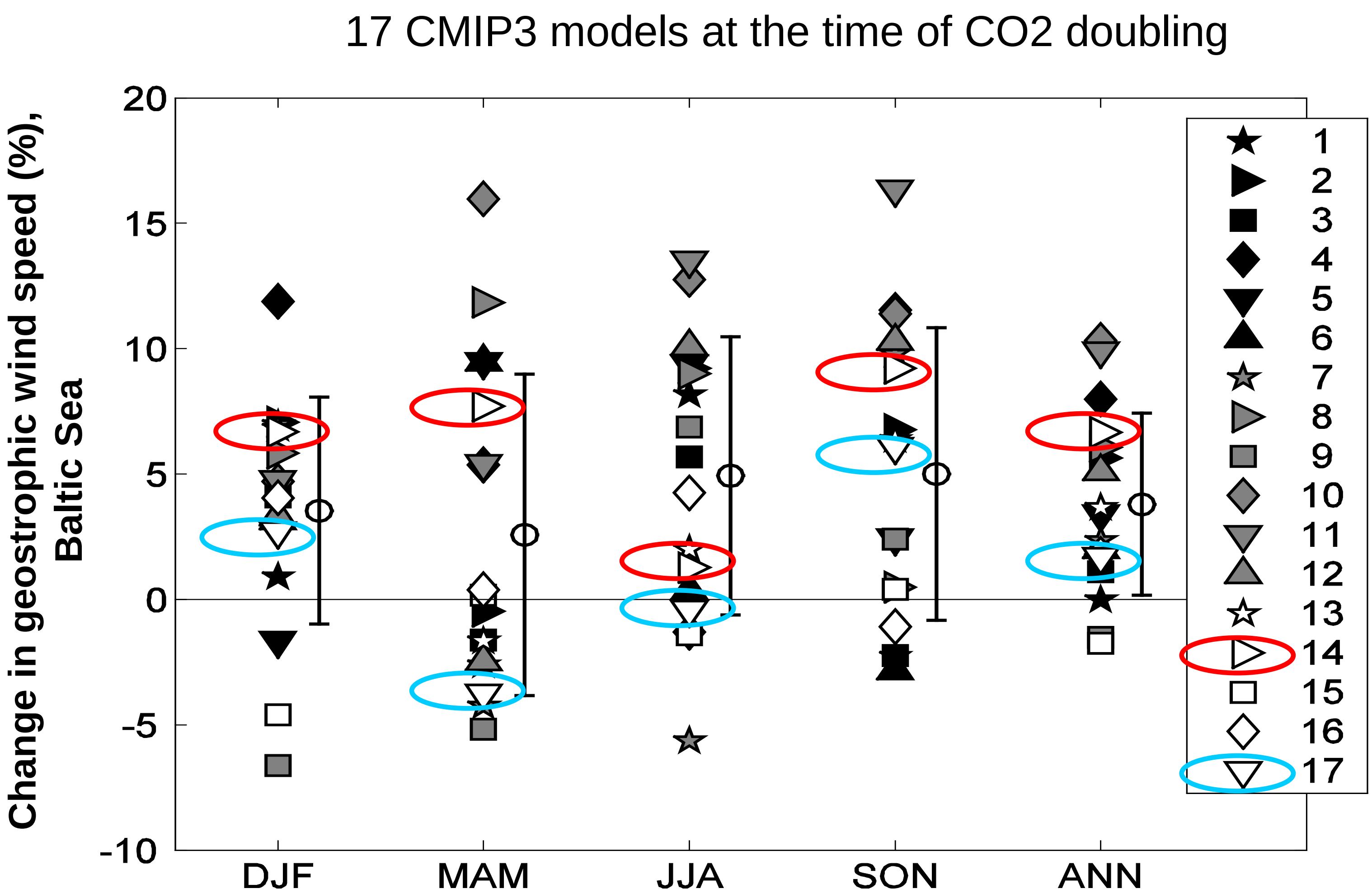
RCM@12km RCM@1.5km



Really high-res models show a larger increase in the most intense precipitation compared to what is ”standard high resolution” in todays models

