Climate of the Baltic Sea Region

Climate Modeling – the global and regional perspective
(acknowledge Erik Kjellström, Askö 2015)

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The WGI Contribution to the IPCC 5th Assessment Report

Thomas Stocker & Qin Dahe
259 Authors from 39 Countries
WGI Technical Support Unit Team

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Working Group II: Impacts, Adaptation and Vulnerability
Working Group III: Mitigation of Climate Change

Key SPM Messages

19 Headlines

on less than 2 Pages

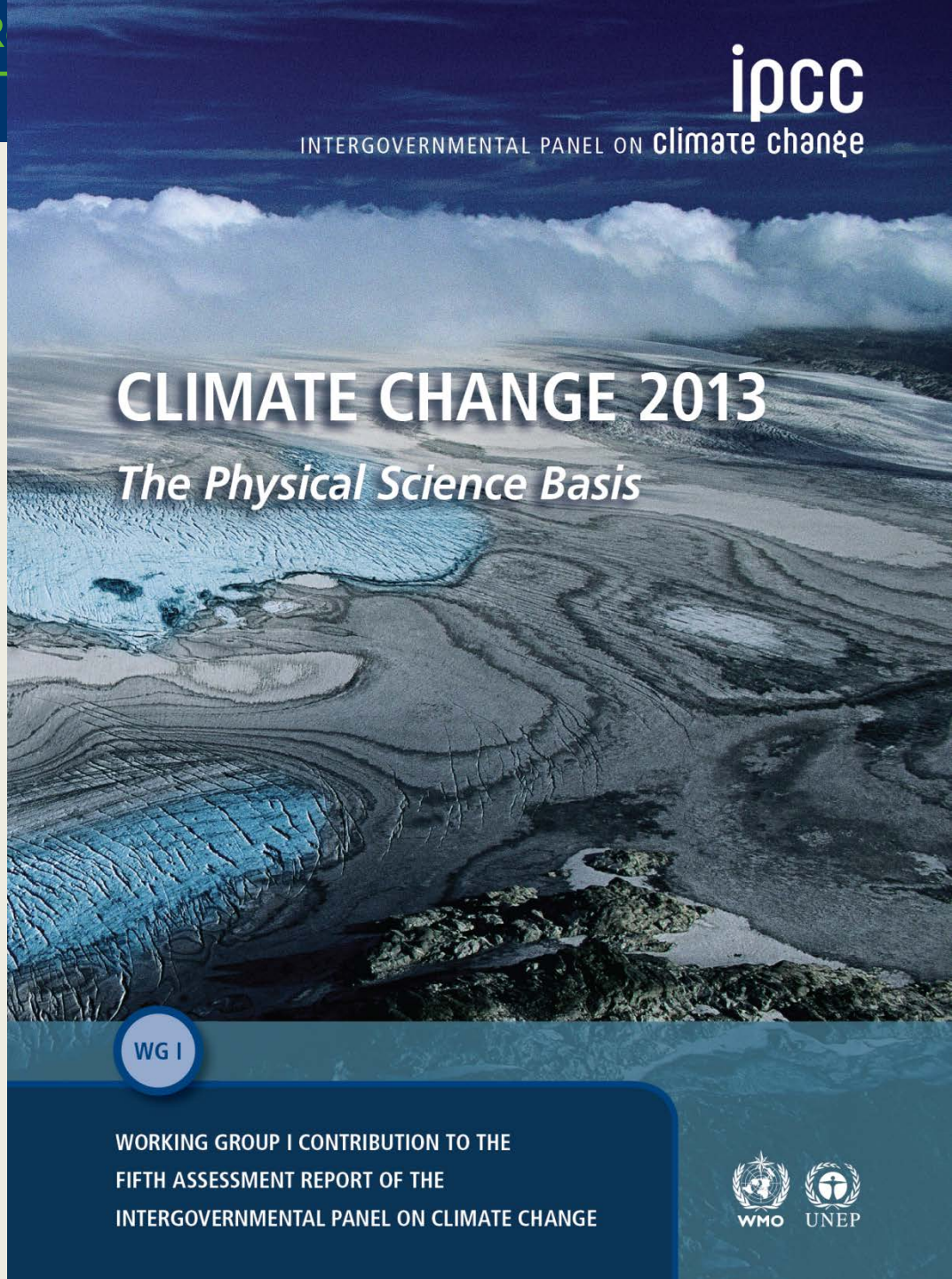
Summary for Policymakers
ca. 14,000 Words

14 Chapters
Atlas of Regional Projections

54,677 Review Comments
by 1089 Experts

2010: 259 Authors Selected

2009: WGI Outline Approved



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3rd Lead Author Meeting, Marrakech, Morocco, April 2012

IPCC Assessment Reports since 1990: WGI Contribution

Why do we need climate models?

Why do we need climate models?

1. to better understand climate system behaviour,
2. to explore the causes of past climate change, and
3. to make predictions of possible future climate change

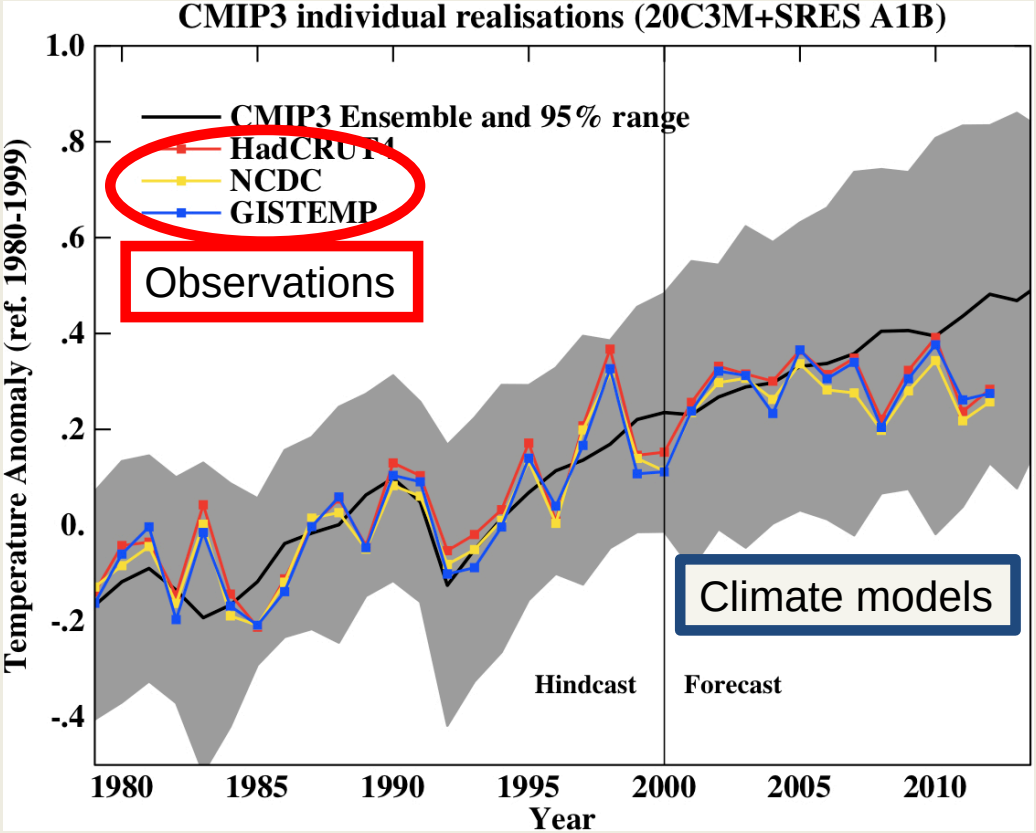
Current climate change

New temperature records are often broken

Many of the recent years are record breakers

1990s warmer than the 1980s

2000s warmer than the 1990s

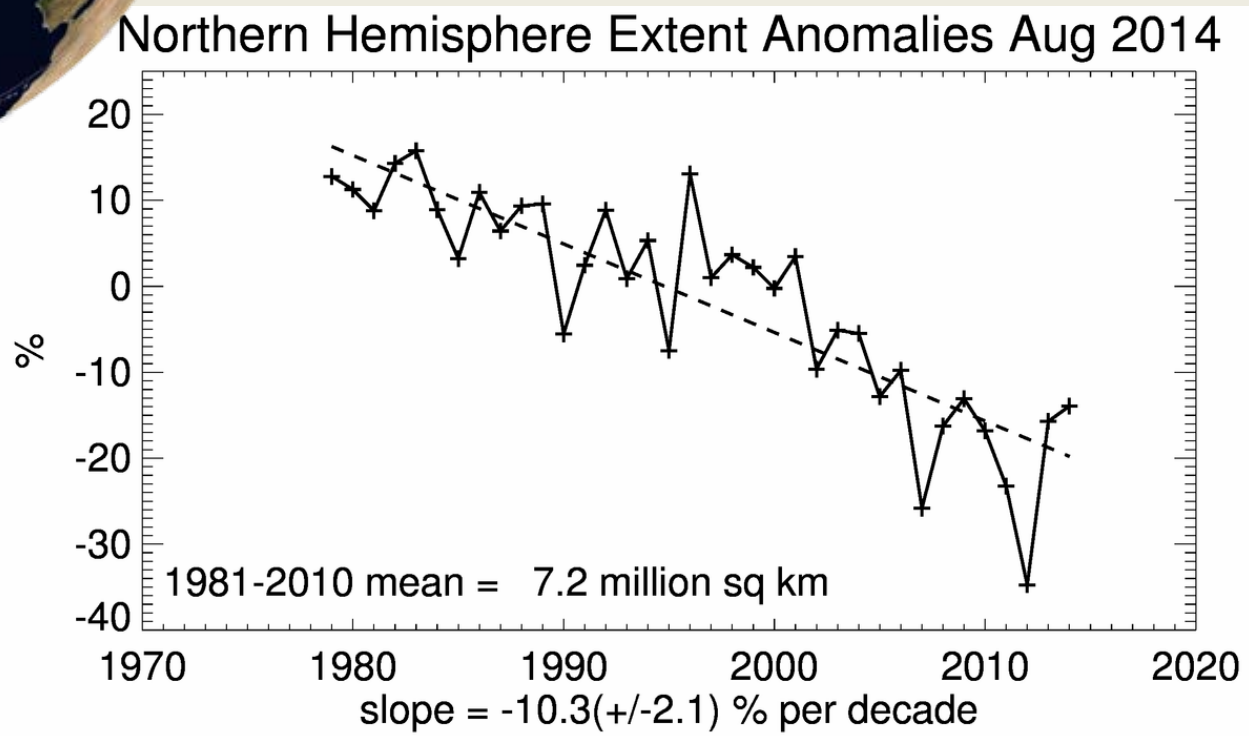


Downloaded from www.realclimate.org 2013-02-10

Arctic Ocean sea ice

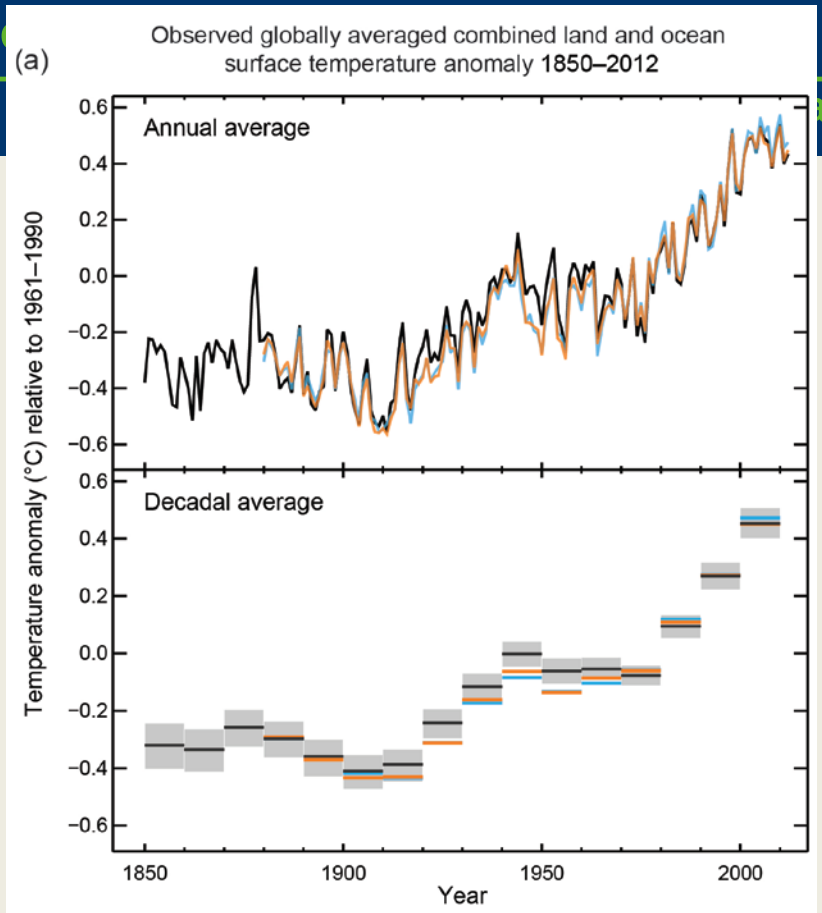
National Snow and Ice Data Center / NASA Earth Observatory

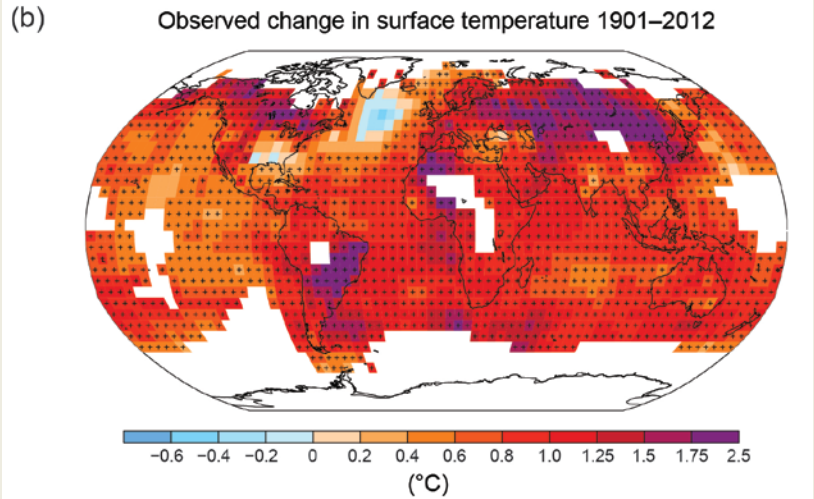
Daily Sea Ice Extent for: Sep 17, 2014



IPCC's Fifth Assessment Report (AR5)

http://ipcc.ch





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Climate models

-

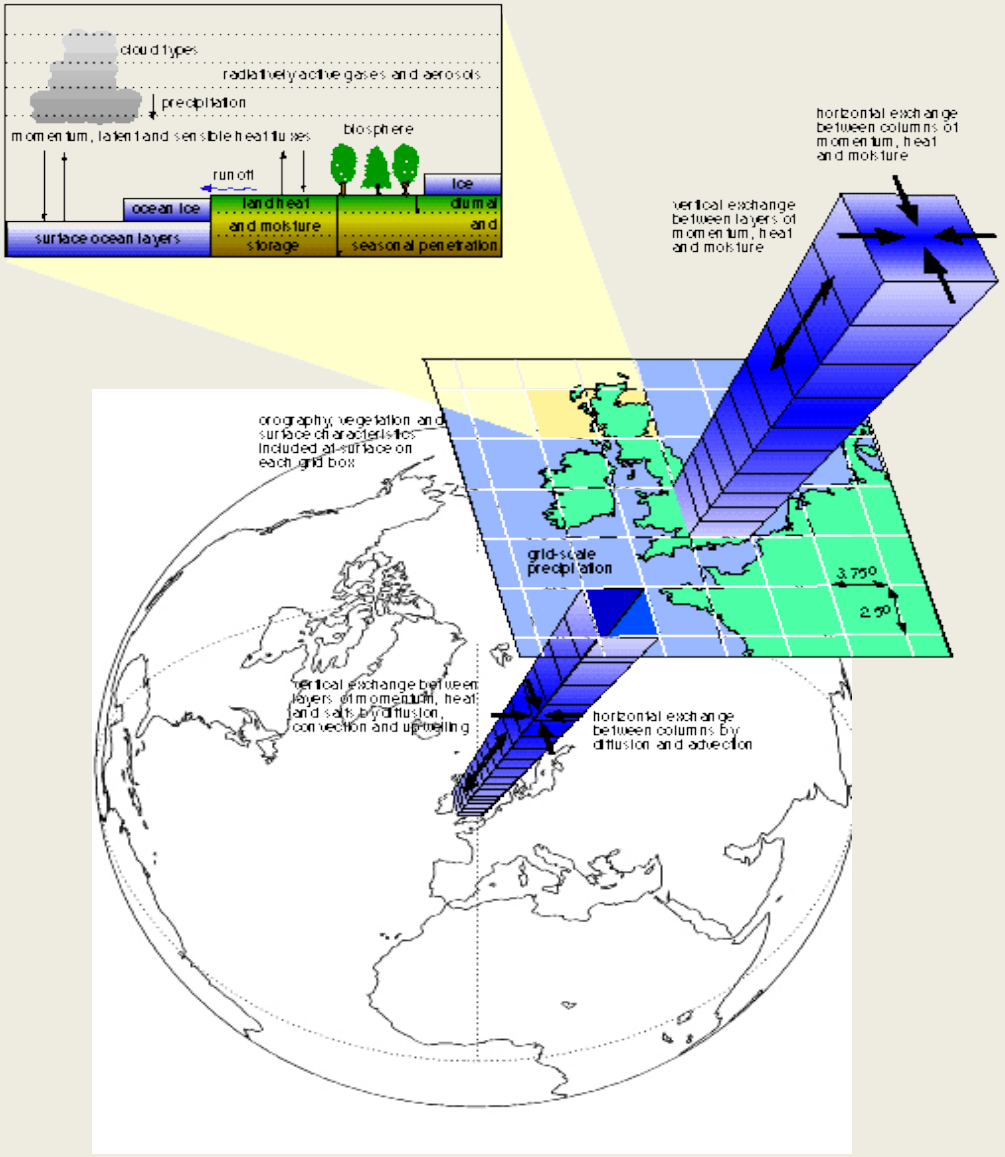
numerical models describing the climate system

A numerical climate model

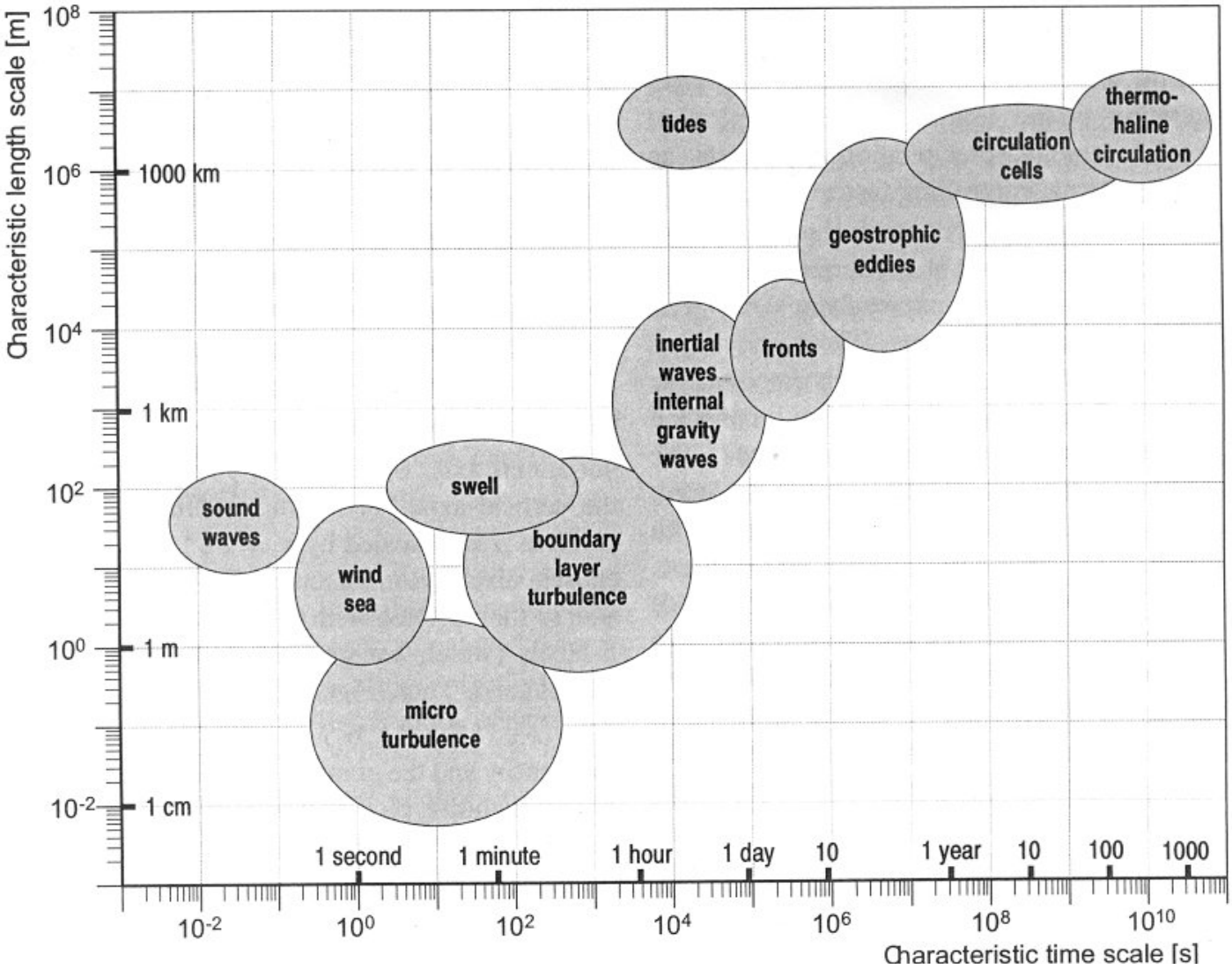
- Model describing the General Circulation (GCM) of the atmosphere and oceans

- In a GCM grid boxes covers the whole Earth

- Typical resolution (atm):
  - 100-400 km (horizontally)
  - 20-40 vertical levels
  - Time step c 30 min



Spatial and temporal scales in the ocean



(source: von Storch and Zwiers, 1999)