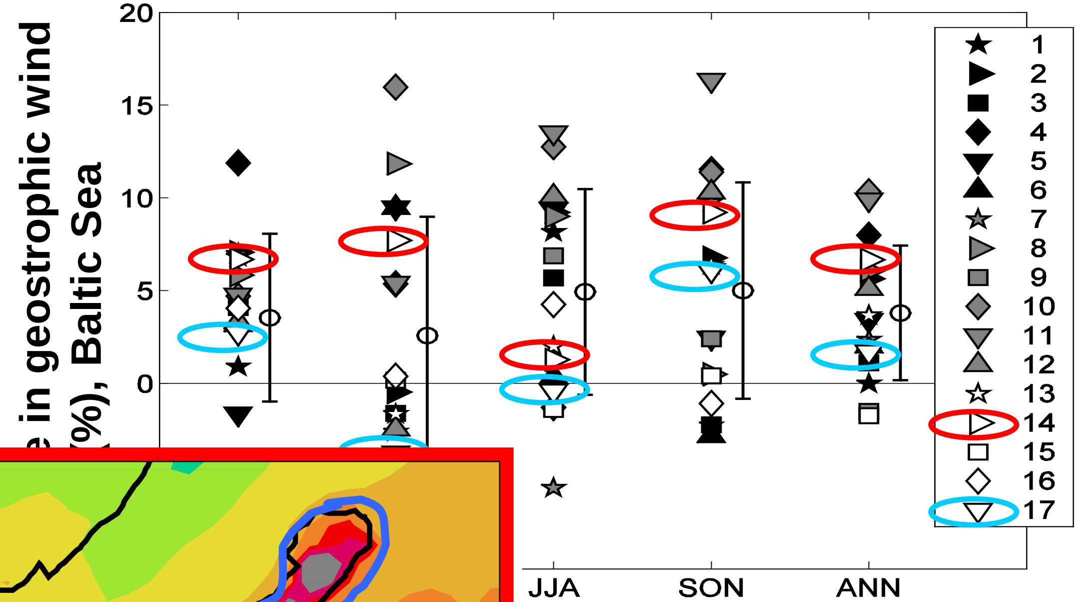
Kendon et al., Nature Climate Change, 2014