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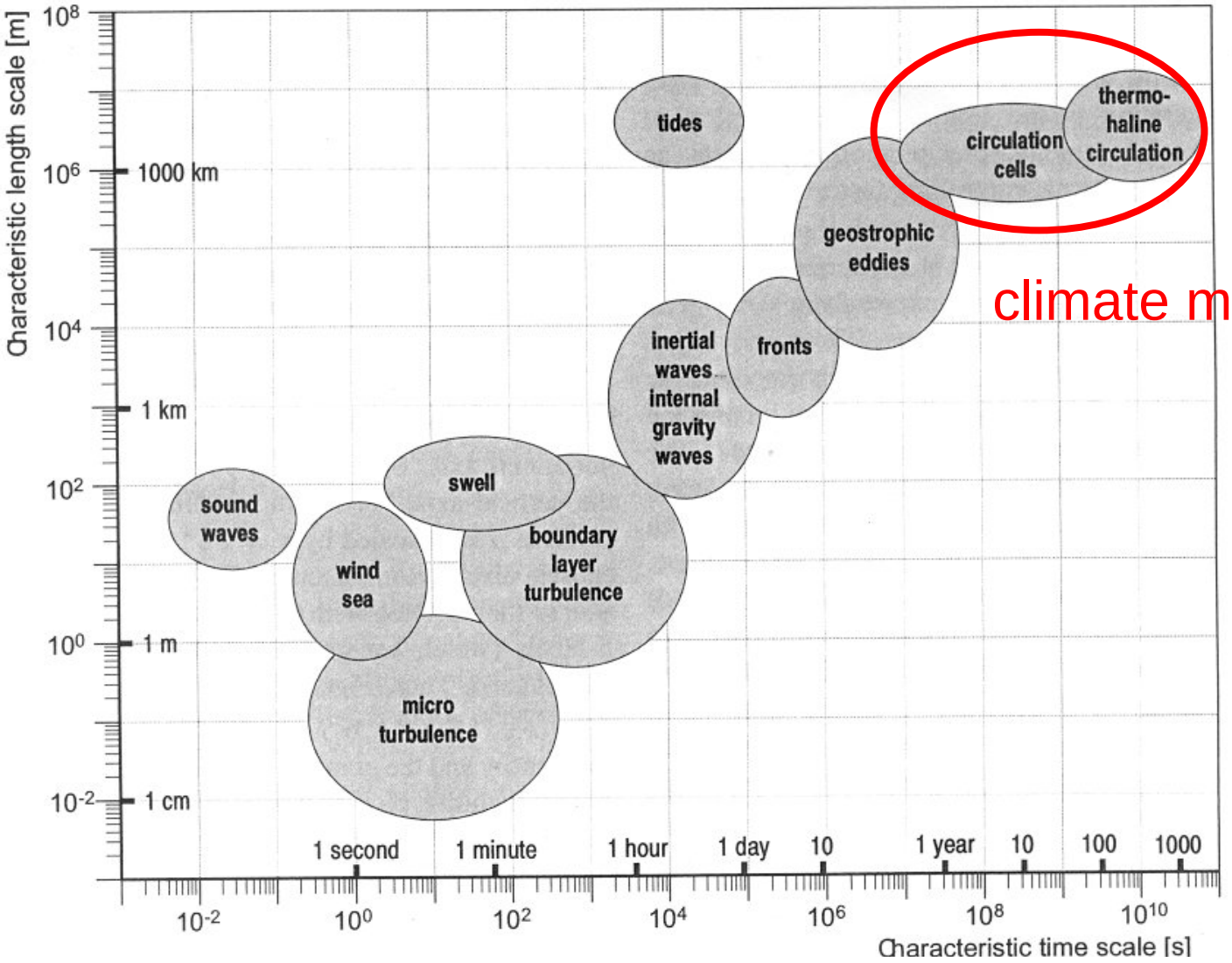
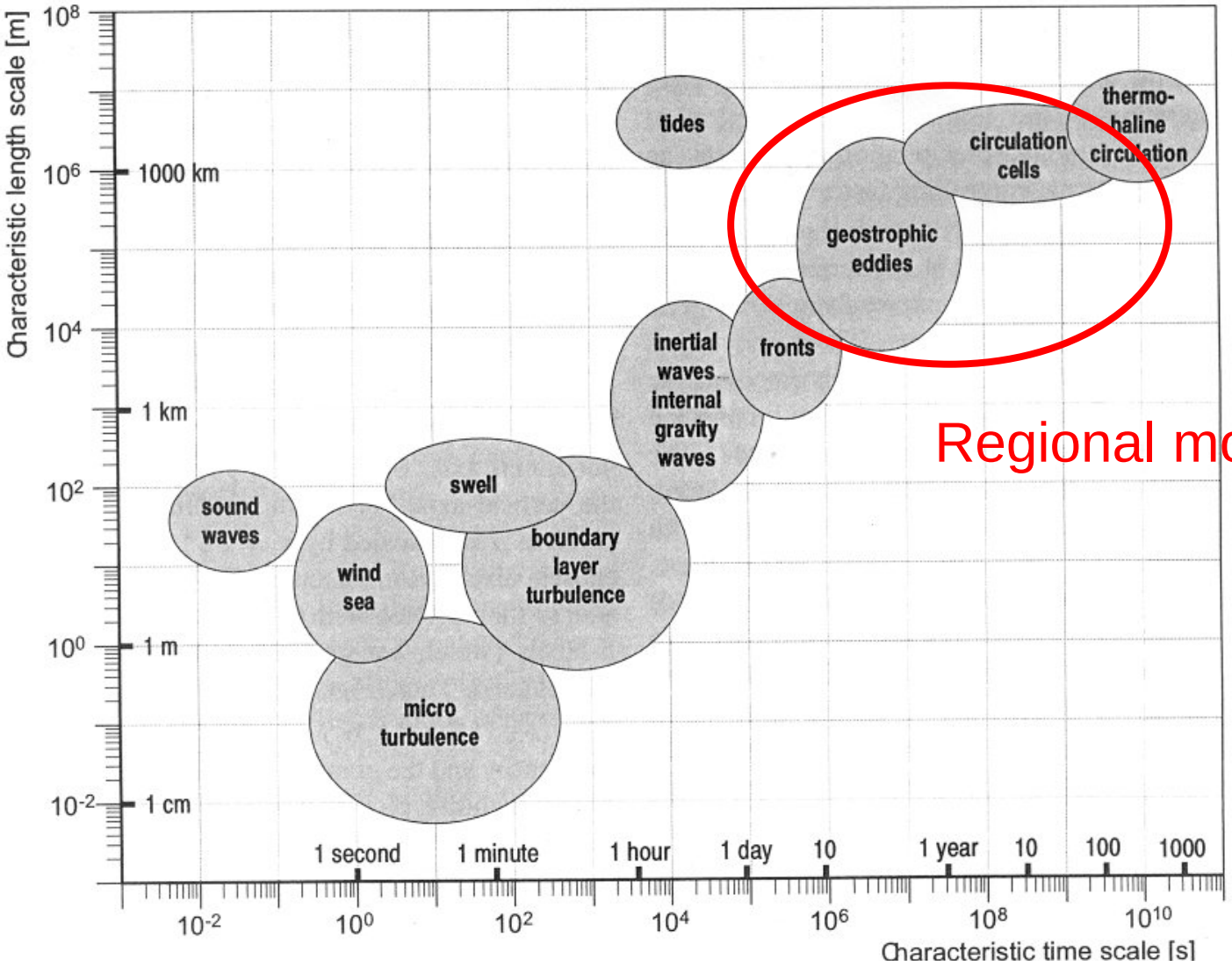


climate model

(source: von Storch and Zwiers, 1999)

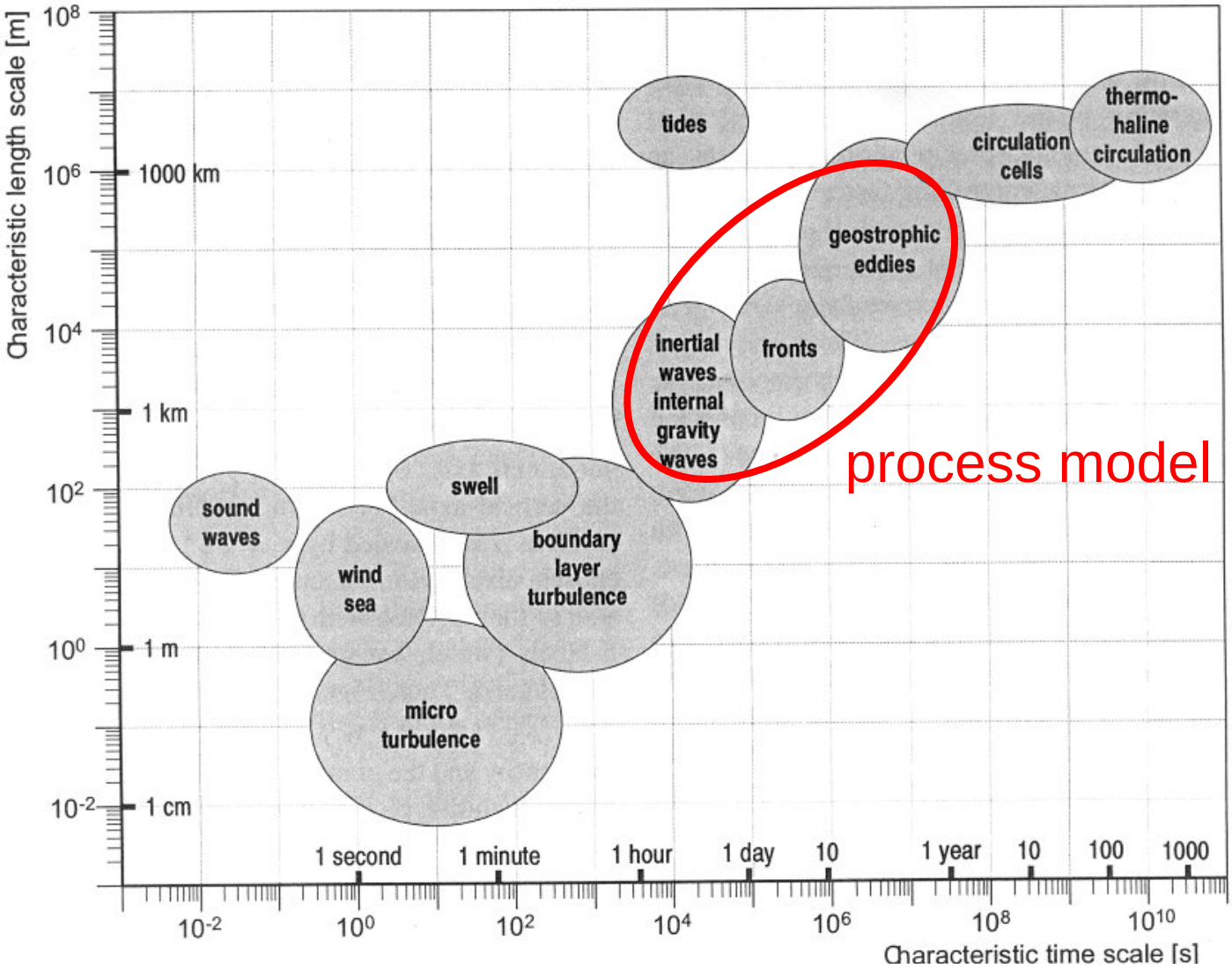
Spatial and temporal scales in the ocean



Regional model

(source: von Storch and Zwiers, 1999)

Spatial and temporal scales in the ocean



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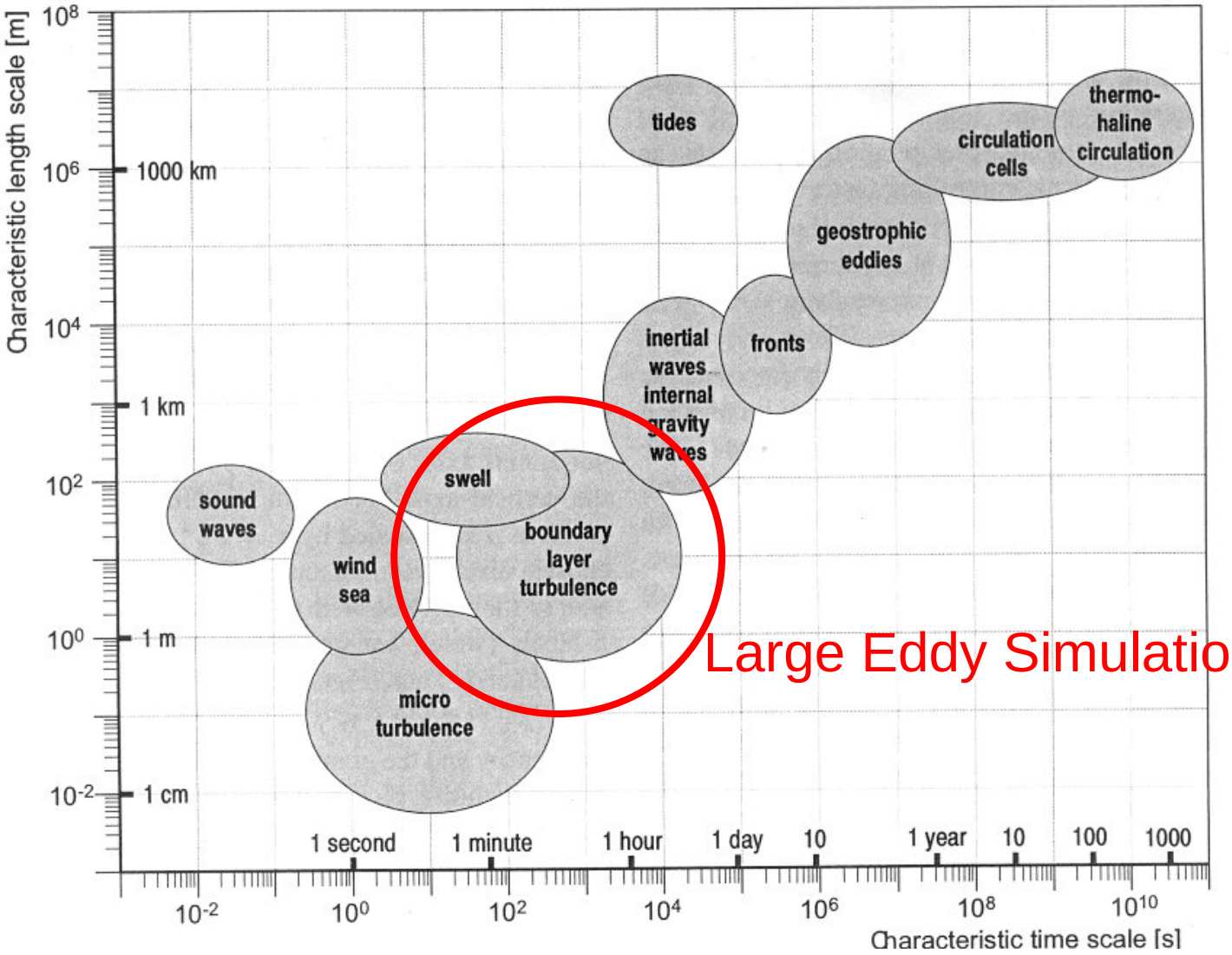

(source: von Storch and Zwiers, 1999)

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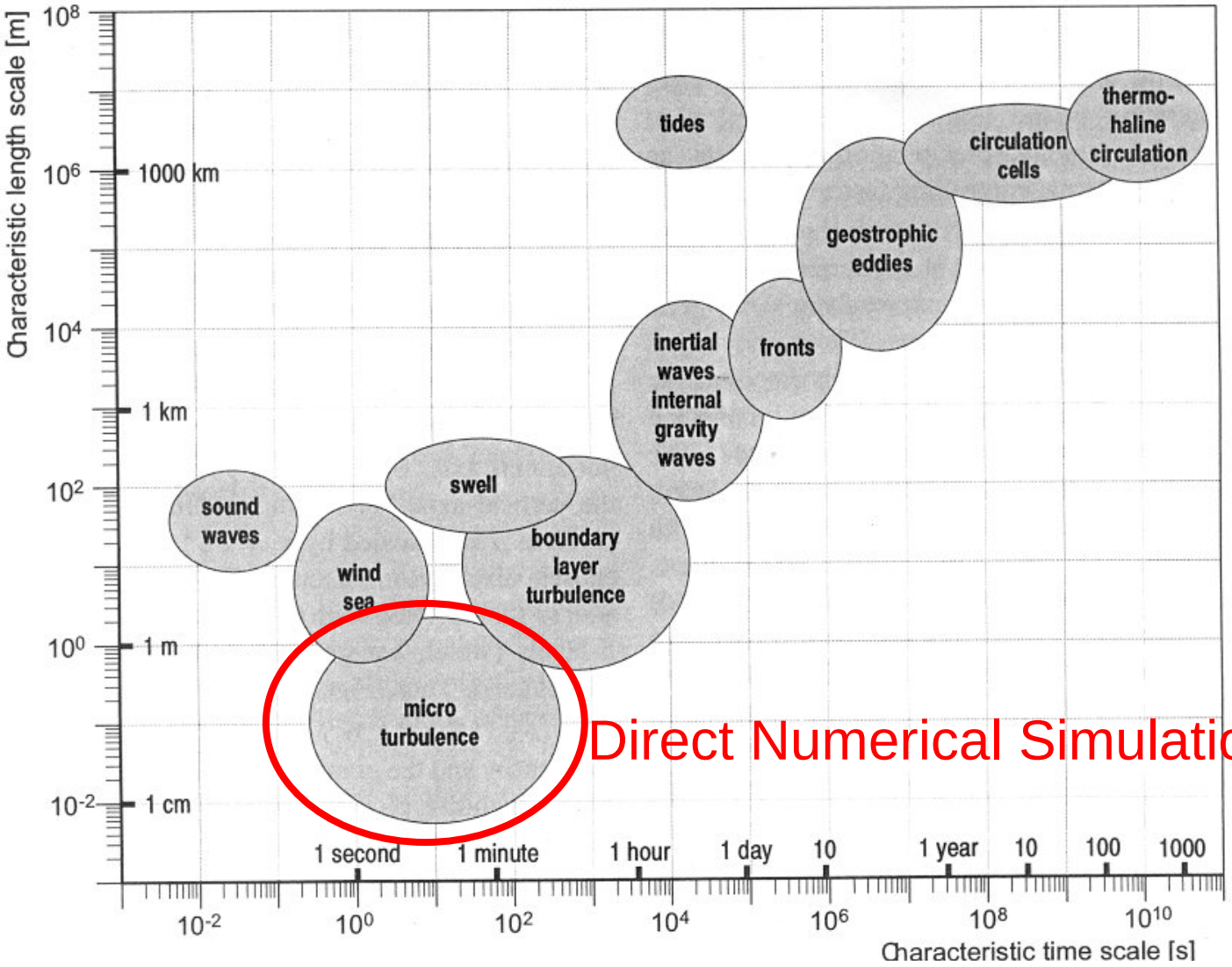

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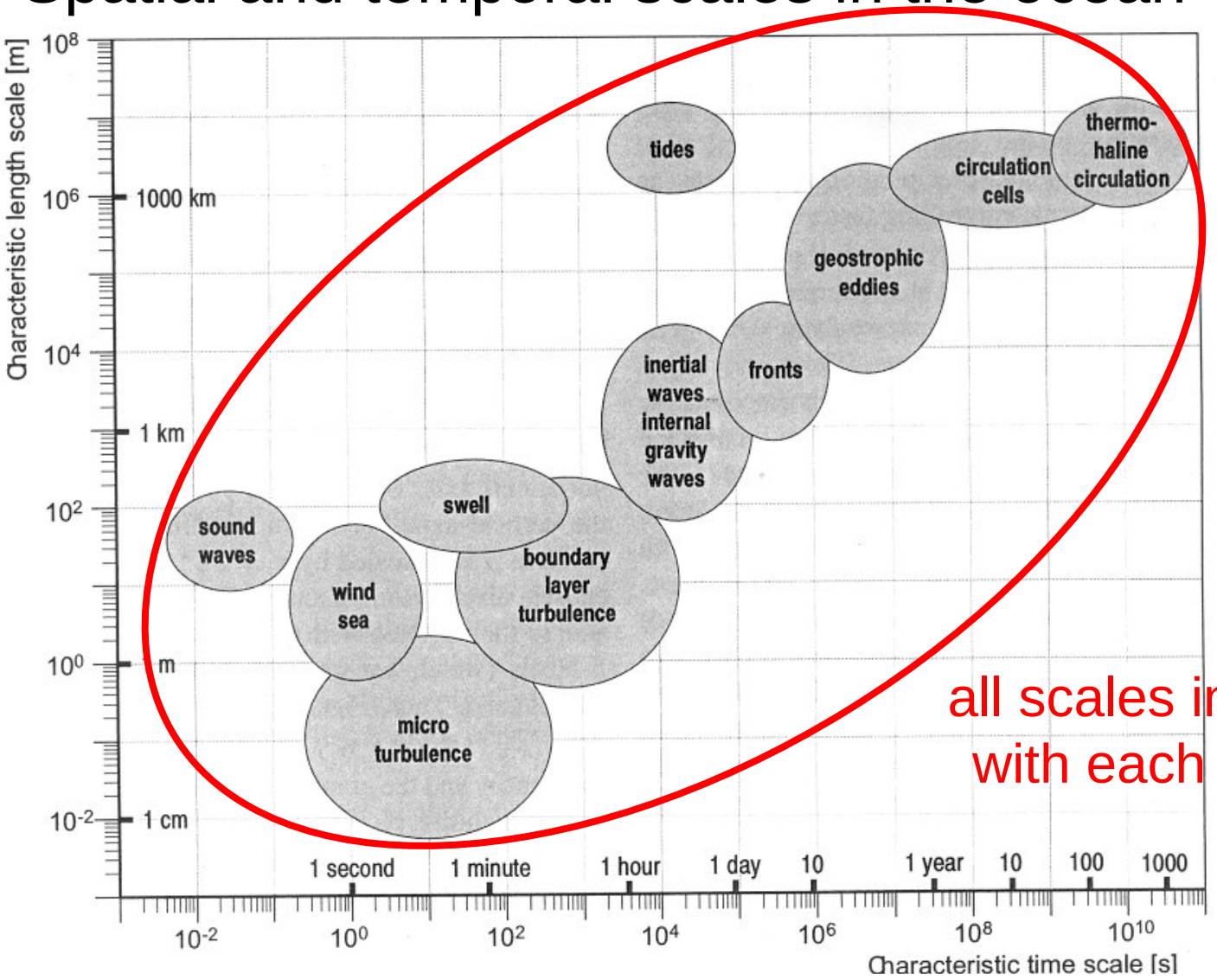
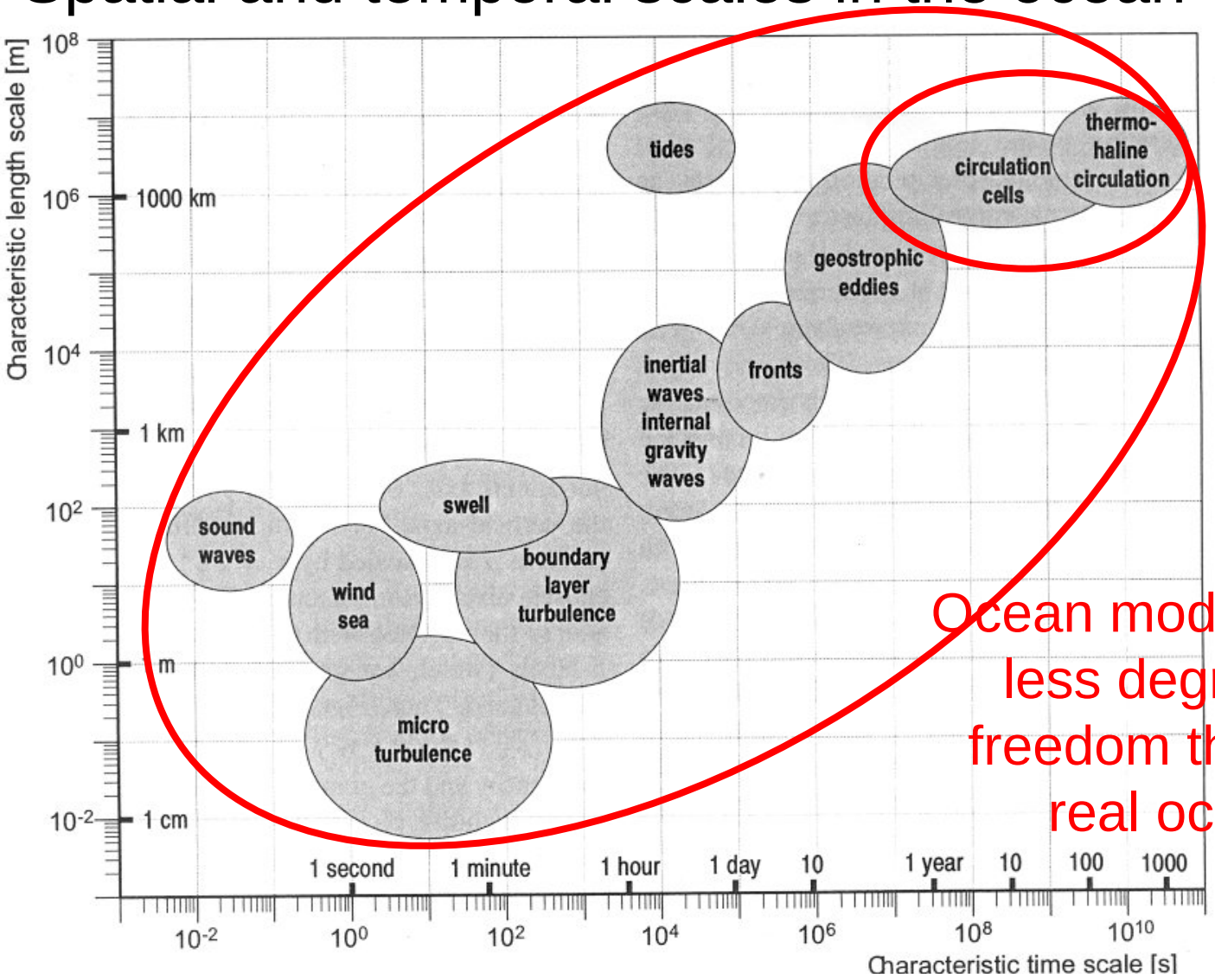


all scales interact with each other

(source: von Storch and Zwiers, 1999)

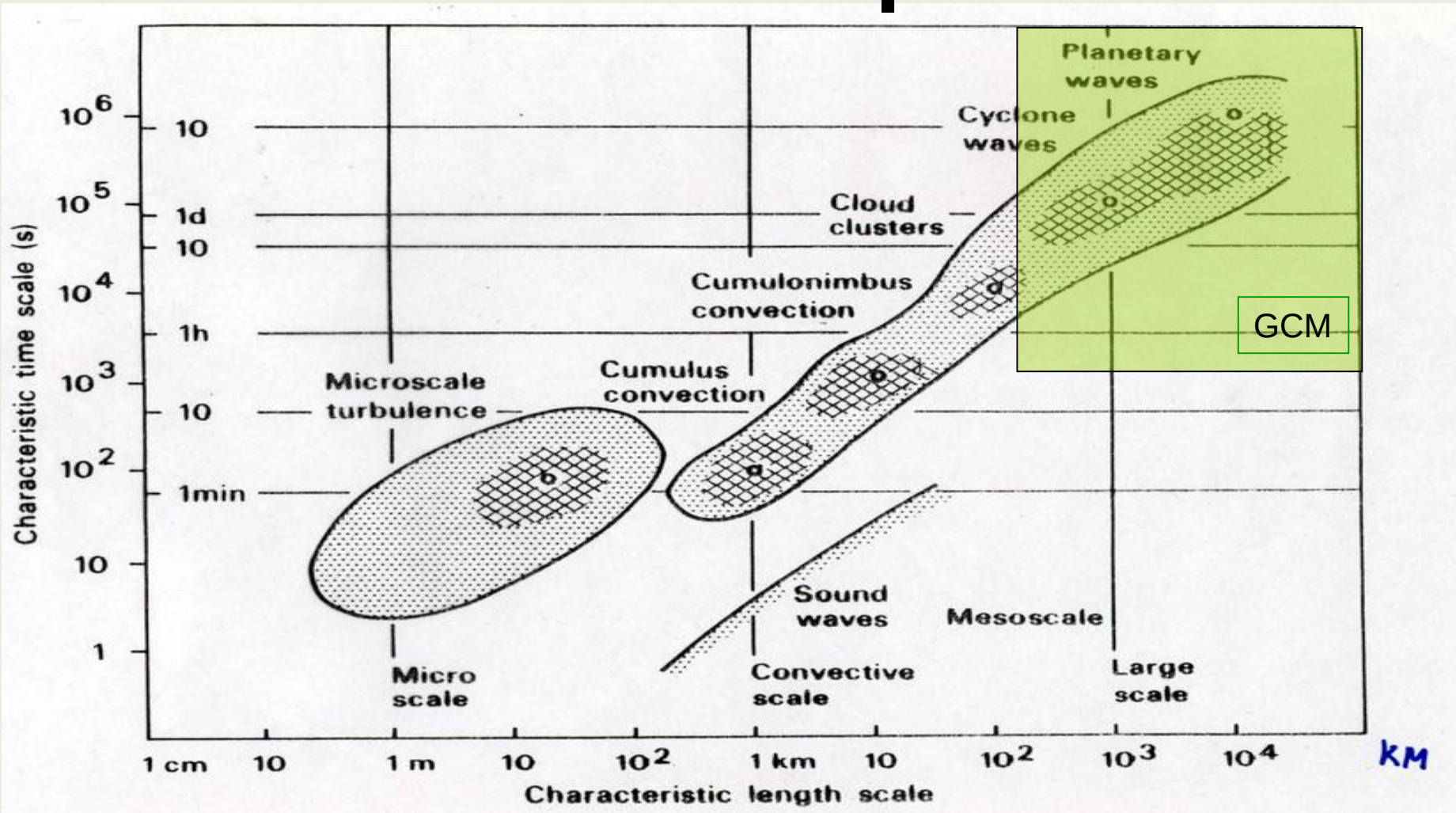
Spatial and temporal scales in the ocean



Ocean models have less degree of freedom than the real ocean

(source: von Storch and Zwiers, 1999)

Spatial and temporal scales in the atmosphere



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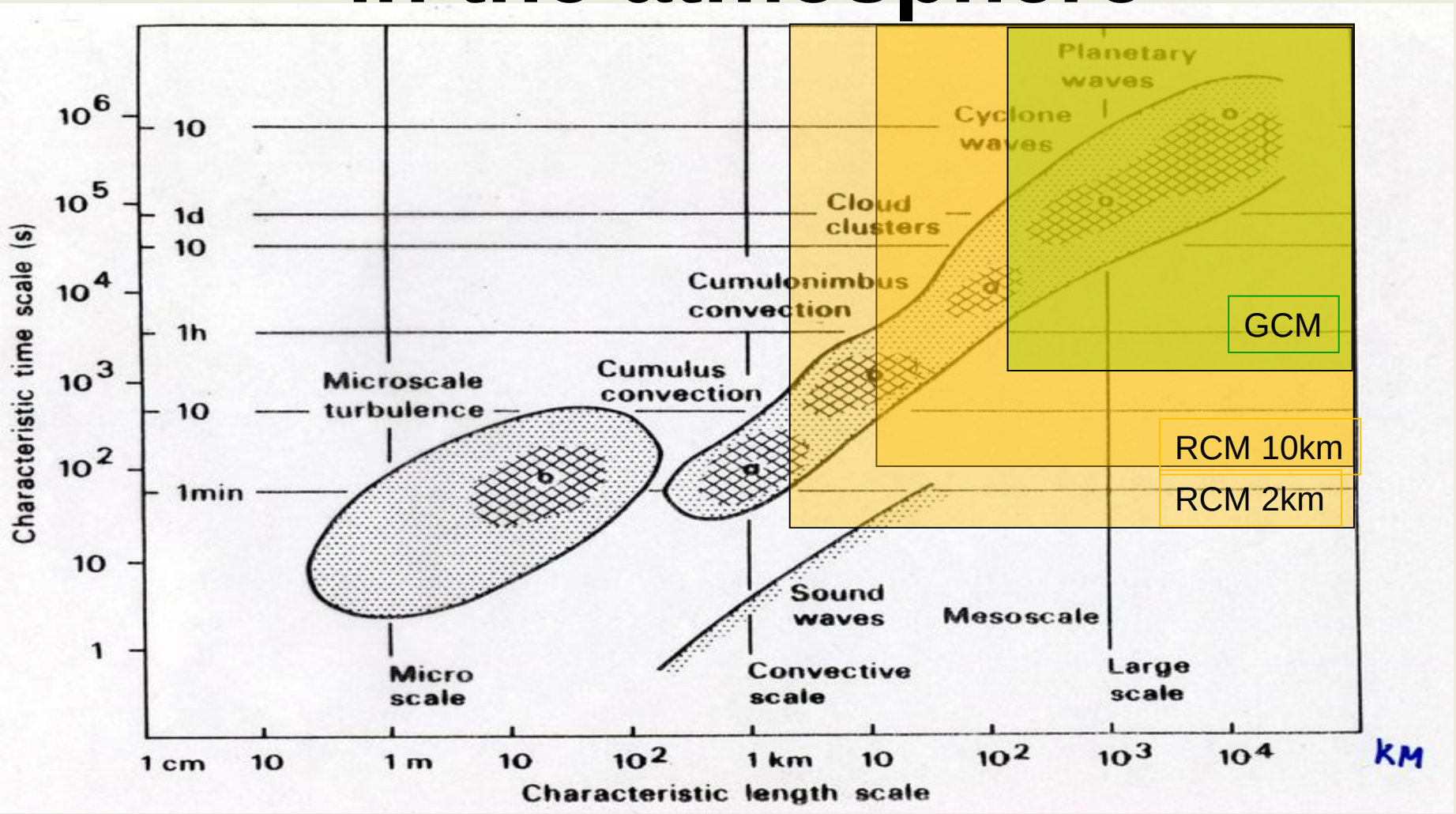


The atmosphere in a GCM

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

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

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

$$p\alpha = RT$$

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

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

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

Principle of running a GCM

- Start from a given state of the climate system
- Calculate time tendencies of state variables
- Add tendencies to the state of the system
- Derive new tendencies, add to the state, etc.

- What state to start from?
- The initial state is important for the entire integration

Vilhelm Bjerknes (1862-1951):

”Das Problem der Wettervorhersage, betrachtet vom Standpunkte der Mechanik und der Physik” (Meteorologische Zeitschrift, 1904)

http://www-gap.dcs.st-and.ac.uk/~history/Mathematicians/Bjerknes_Vilhelm.html

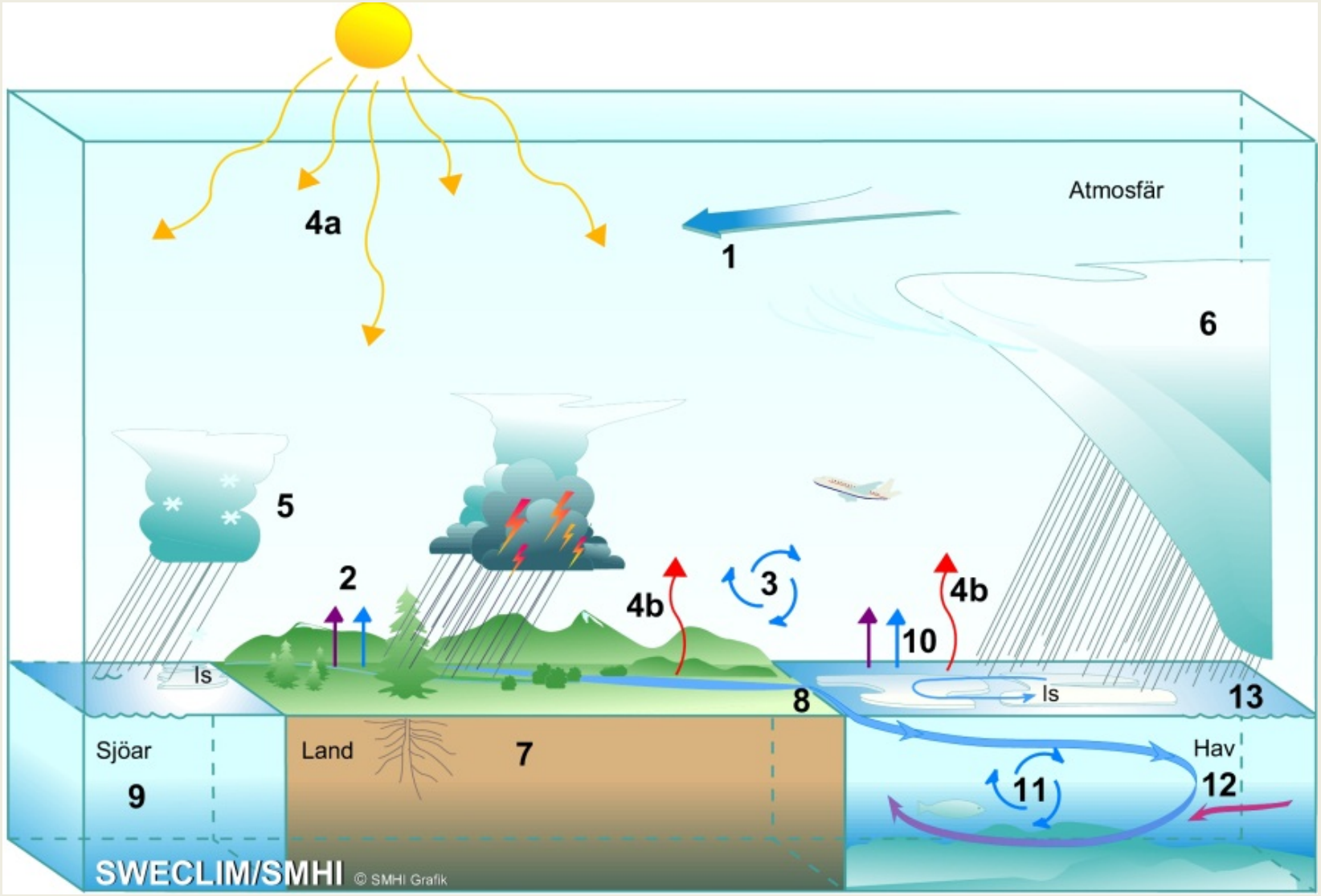
How can we simulate the climate 100 years into the future when we can’t even say something about the weather in the next month?

Climate is statistics of weather!

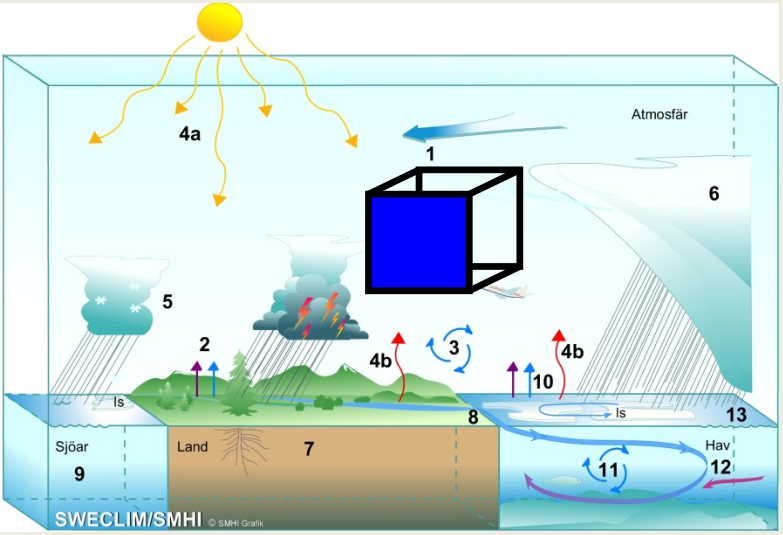
Weather forecasts and climate scenarios

- Similar numerical models
- Weather forecasts take as a starting point a given (well-observed) weather situation. Climate scenarios often start in preindustrial times (poor observations)
- Properties of the atmosphere implies that reliable weather forecasts beyond c 10 days can not be done
- A climate model can therefore not say anything about the weather at any given day in the future (in 30 years, on New Years Eve 2016, next month, etc.)
- But, models can be run for long time periods (weeks, months, years, centuries, etc) and result in realistic weather situations
- Climate models simulate the statistical properties of the weather

GCMs describe all relevant processes

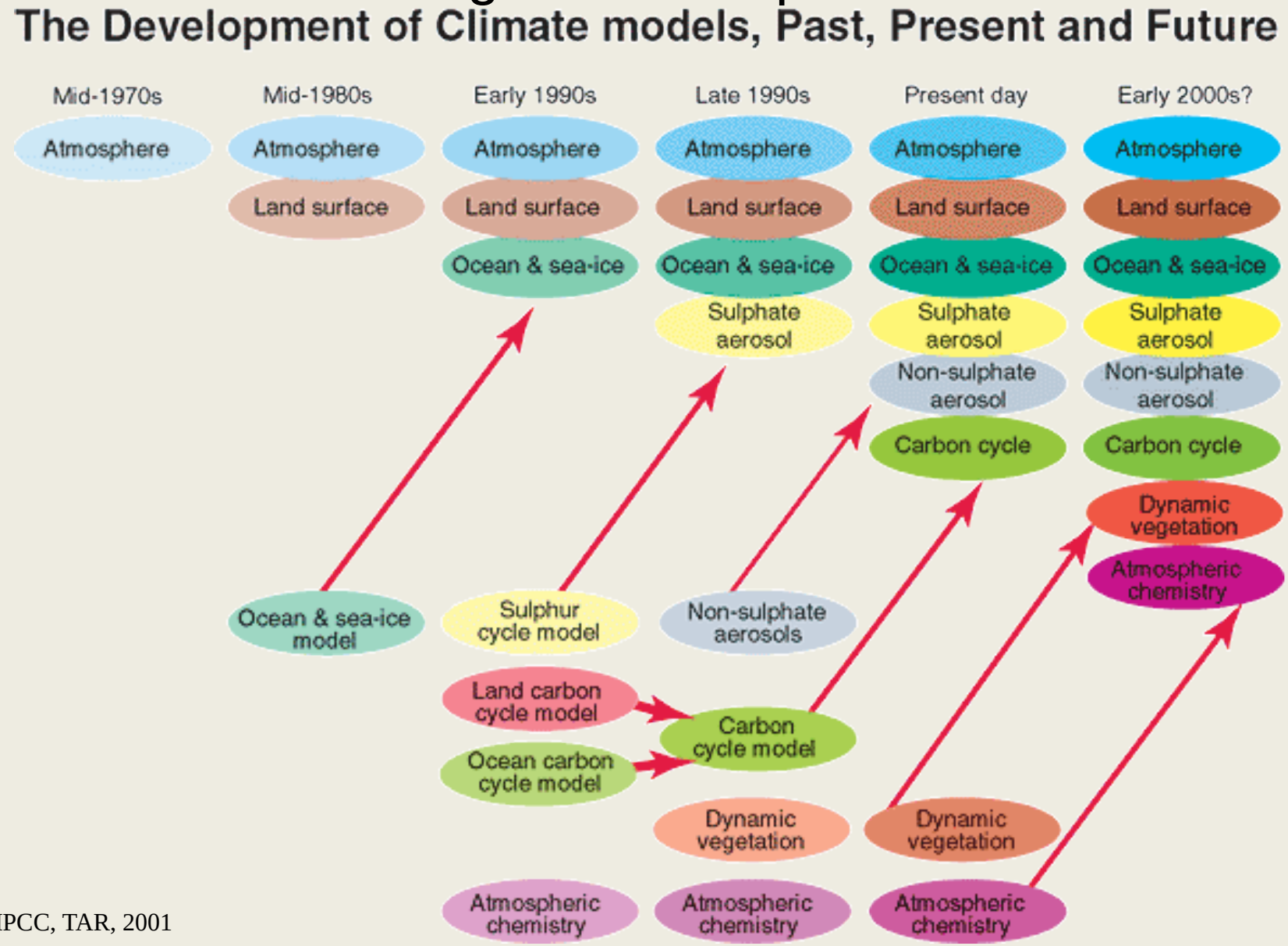


Limitations in a GCM (NWP)



- Not all processes are resolved
- Approximations for e.g. turbulence, clouds and precipitation, …
- Parametrizations (express small scale phenomenon in large scale parameters)
- GCMs (NWPs) compromise between detailed descriptions and high computational speed

Building more complex models



Source: IPCC, TAR, 2001

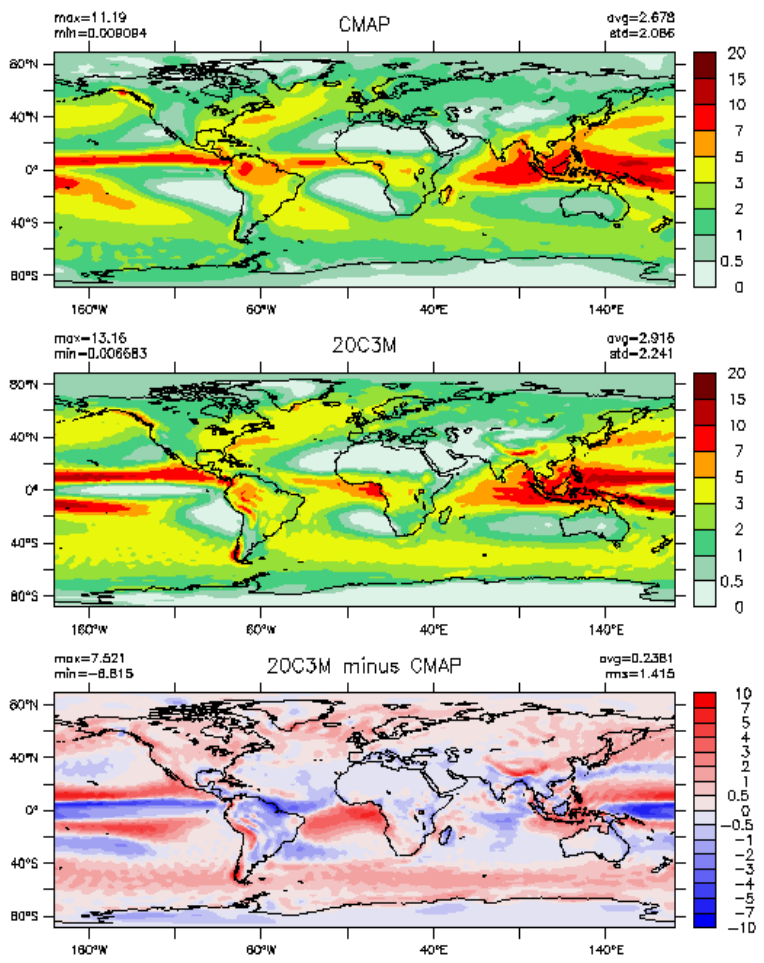
Evaluation of climate models

Today's GCMs reproduce large parts of the observed climate, both in terms of long term averages, variability and extreme conditions

Some weaknesses are that:

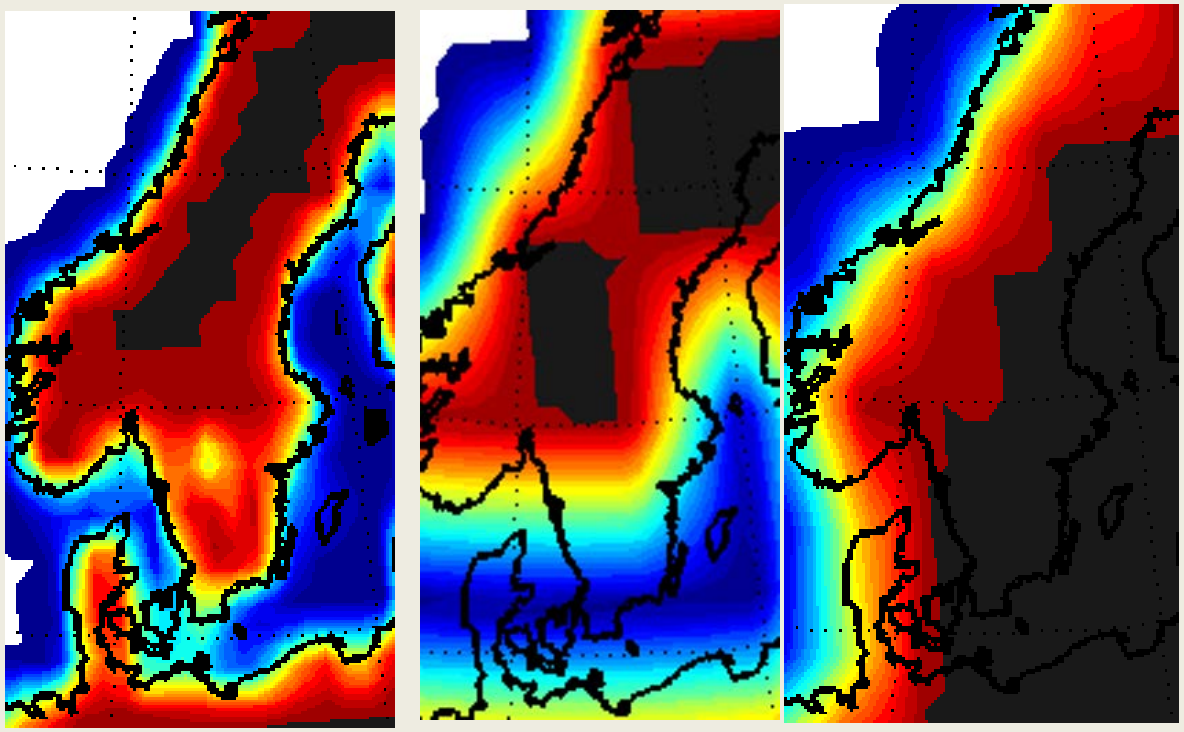
- GCMs only represent large scale (>100km) phenomena explicitly,
- not all GCMs include all relevant processes (eg. carbon cycle feedback),
- we do not fully understand how relevant processes can be described in the models (particularly clouds)

Annual mean precipitation: OBS vs. AOGCM



What is resolved in a GCM?