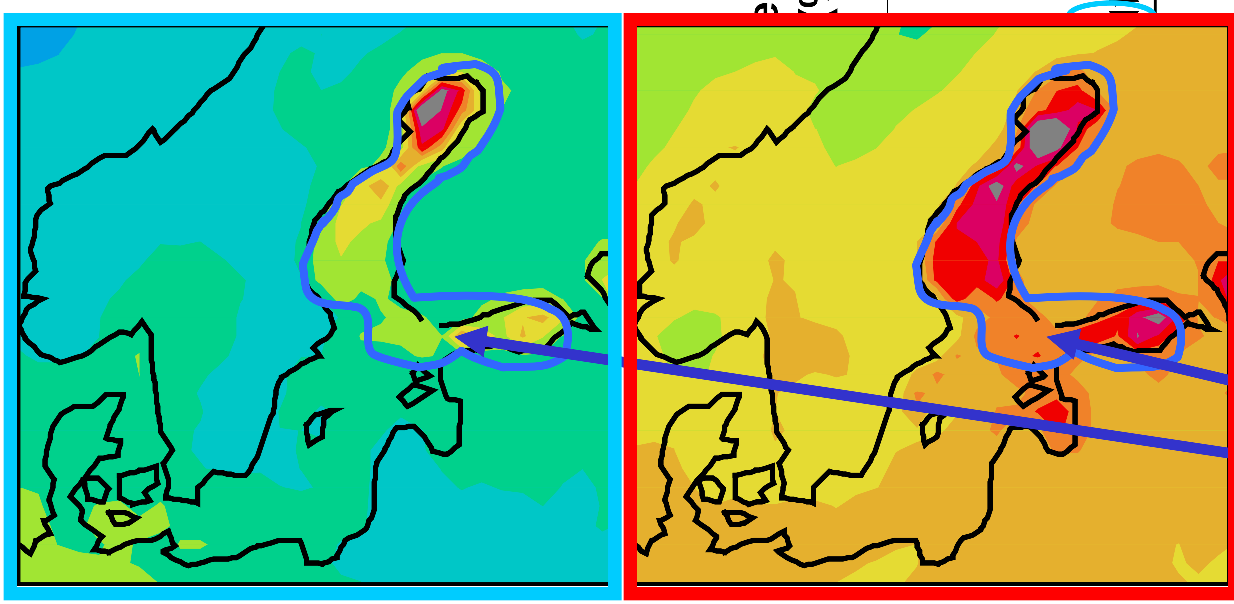
Wind speed changes



RCMs may help identifying robust results on the regional scale

Calculated change in 10m wind
RCAO, SRES A2
2071-2100 vs 1961-1990
(DJF)

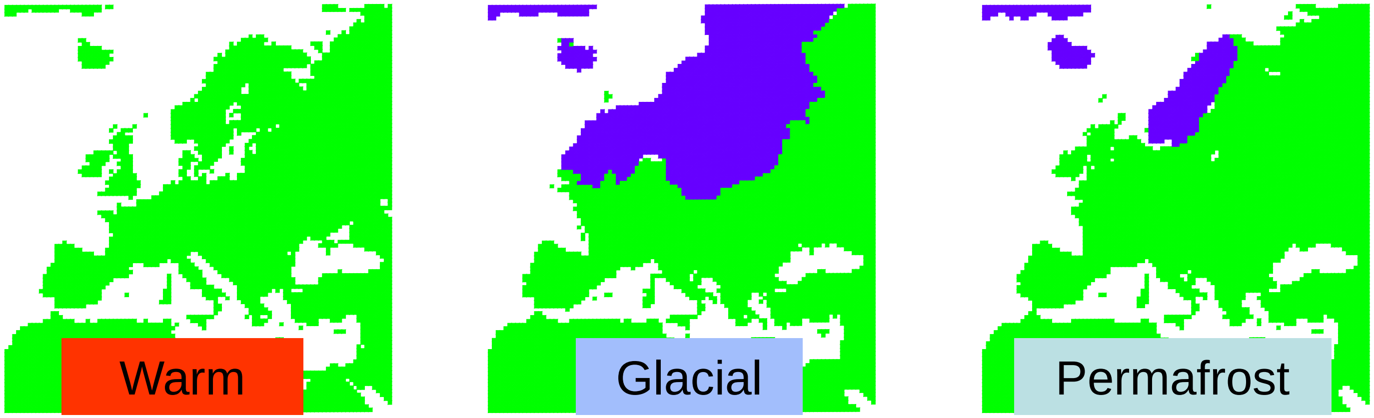




Increased wind Speed when Sea-ice disappears

Meier et al., RMK109, 2006

Ex. of set up of a RCM for past climates



Insolation	1365 Wm^{-2}	1365 Wm^{-2}	1365 Wm^{-2}
Orbital year	1990	21 ka BP	44 ka BP
CO_2	750 ppm_v	185 ppm_v	200 ppm_v
CH_4	RP (1714 ppb_v)	350 ppb_v	420 ppb_v
N_2O	RP (311 ppb_v)	200 ppb_v	225 ppb_v
Ozone	PI	PI	PI
Sulphate	PI	PI	PI
Dust, sea salt	PI	PI / *PI x 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 / *GHG*	RP / *LGM*	RP

Kjellström, E., Brandefelt, J., Näslund, J.O., Smith, B., Strandberg, G. and Wohlfarth, B, 2009: Climate conditions in Sweden in a 100,000 year time perspective. Svensk Kärnbränslehantering AB, report TR-09-04, Swedish Nuclear Fuel and Waste Management, SE-10124 Stockholm, Sweden, 139 pp.