Land-sea mask in three CMIP3 GCMs



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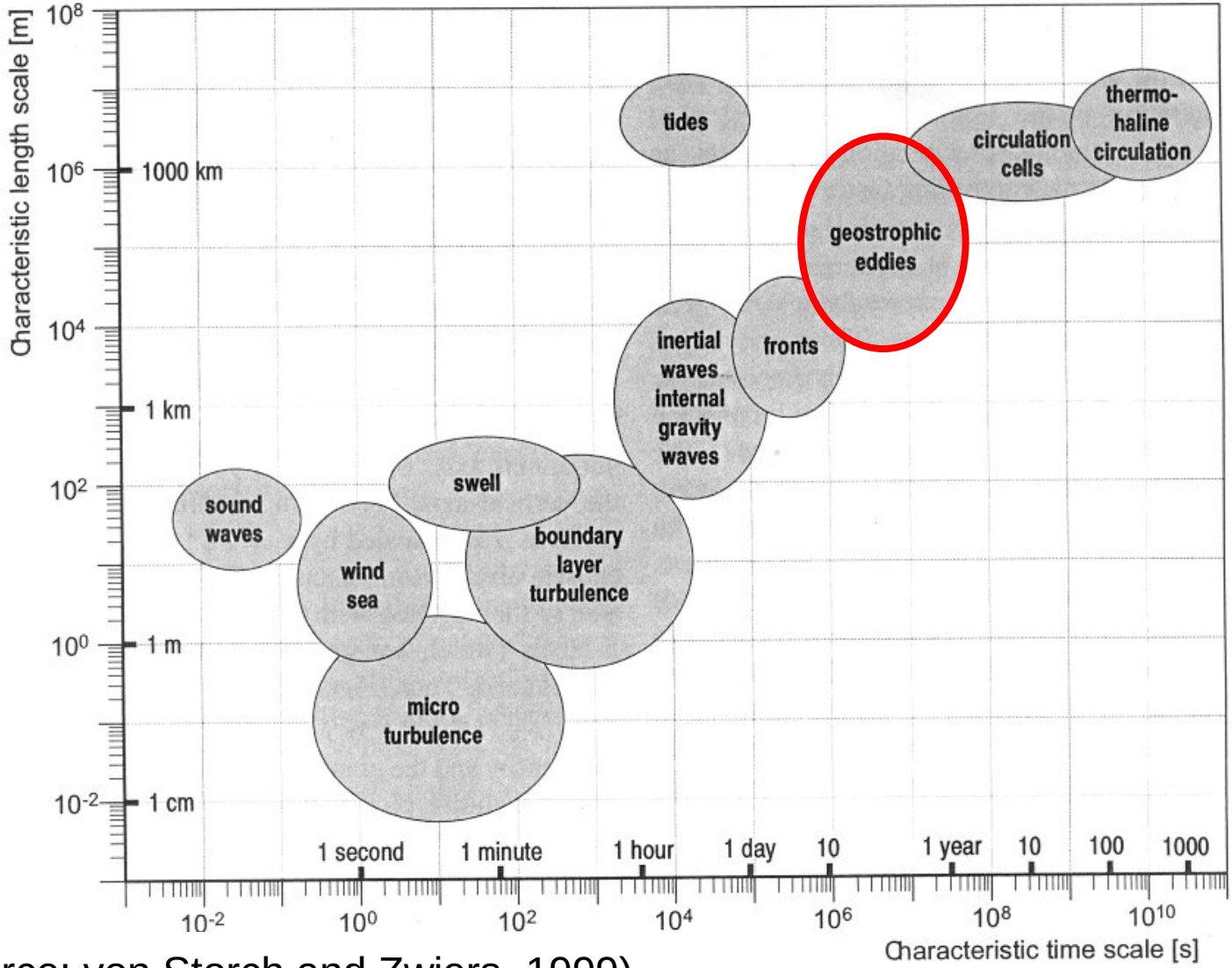
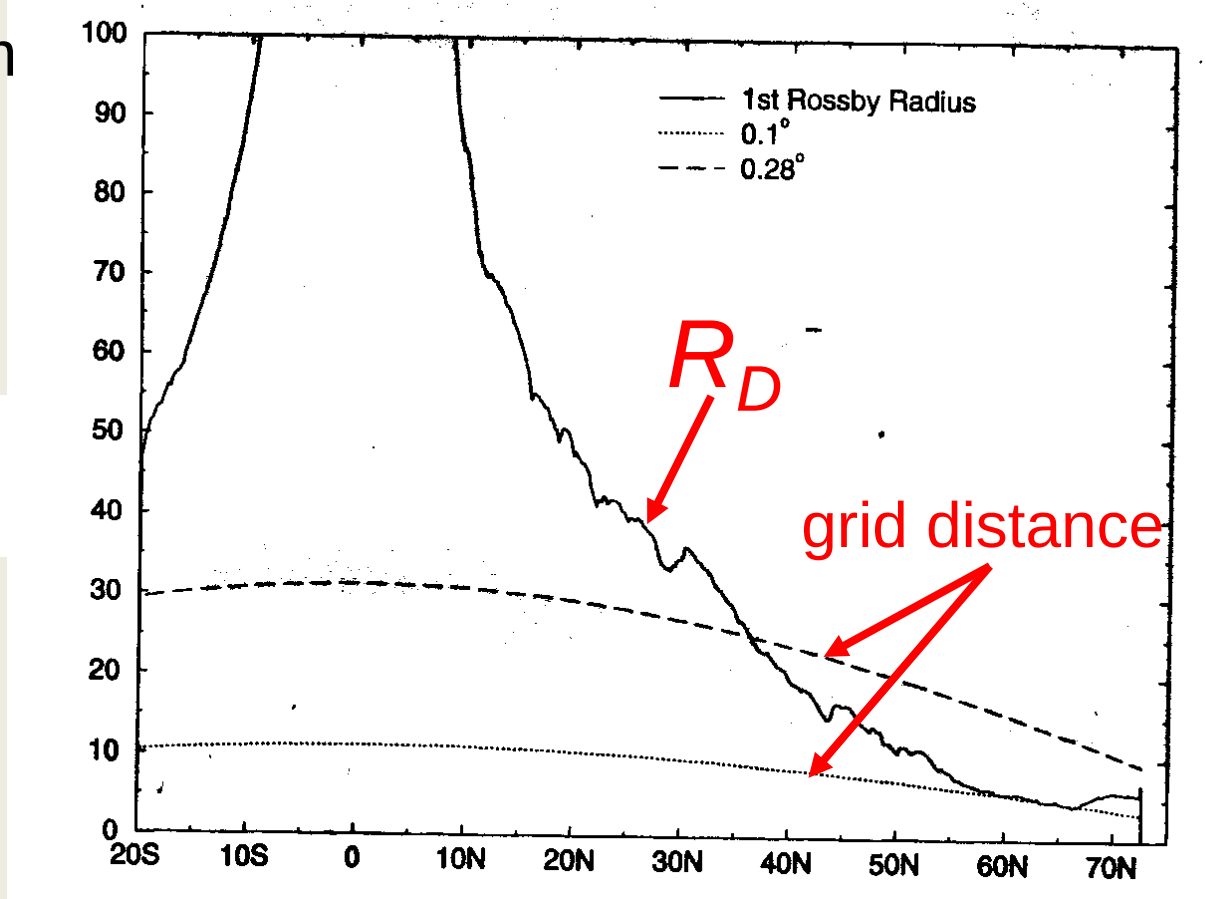


(source: von Storch and Zwiers, 1999)

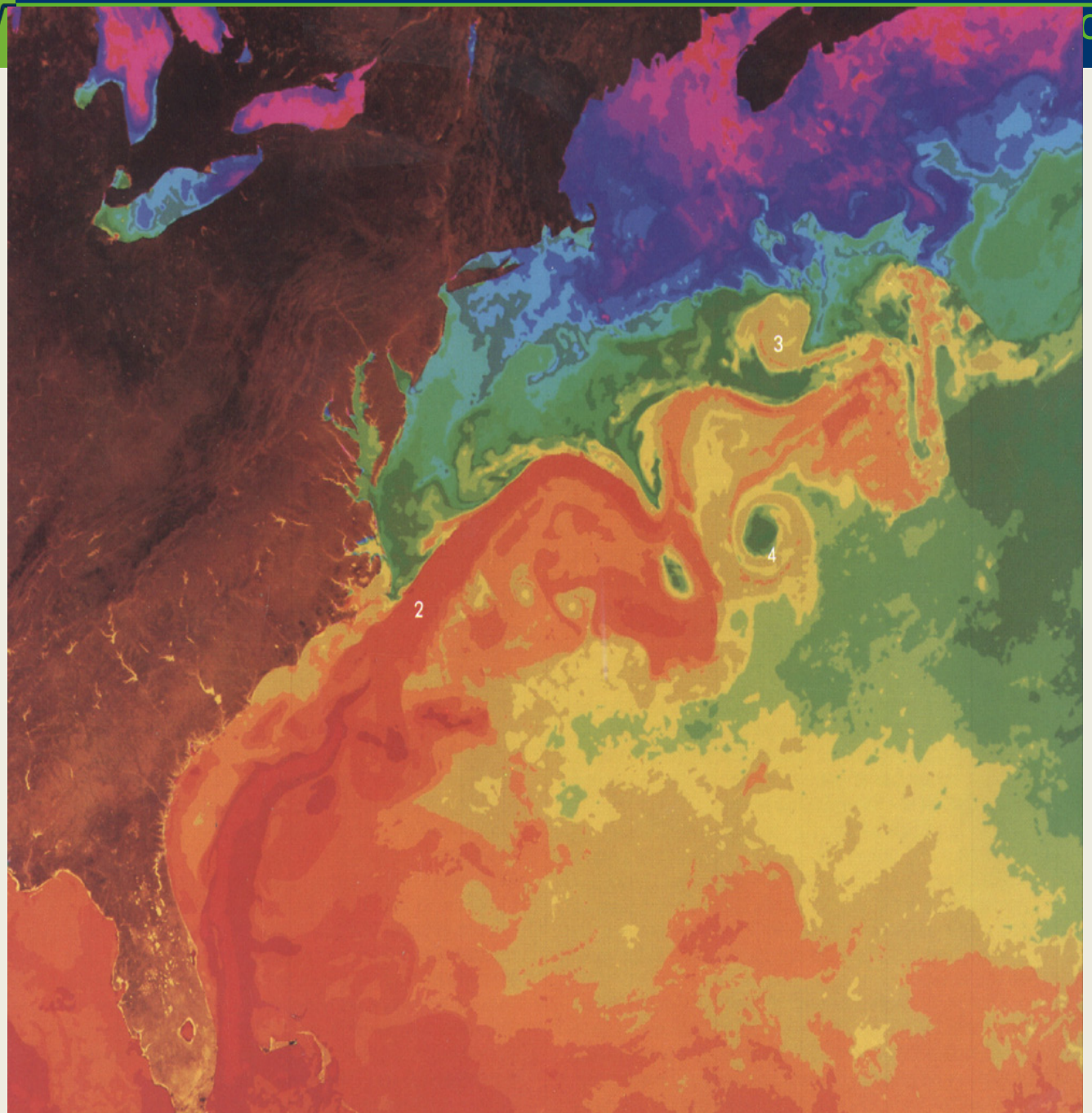
Rossby's deformation radius

$$R_D = \frac{\sqrt{gh_e}}{f}$$

g: gravitation,
h_e: equivalent depth,
f: Coriolis parameter



(source: Smith et al., 2000)

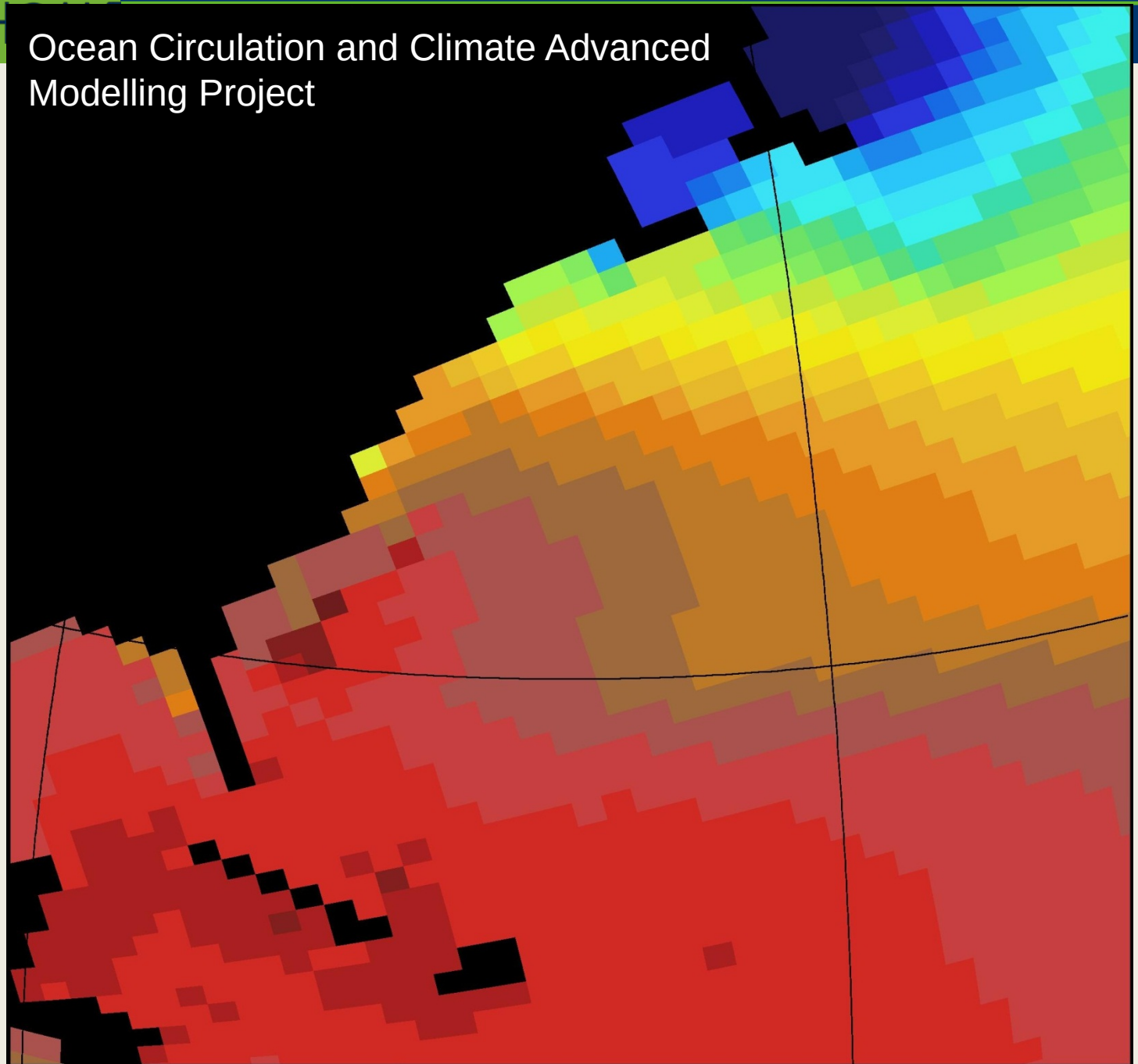


satellite observations

sea surface temperature

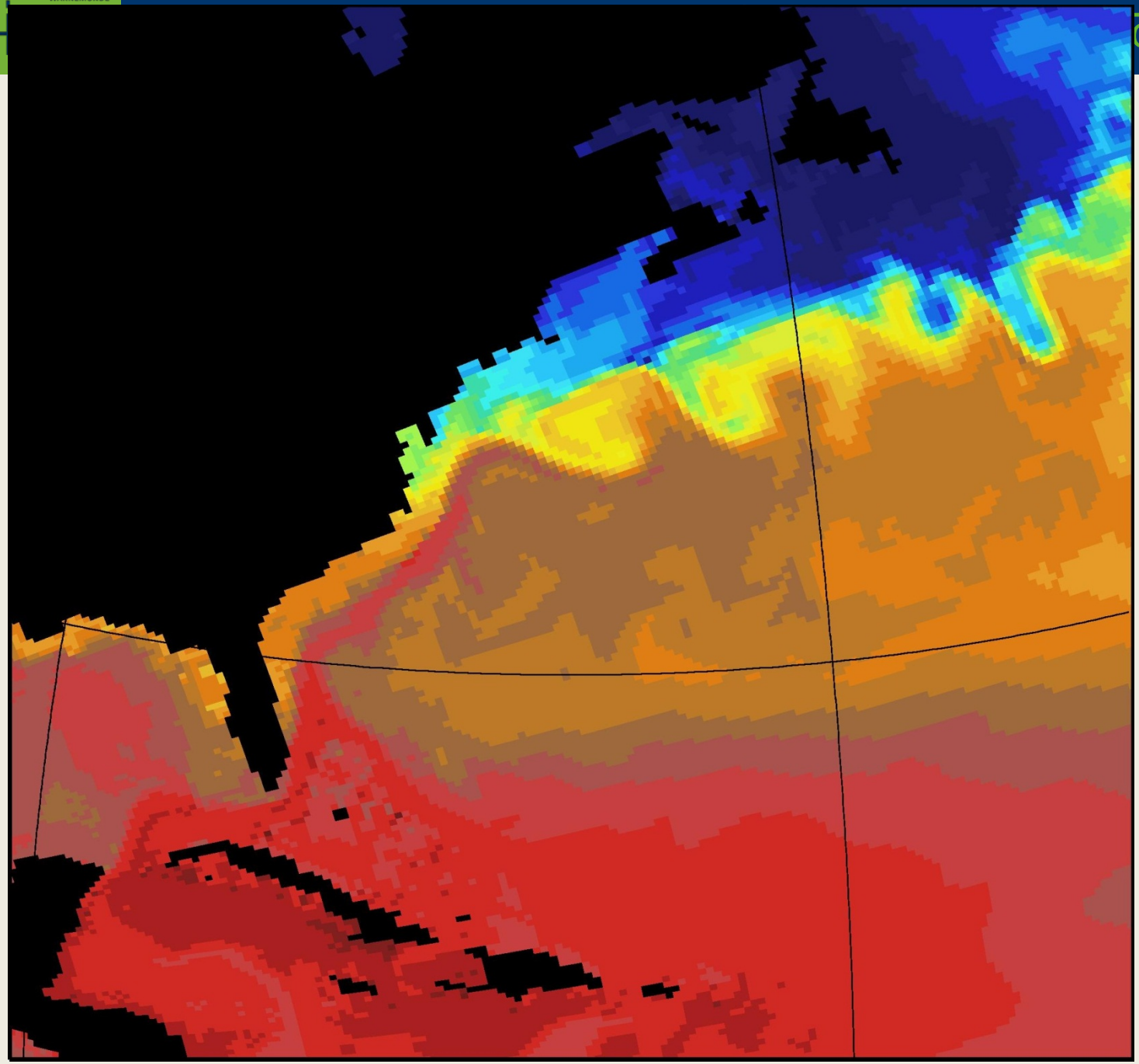
(source: A. Coward)

Ocean Circulation and Climate Advanced Modelling Project



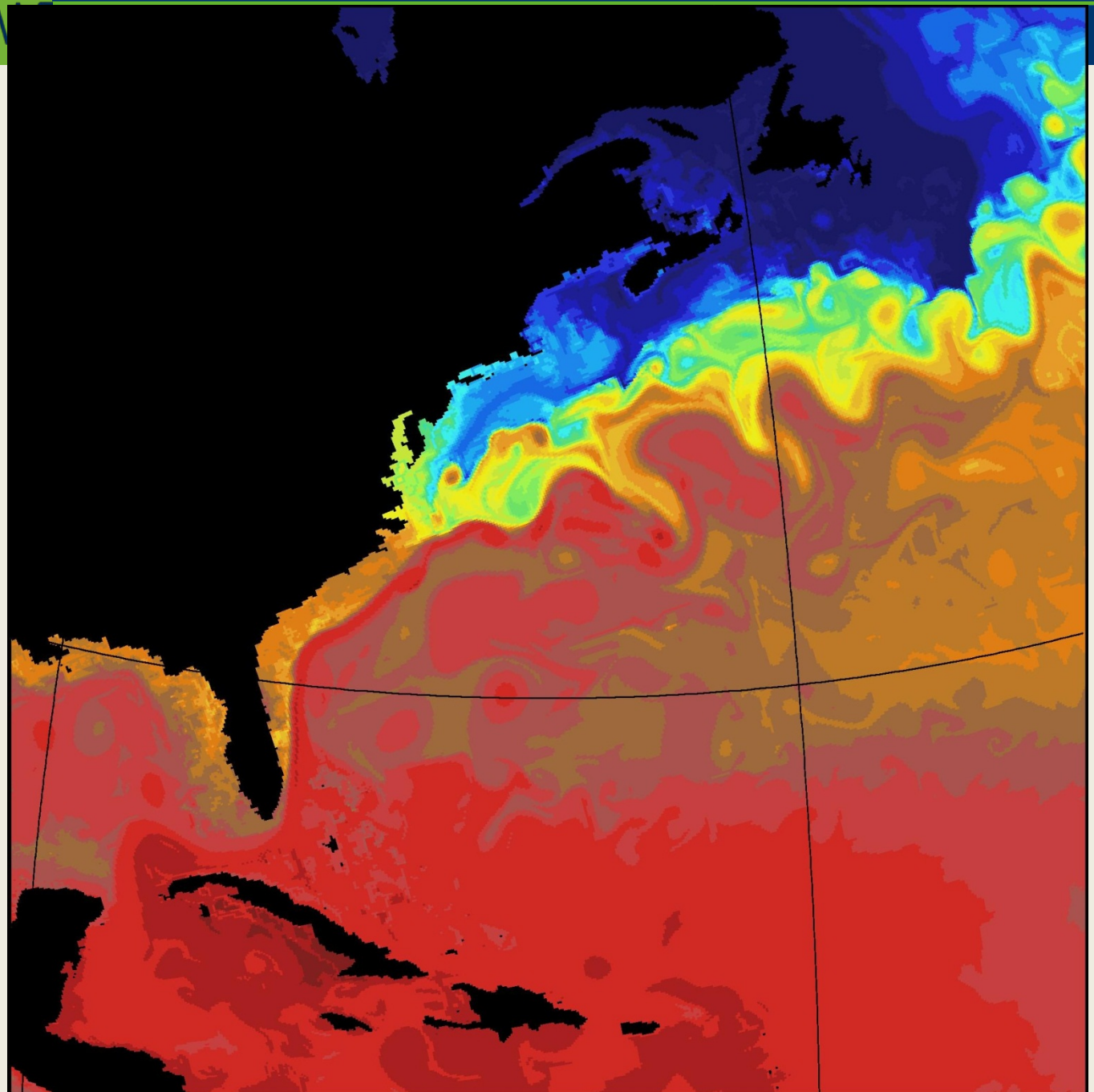
OCCAM
1°

(source:
A. Coward)



OCCAM
1/4°

(source:
A. Coward)



OCCAM
1/12°

(source:
A. Coward)

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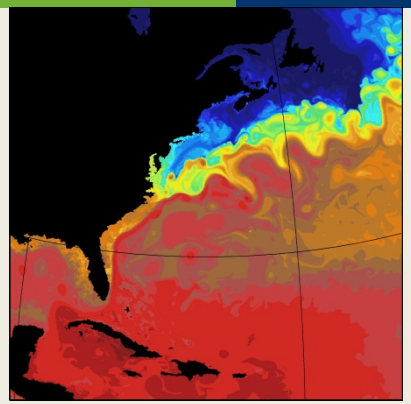
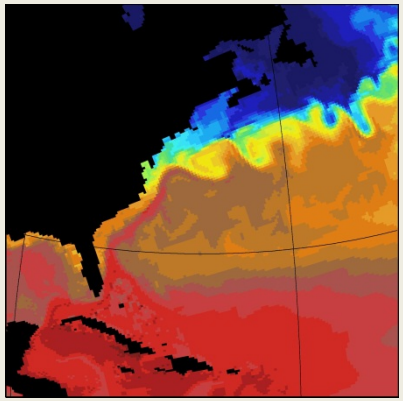
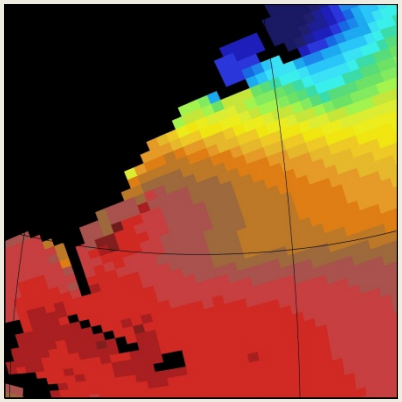
Sea surface temperature



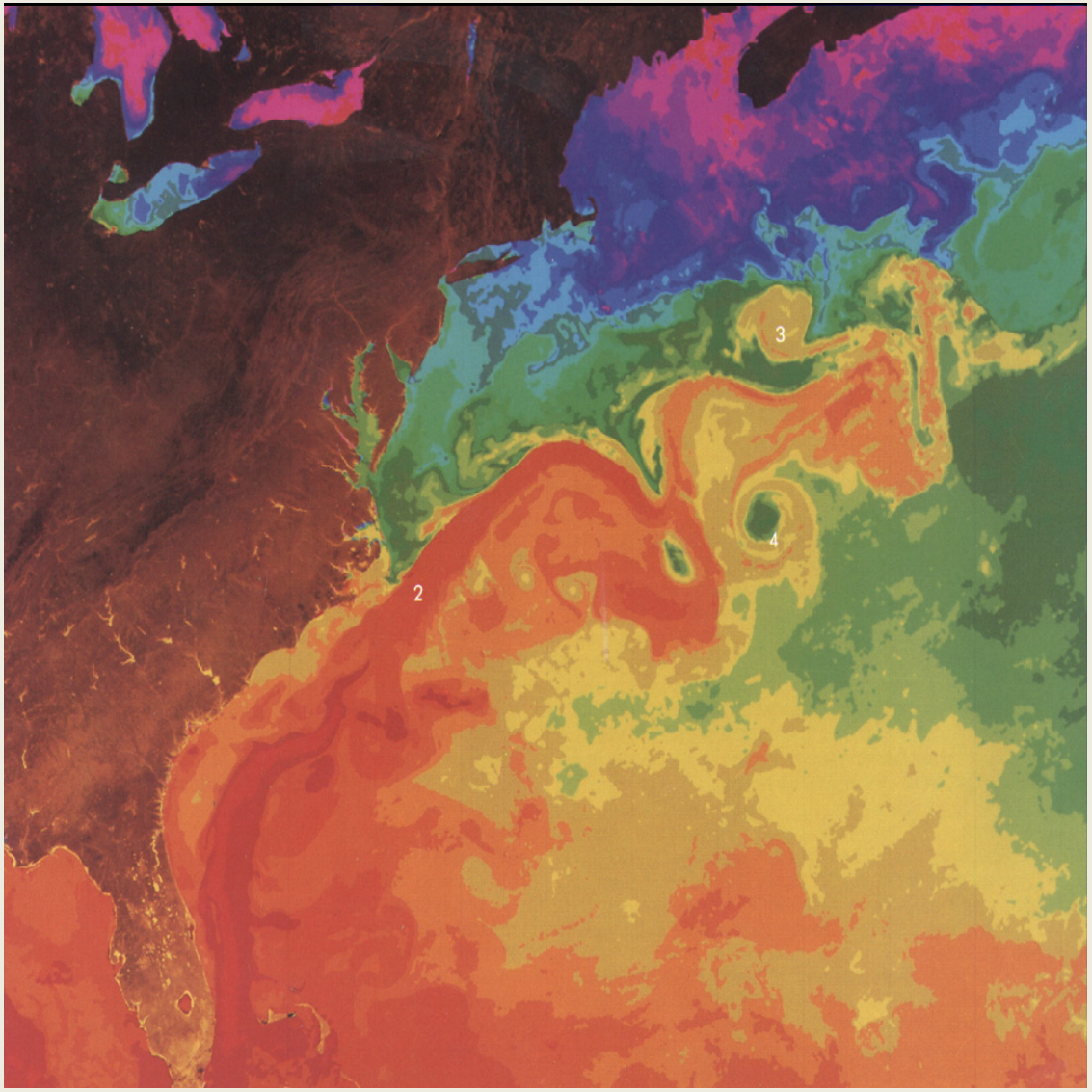
1/12°



1/4°

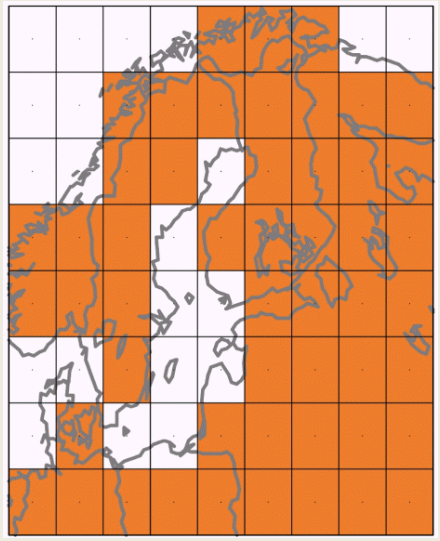


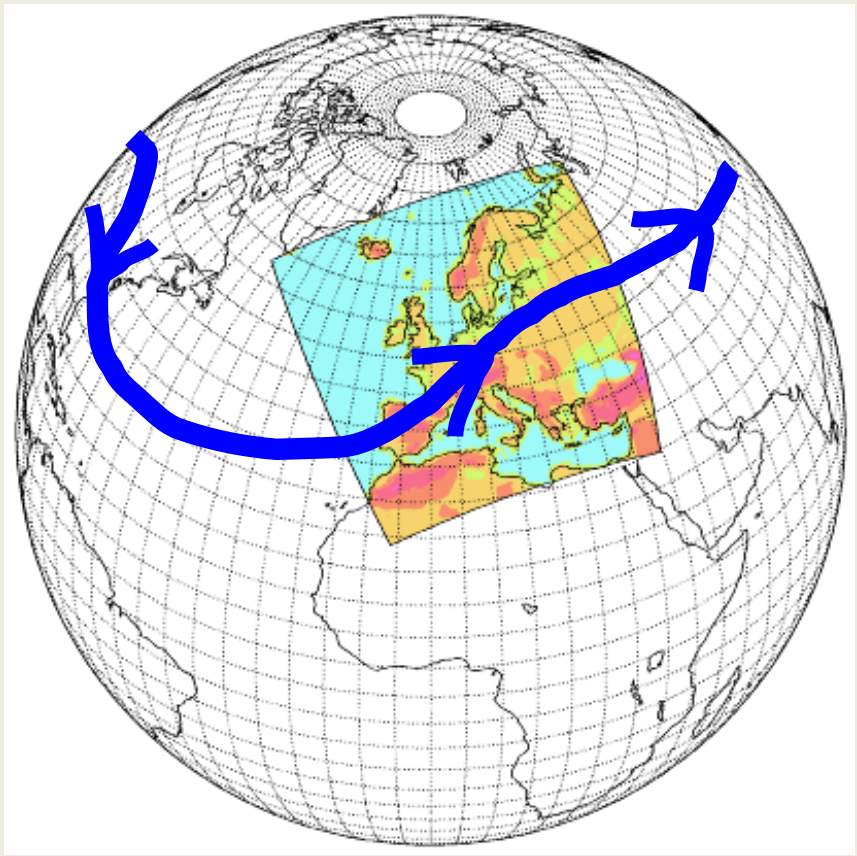
1°

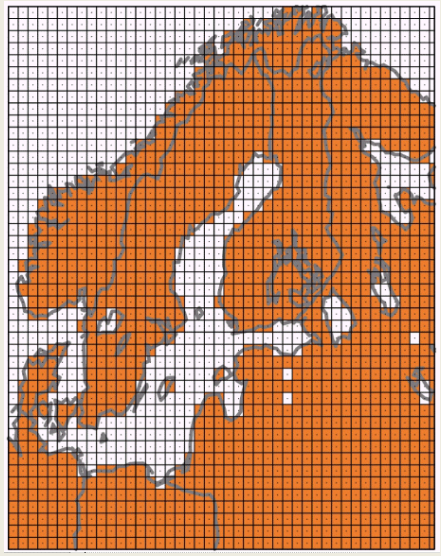


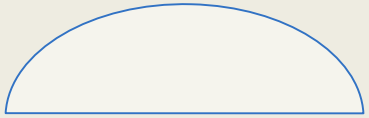
Satellite observations

Using Regional Climate Models (RCMs) to refine the information

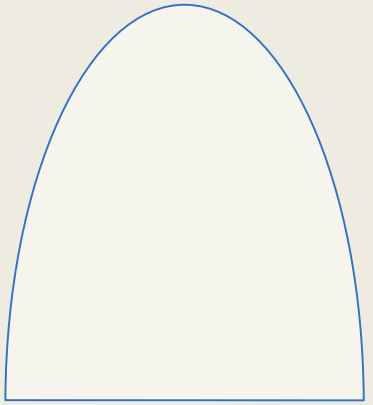




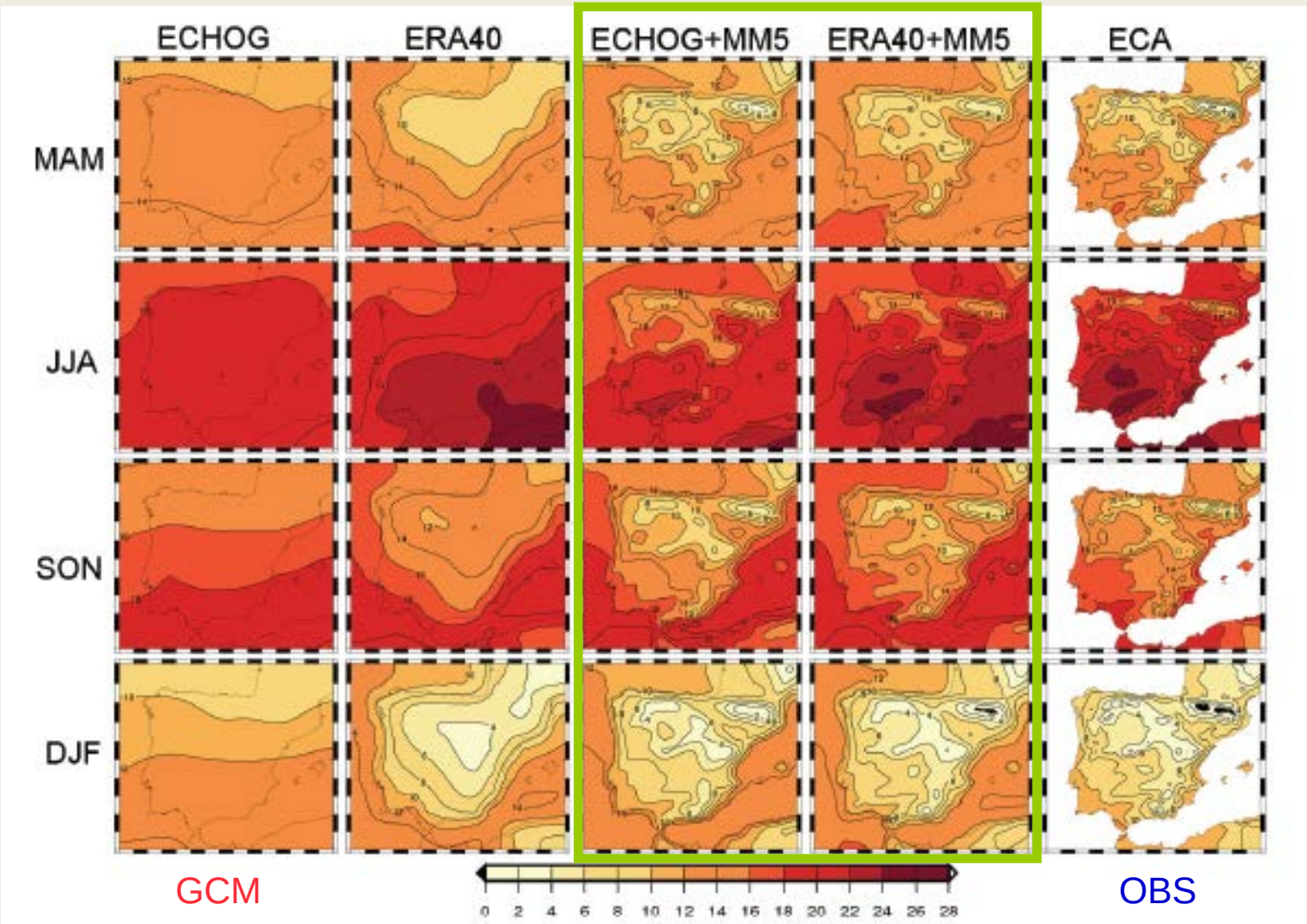




The Scandes



RCMs add detail and improves the results compared to the GCM
Comparing MM5 to observations and driving boundary data sets



Results for 1961-1990

J. J. Gómez-Navarro, J. P. Montávez, S. Jerez, P. Jiménez-Guerrero, R. Lorente-Plazas, J. F. González-Rouco, and E. Zorita. 2010. A regional climate simulation over the Iberian Peninsula for the last millennium. Clim. Past, 7, 451–472, 2011

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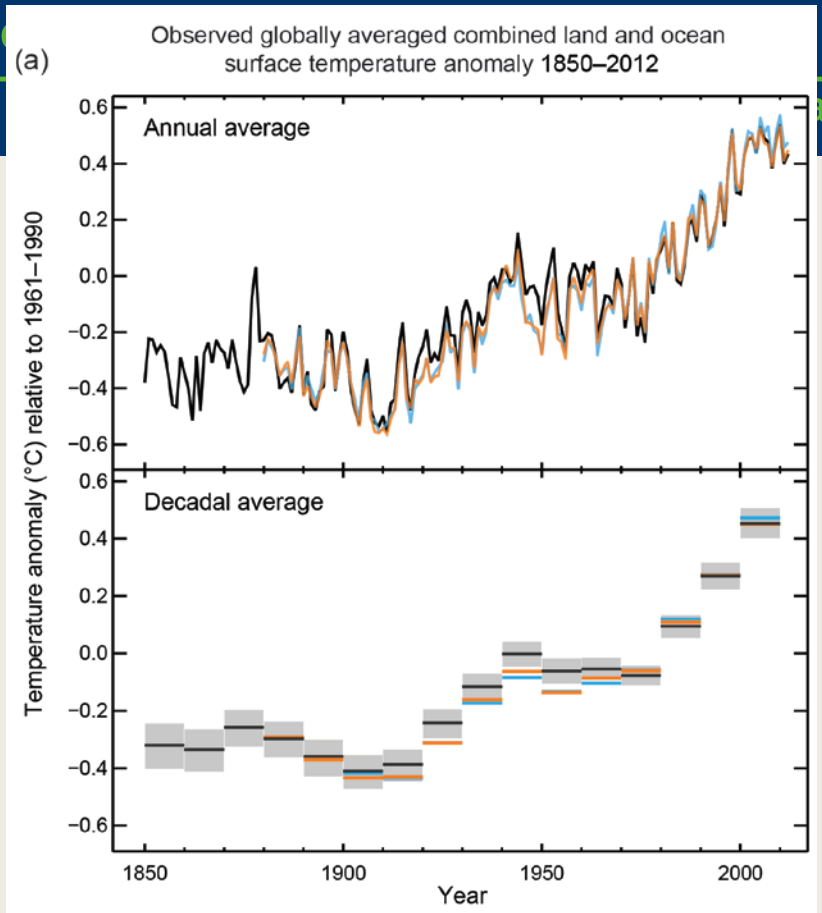
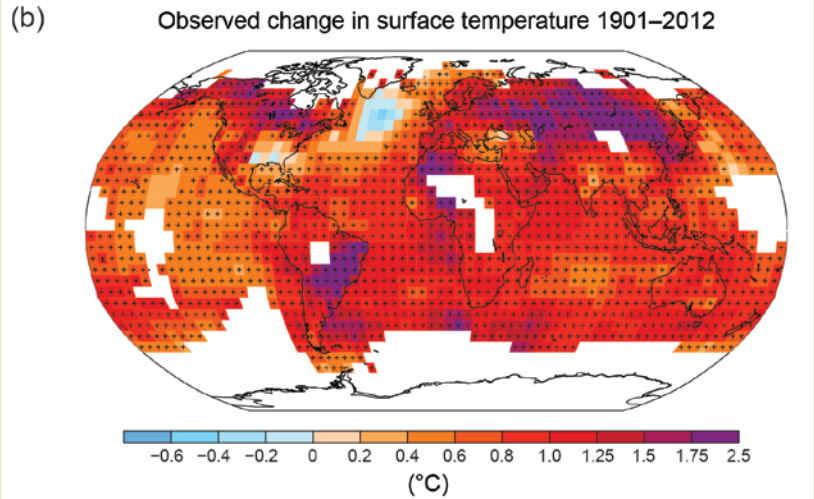
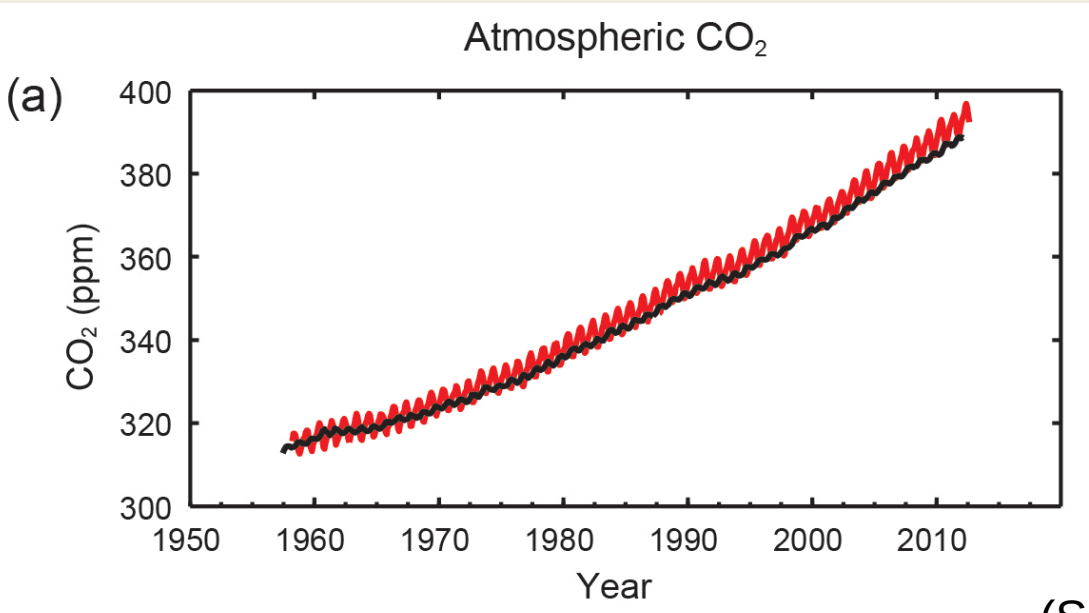
Attribution

IPCC's Fifth Assessment Report (AR5)

http://ipcc.ch







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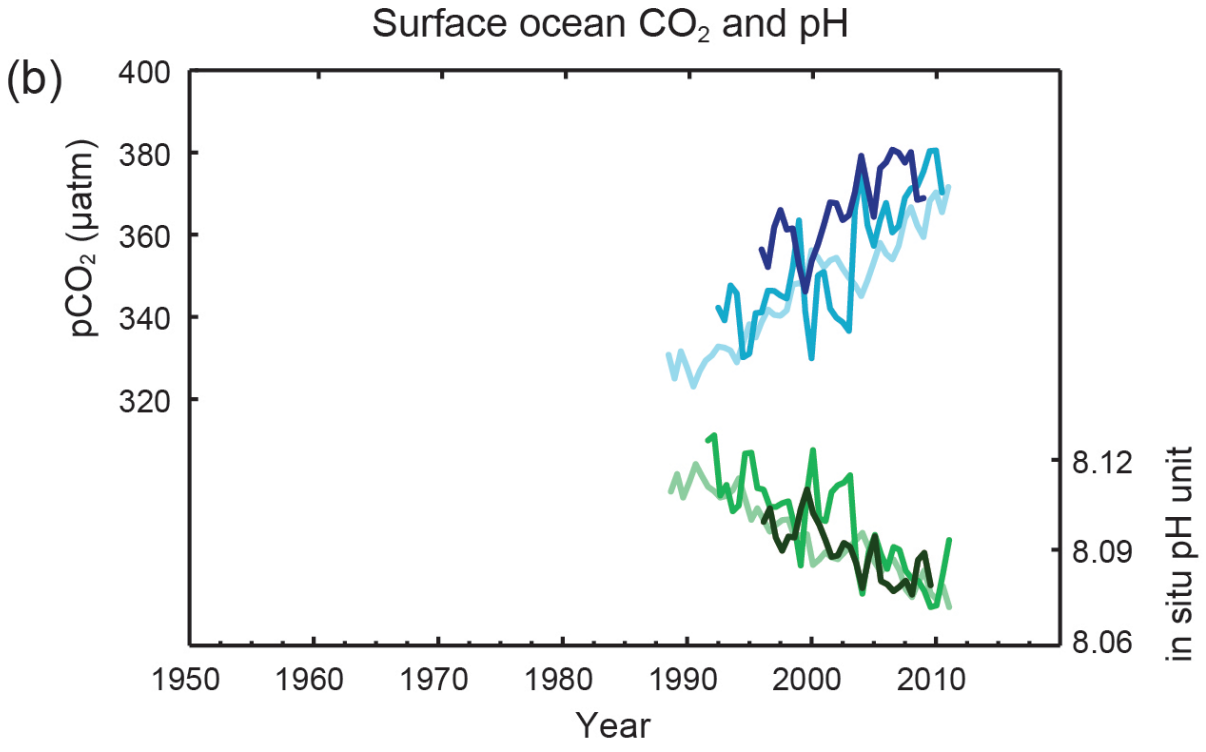
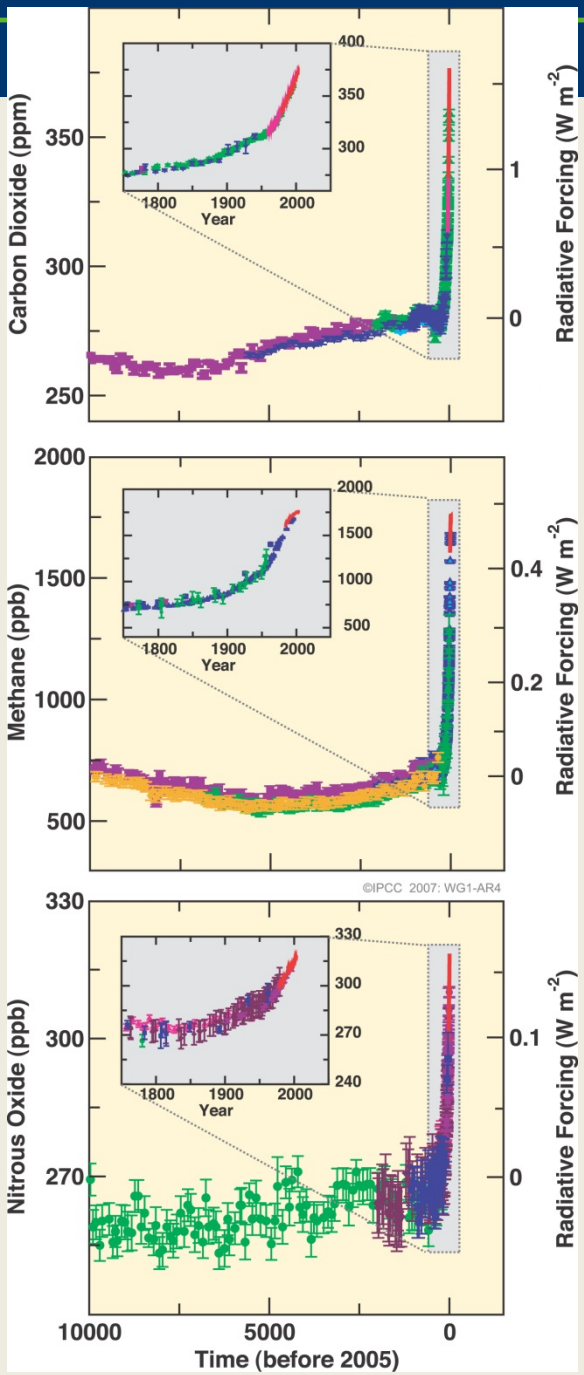
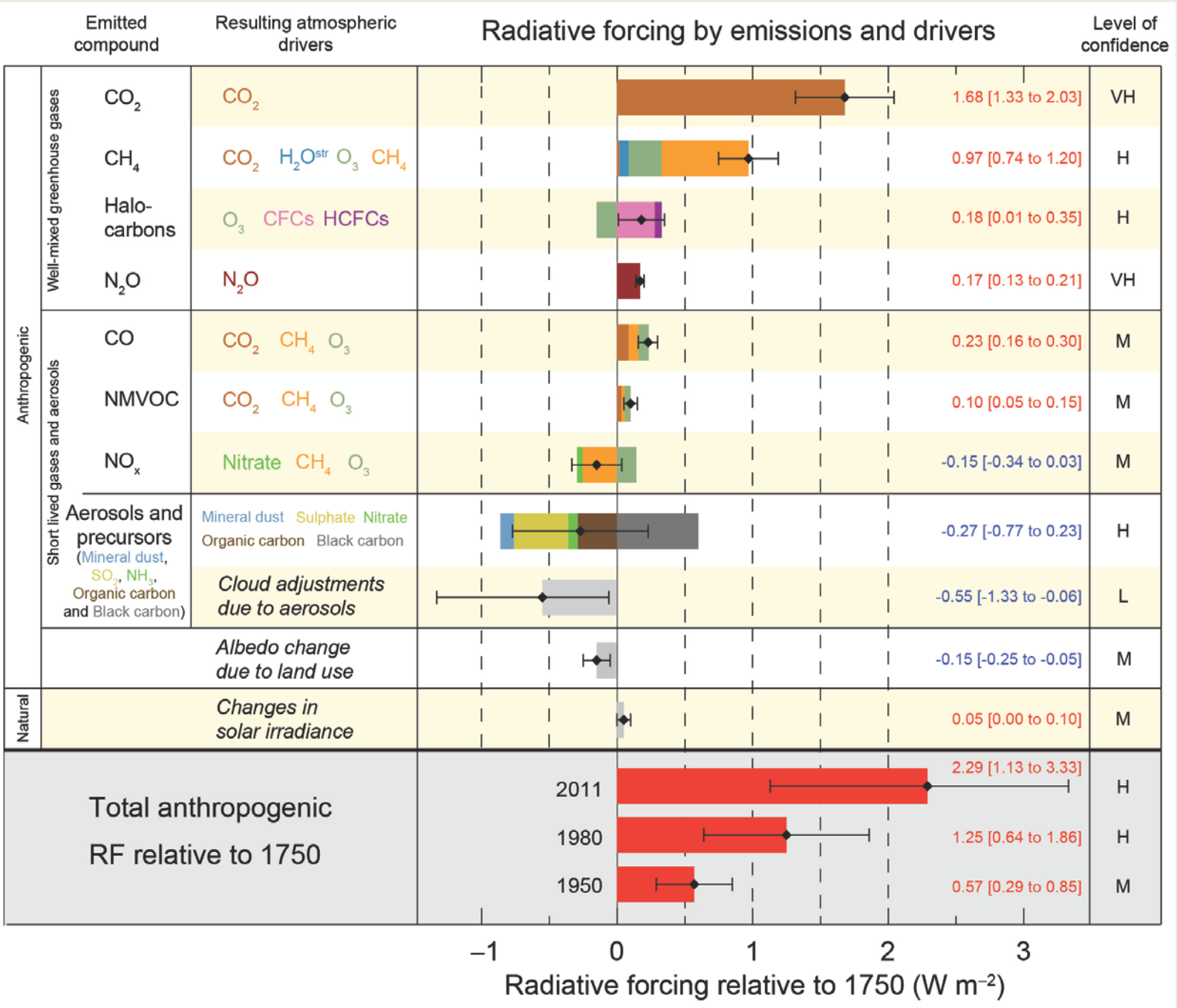
(Source: IPCC, 2013)