Results from the regional model

MIS3 (44 ka BP) coldest month warmest

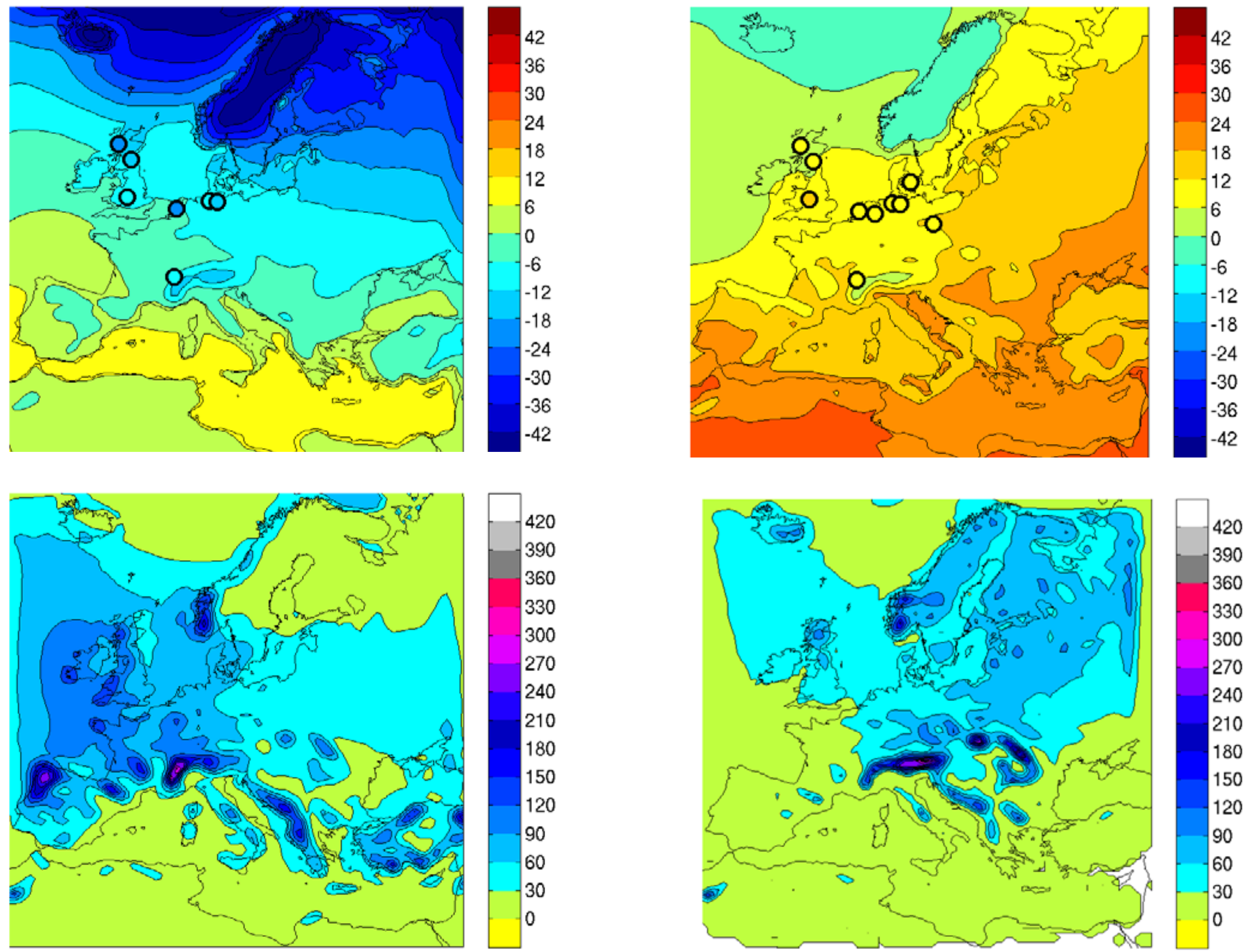
month

Temp

(˚C)

Precip

(mm/mon)



Thanks for your attention!