(Source: IPCC, 2007)



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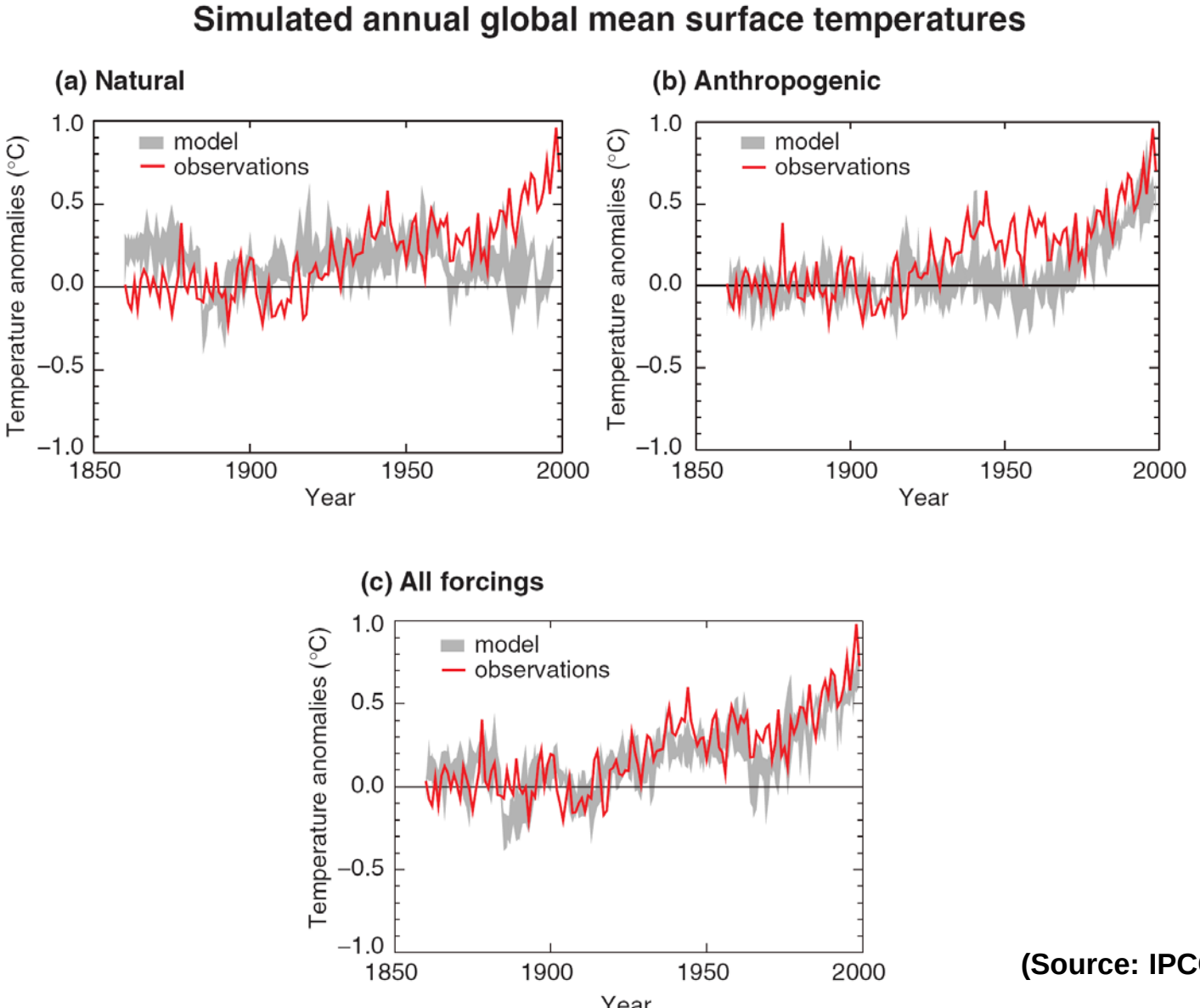
(Source: IPCC, 2013)

How good are the GCMs at reproducing the 20th C?



(Source: IPCC, 2001)

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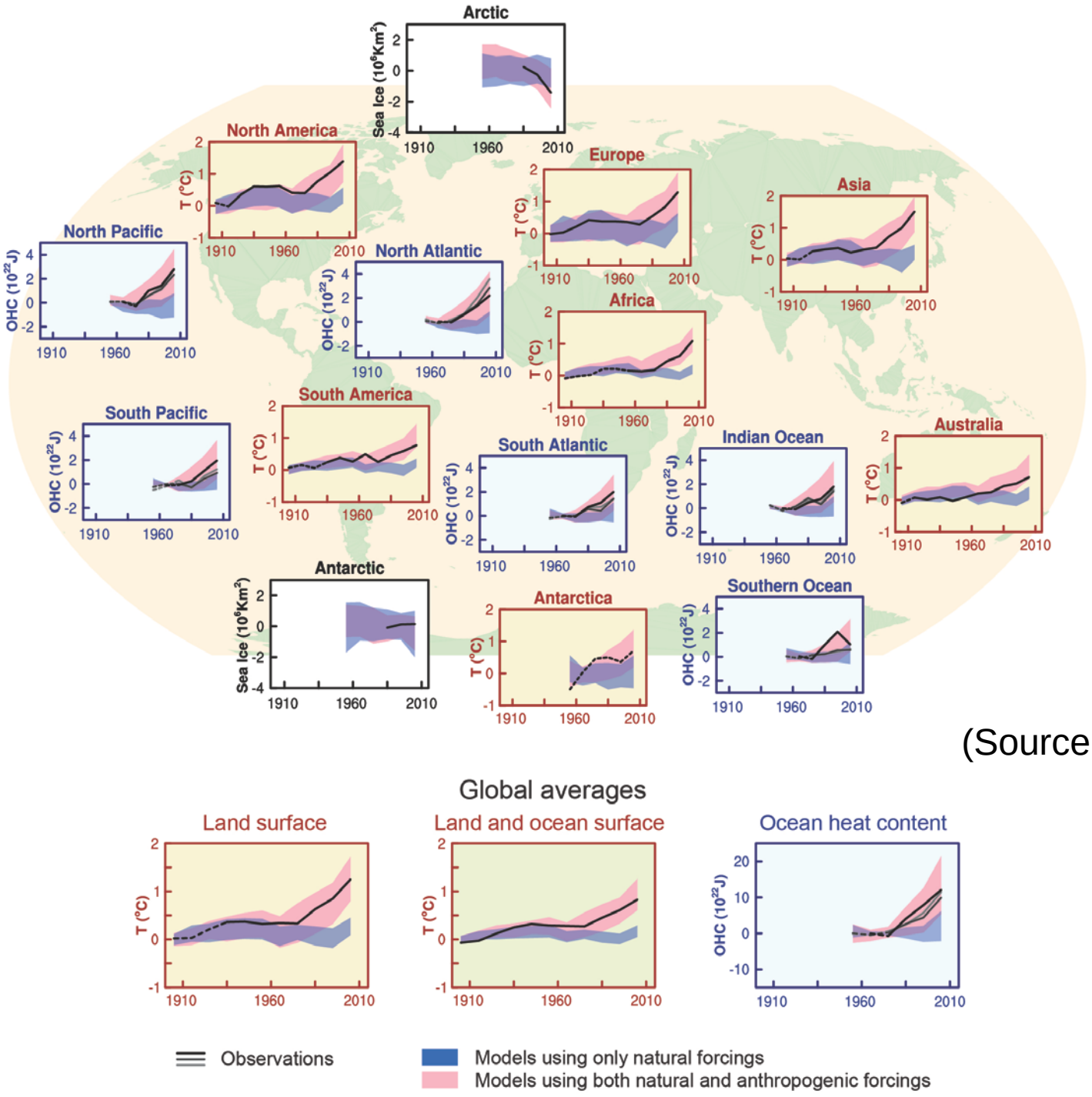


(Source: IPCC, 2013)

Emission scenarios

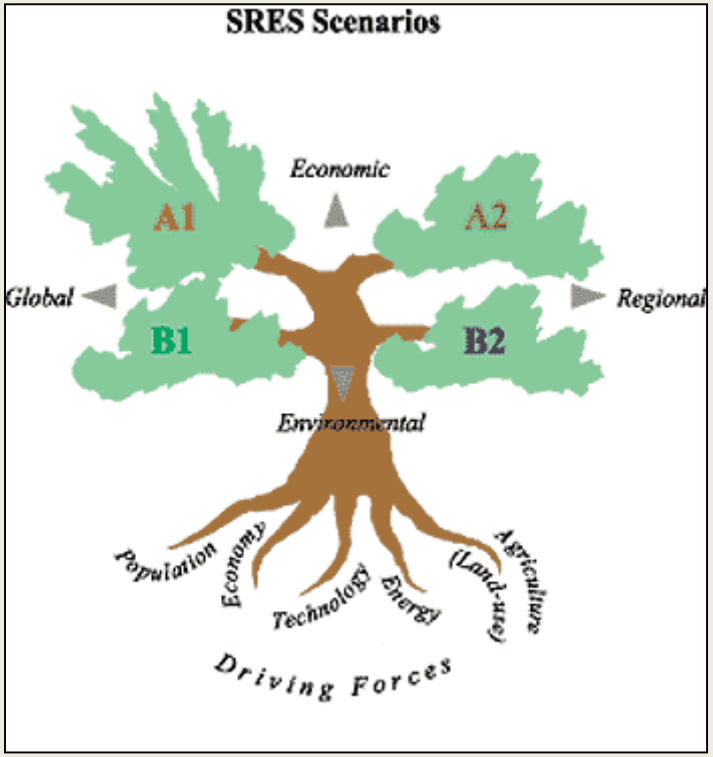
IPCC SRES scenarios

A1: globalization, emphasis on human wealth
Globalized, intensive (market forces)

A2: regionalization, emphasis on human wealth
Regional, intensive (clash of civilizations)

B1: globalization, emphasis on sustainability and equity
Globalized, extensive (sustainable development)

B2: regionalization, emphasis on sustainability and equity Regional, extensive (mixed green bag)

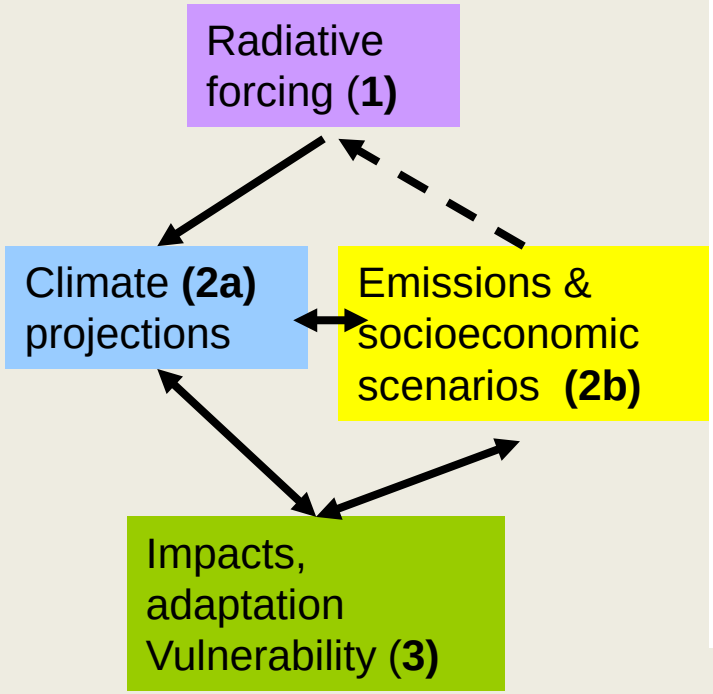


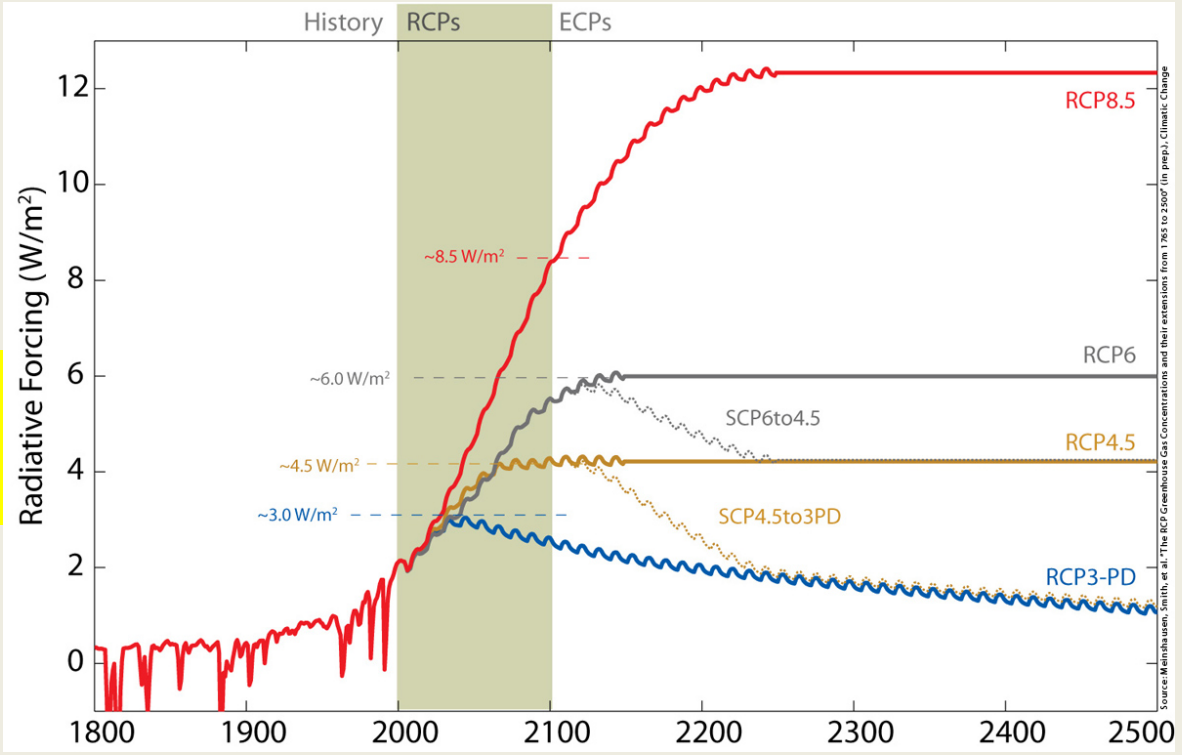
New RCP scenarios

Representative Concentration Pathways (2007) - RCP

To be used in the IPCC 5th assessment report on climate change (AR5, 2013/2014)

RCP 8.5, **RCP 6.0**, **RCP 4.5**, and **RCP 2.6** corresponds to the radiative forcing expressed in W m^{-2} in 2100 (corresponding CO2-equivalents: **1370**, **850**, **650** and **490** ppmv)

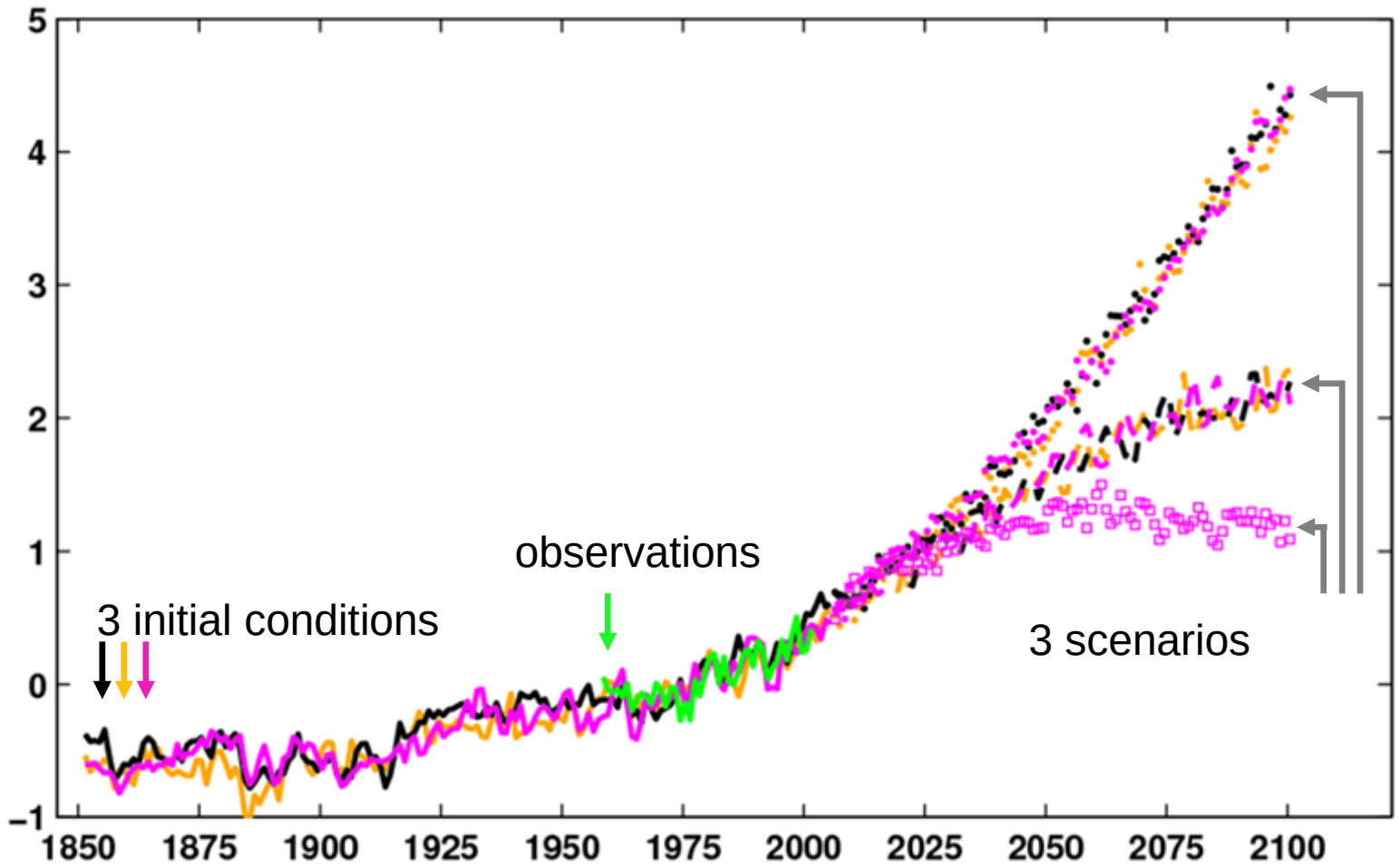




Future projections

Transient climate scenarios

Global annual mean temperature, anomaly w.r.t 1961-1990



Source: Rossby Centre (SMHI) and Stockholms Universitet (MISU). European Centre for Medium Range Weather Forecasts

Figure SPM.7a
Global average surface temperature change

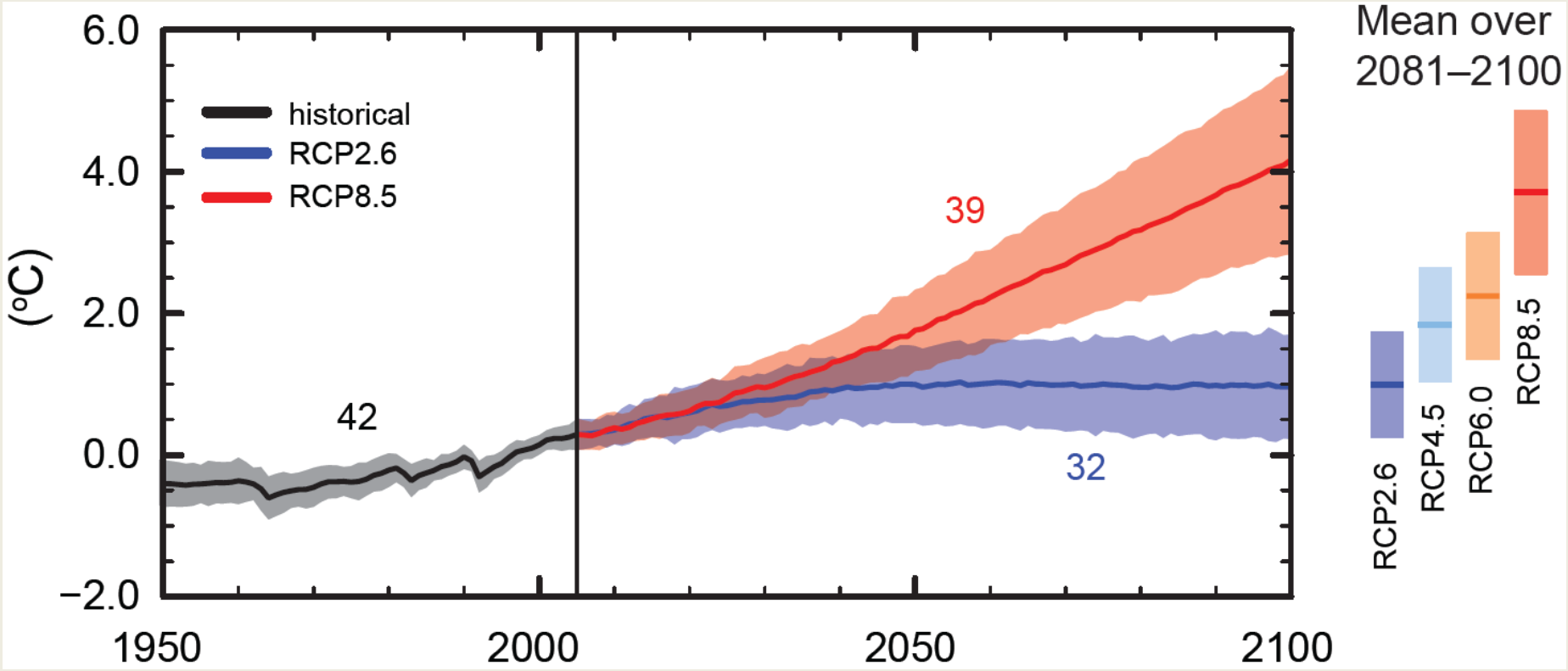


Figure SPM.7b
Northern Hemisphere September sea ice extent

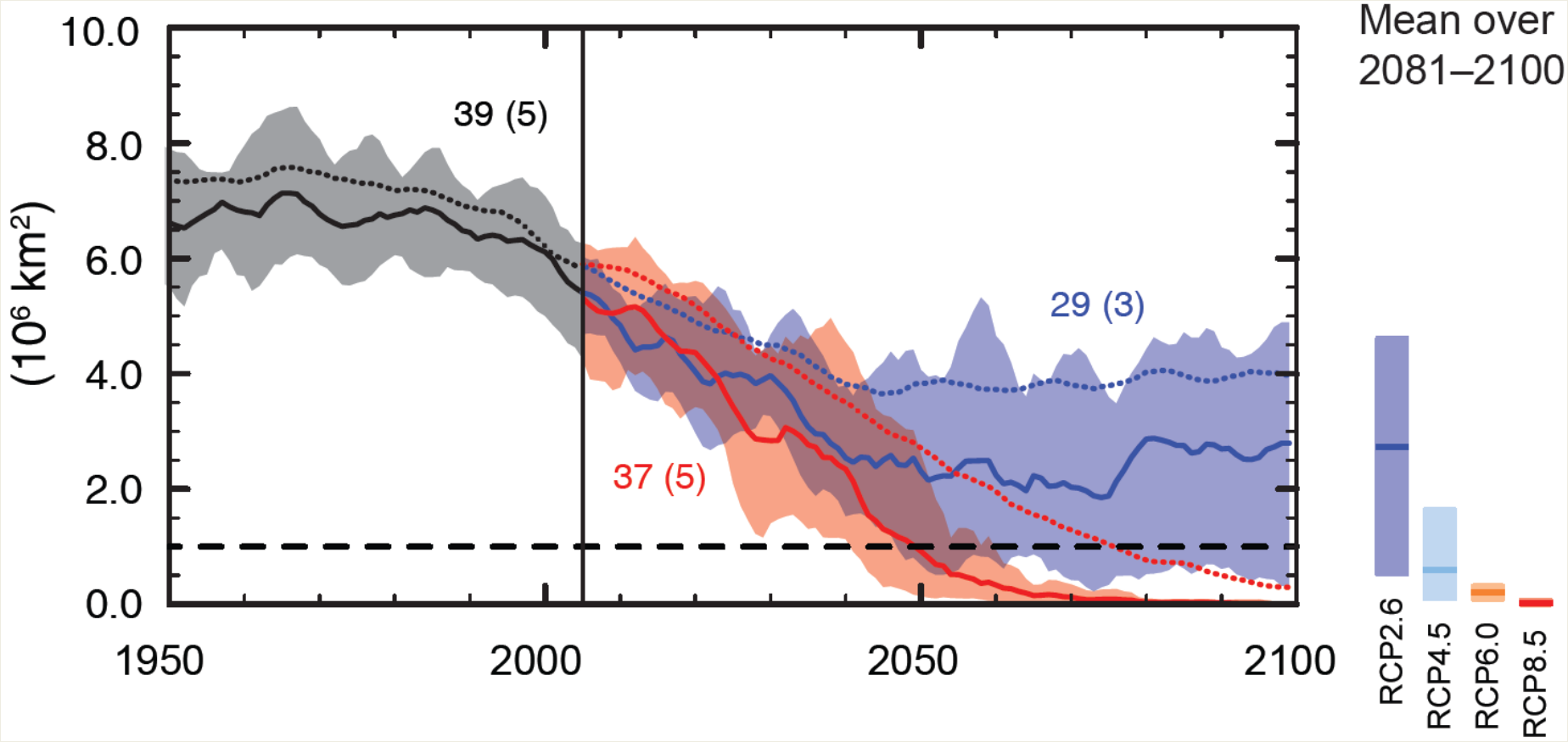


Figure SPM.7c
Global ocean surface pH

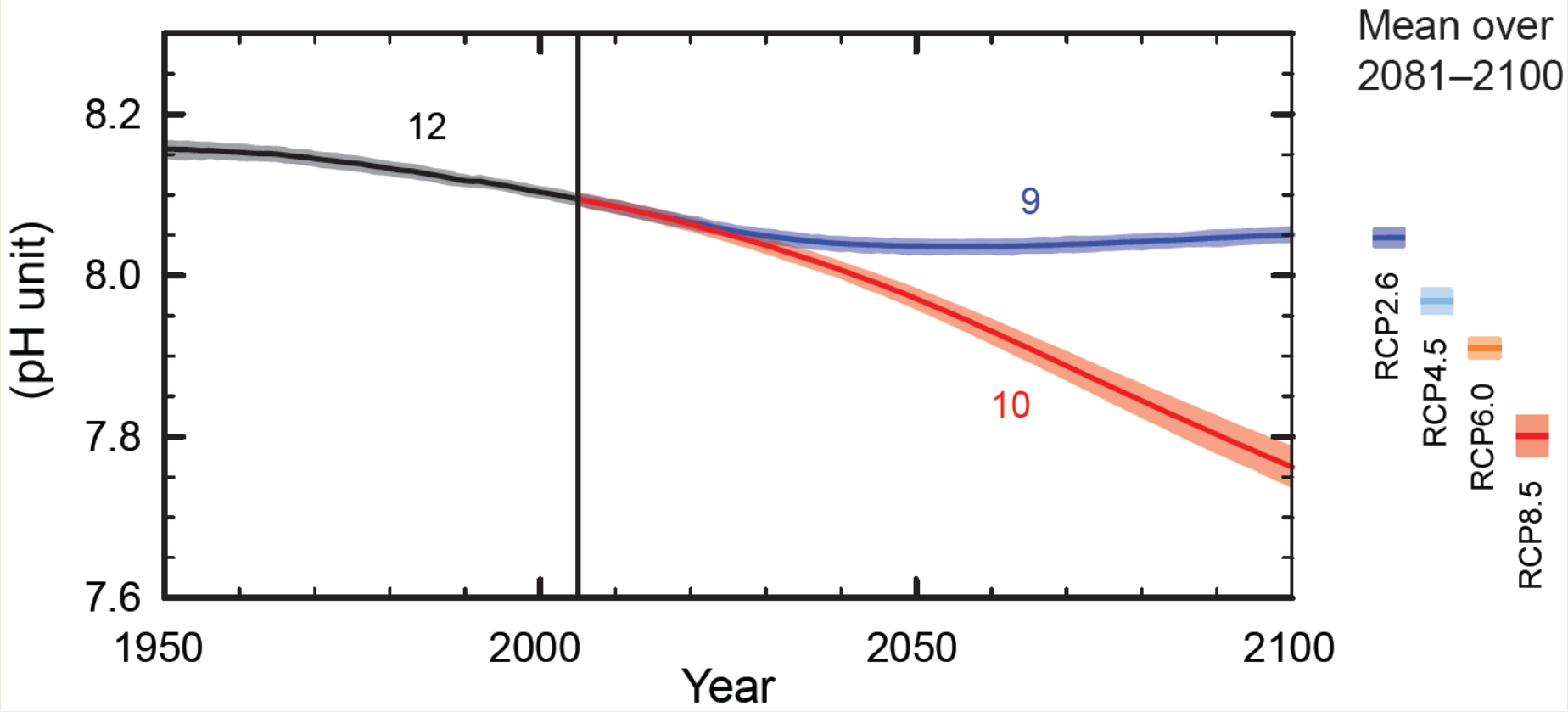


Figure SPM.8a,b
Maps of CMIP5 multi-model mean results

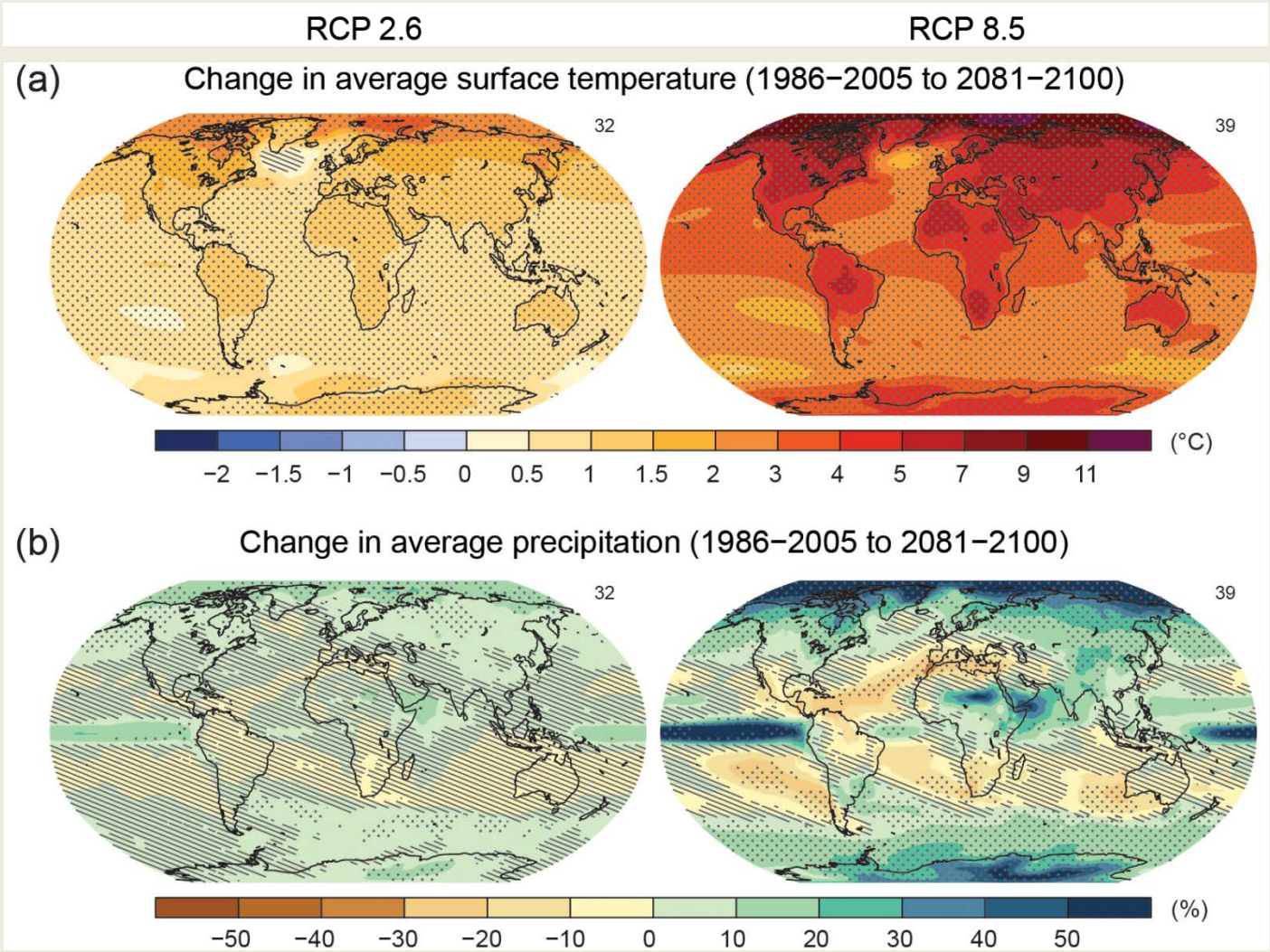


Figure SPM.8c
Maps of CMIP5 multi-model mean results

RCP 2.6 RCP 8.5

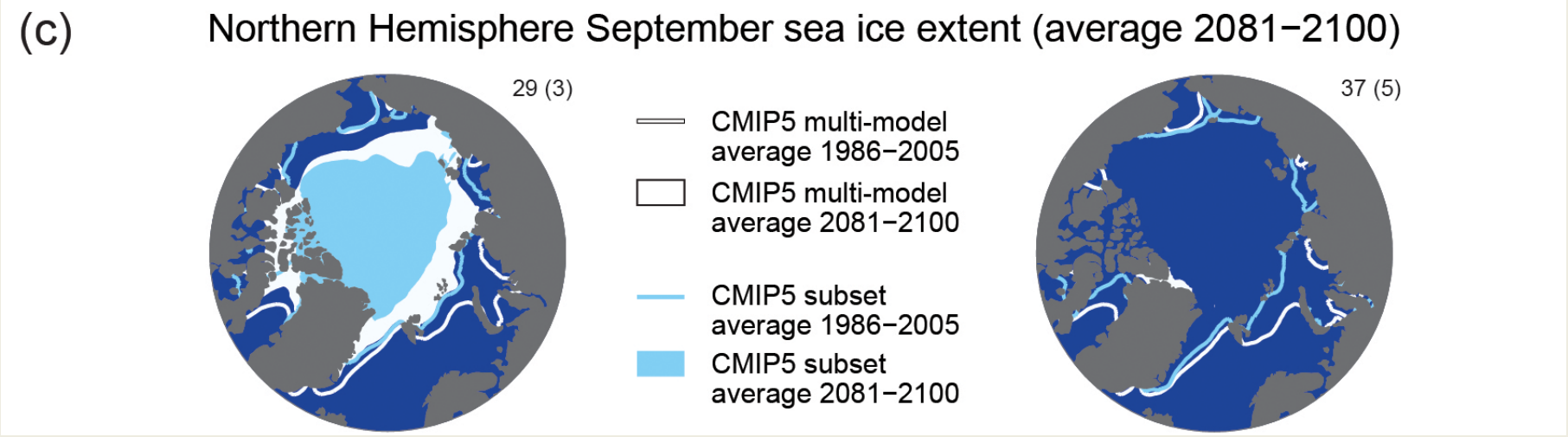


Figure SPM.8d
Maps of CMIP5 multi-model mean results

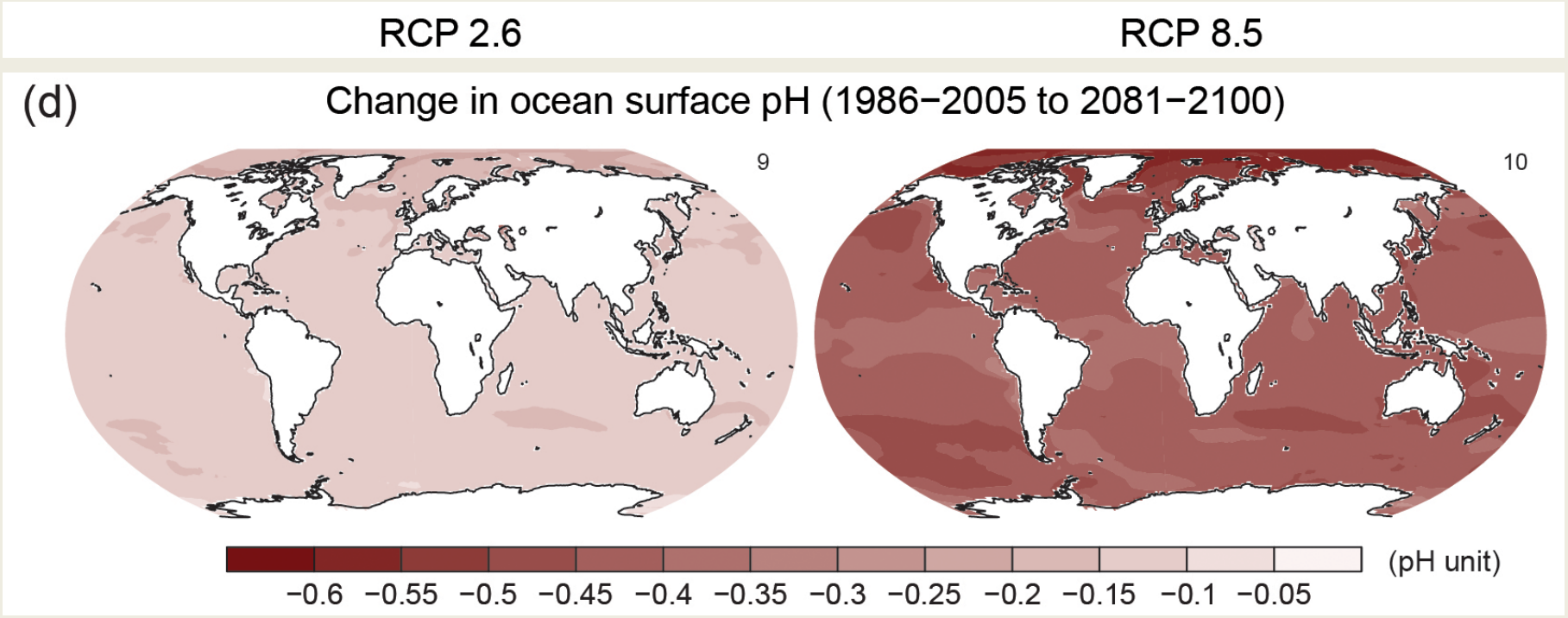


Figure SPM.9
Global mean sea level rise

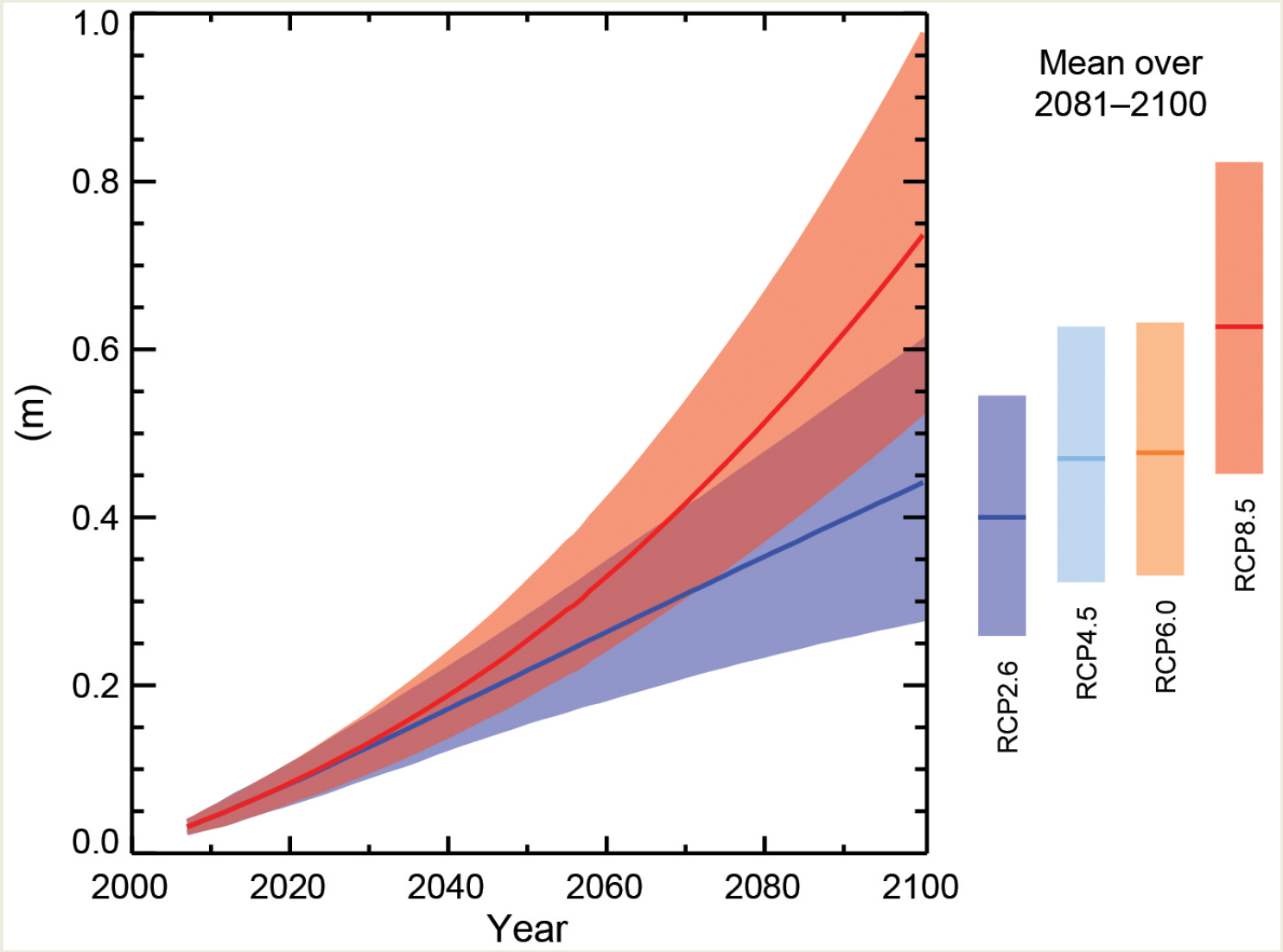
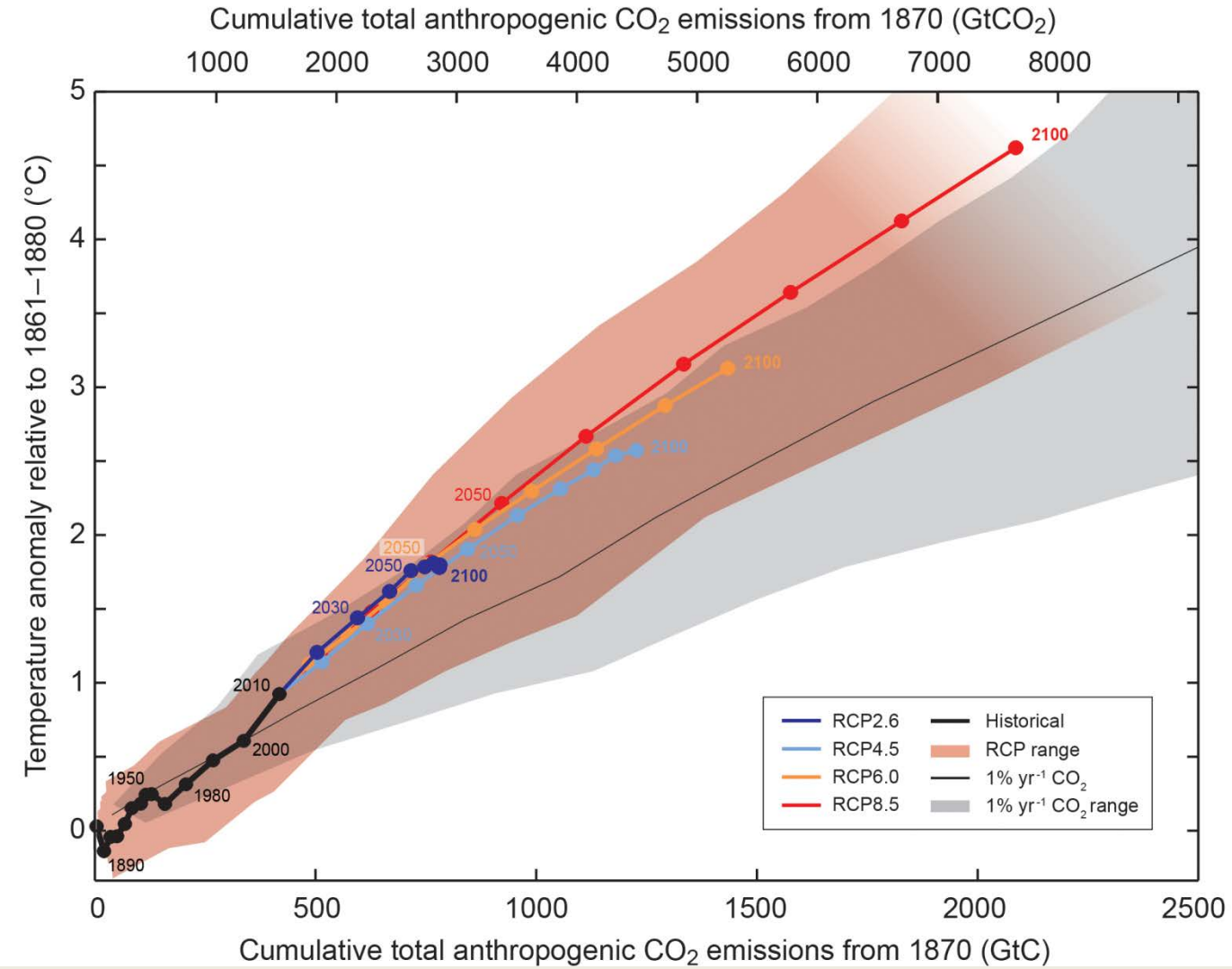


Figure SPM.10
Temperature increase and cumulative carbon emissions

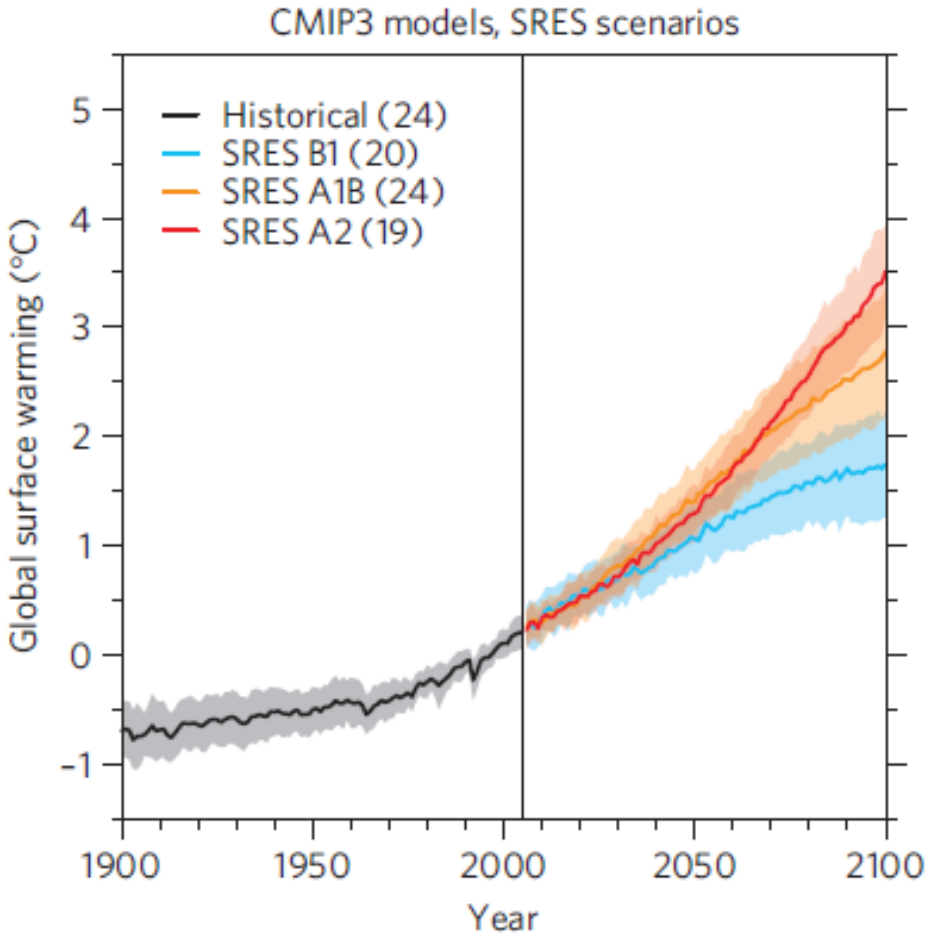


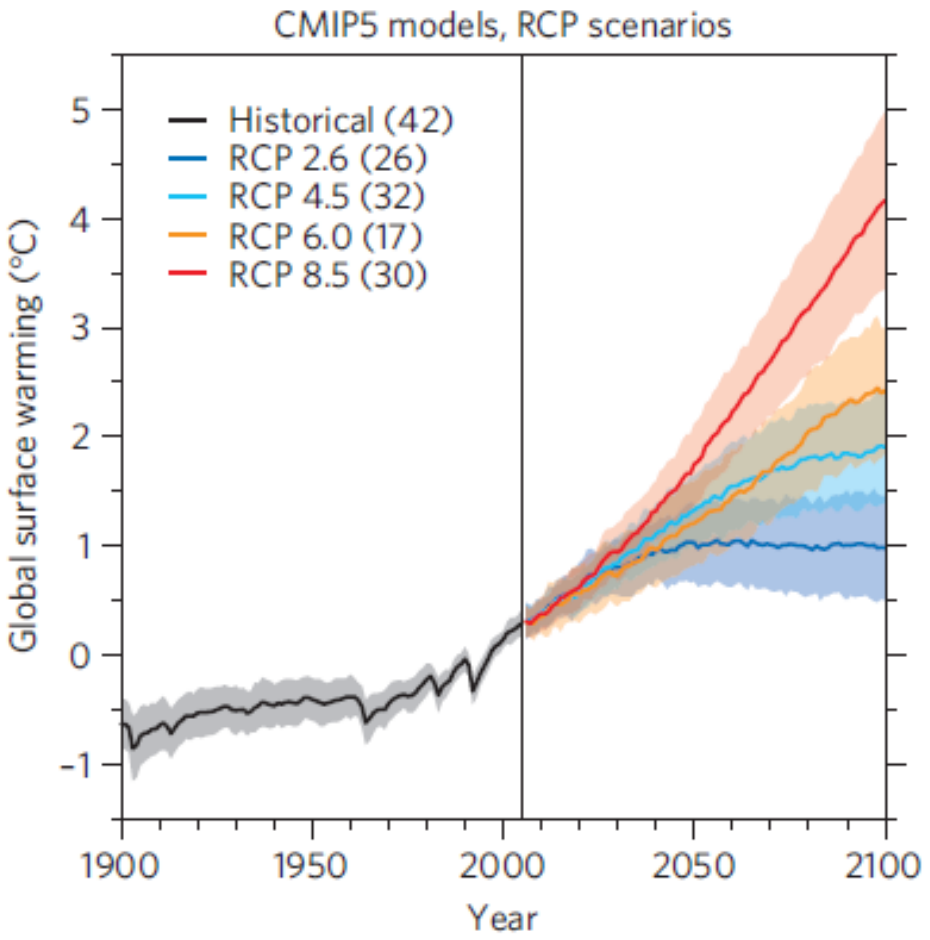
New scenarios in 2013

-

How will these differ from previous ones?

Old and New scenarios

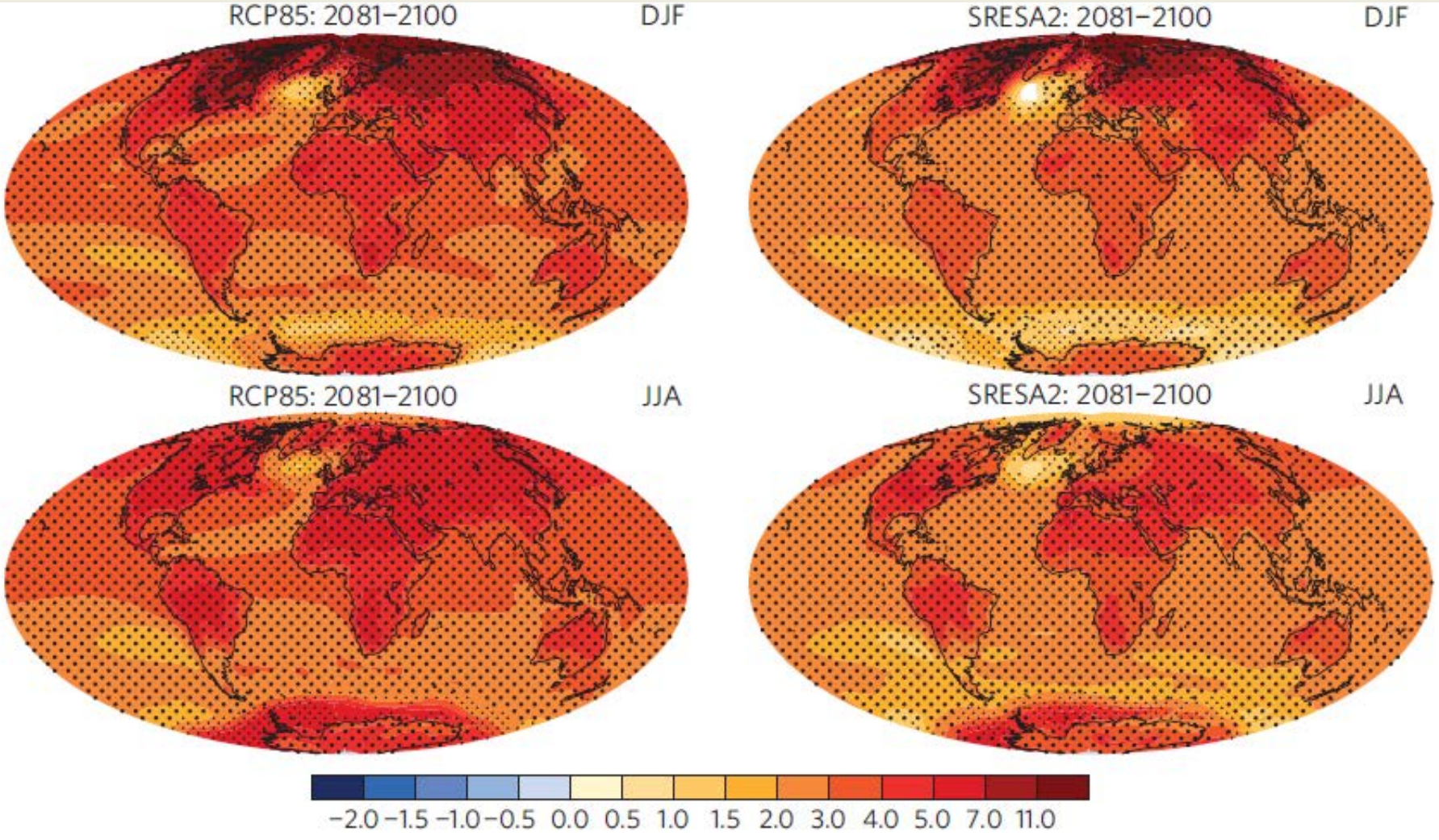




Knutti and Sedlacek, Nature Climate Change, 2012

Old and New scenarios

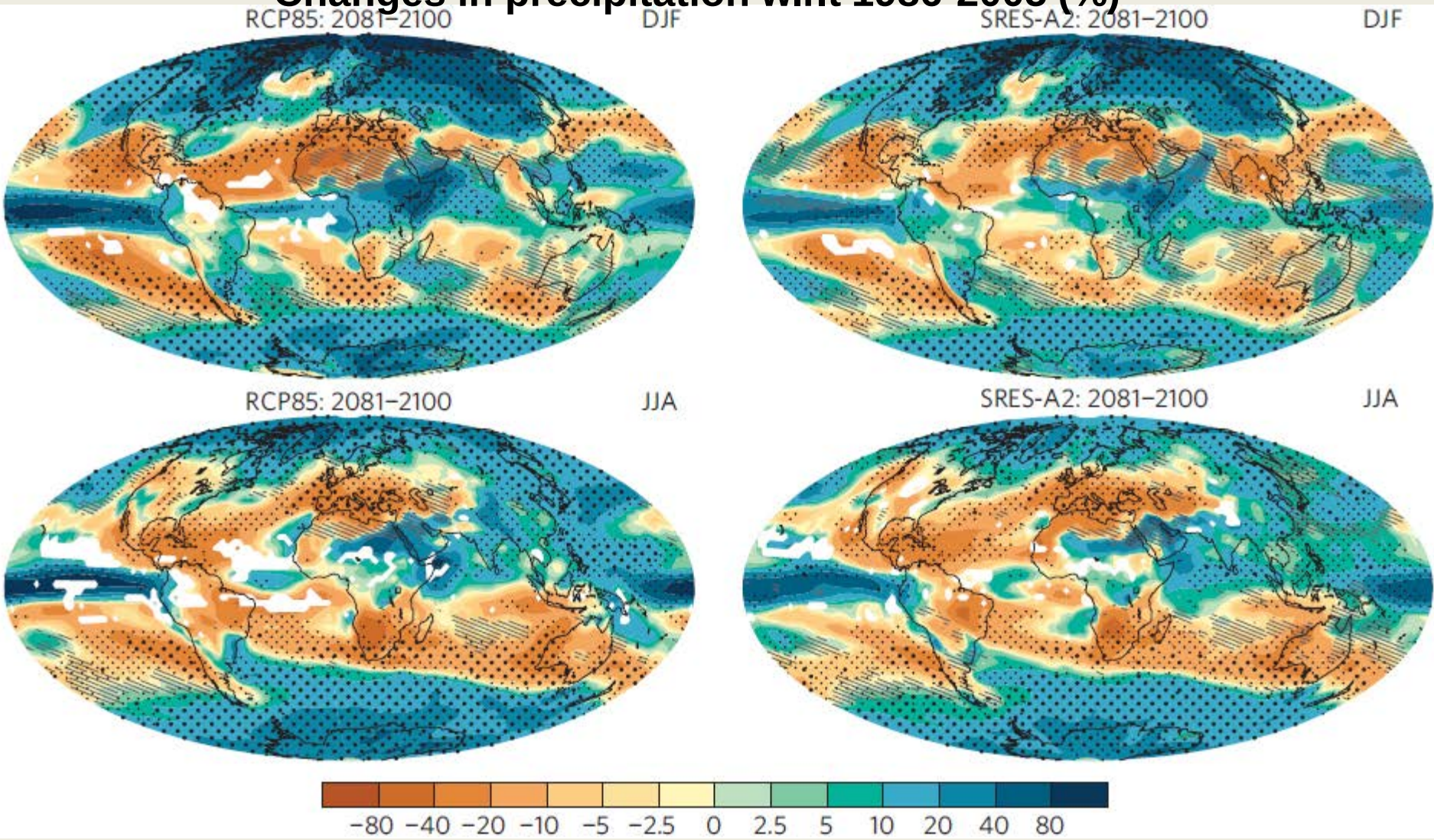
Changes in temperature w.r.t 1986-2005 (˚C)



Knutti and Sedlacek, Nature Climate Change, 2012

Old and New scenarios

Changes in precipitation w.r.t 1986-2005 (%)



Knutti and Sedlacek, Nature Climate Change, 2012

SMHI

Uncertainties

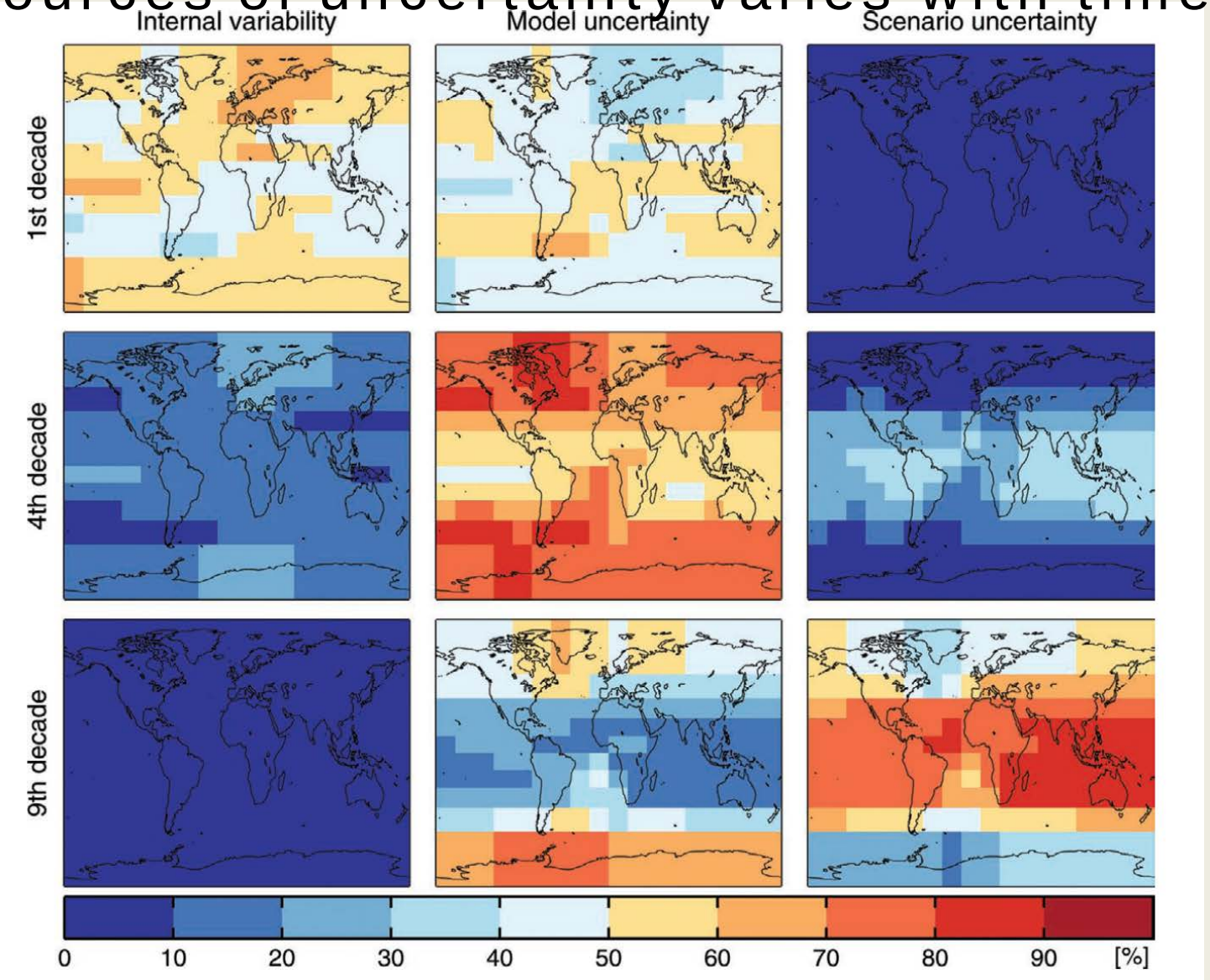
Sources of uncertainty in climate change projections

1. **Emission scenarios**
   - Future behaviour of mankind

2. **Modelling uncertainty**
   - Climate response to changes in atmospheric composition (GCM)
   - Modelling of ocean circulation, biogeochemistry, etc. (RCSM)

3. **Natural climate variability**
   - Solar activity, volcanic eruptions
   - Internal (=unforced) variability generated by the non-linear dynamics of the climate system

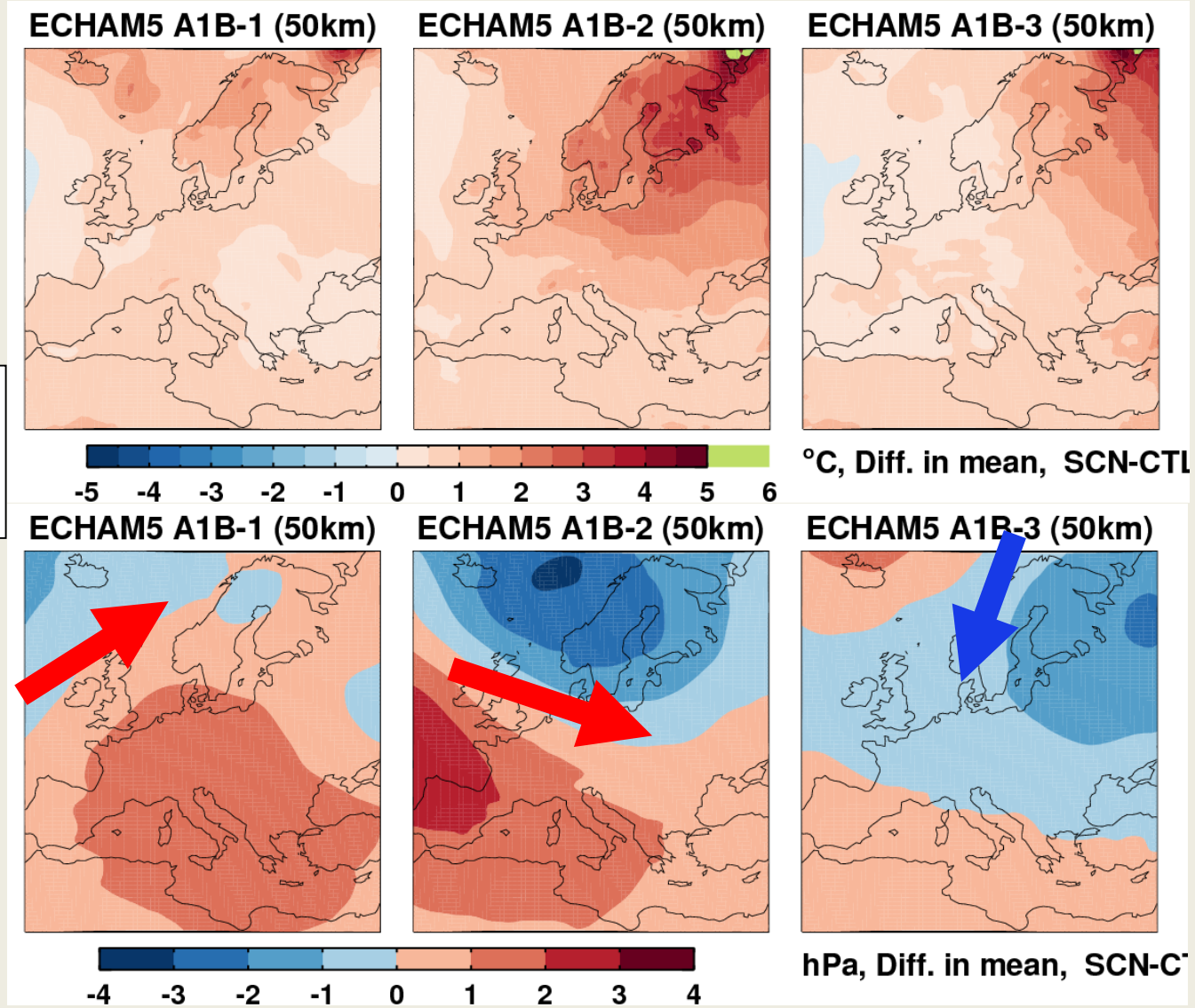
Sources of uncertainty varies with time



Hawkins and Sutton, BAMS, 2009

Uncertainty due to natural variability

2011-2040
vs
1961-1990

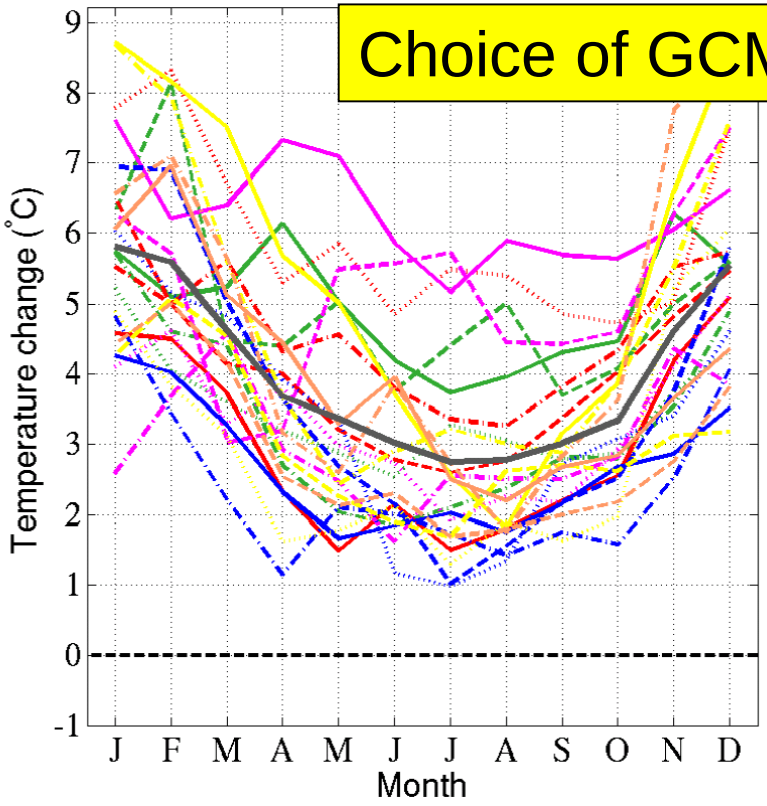


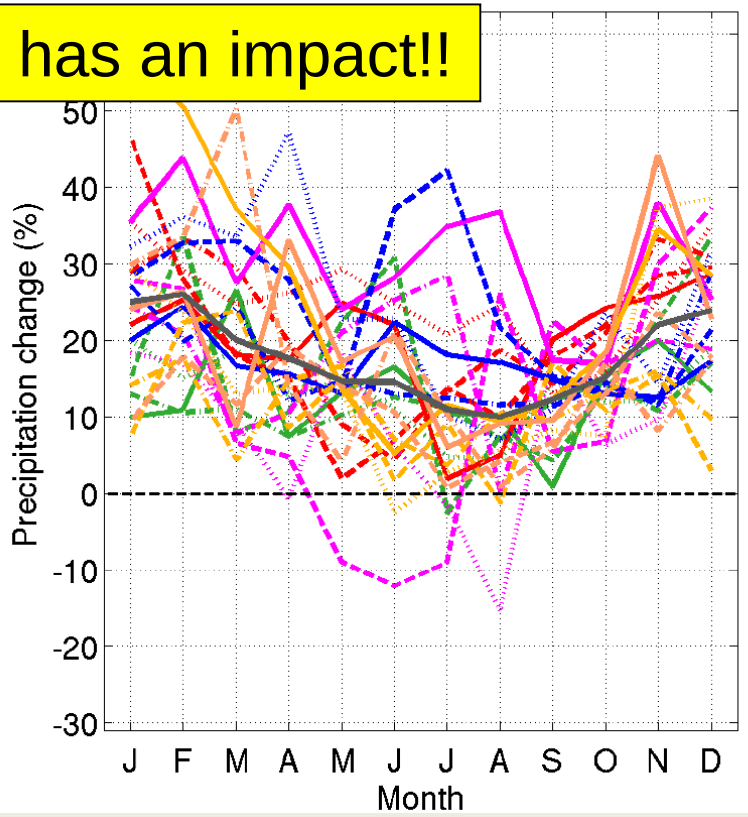
What about Sweden?

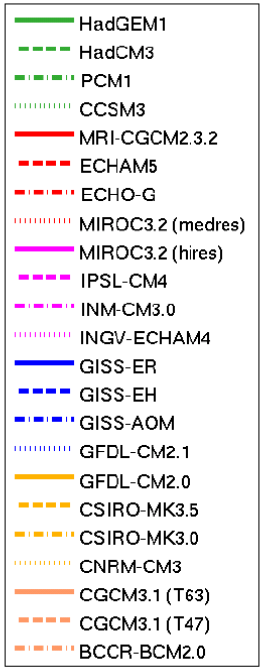
Change in Northern Sweden under A1B

2071-2100 versus1961-1990

Choice of GCM has an impact!!

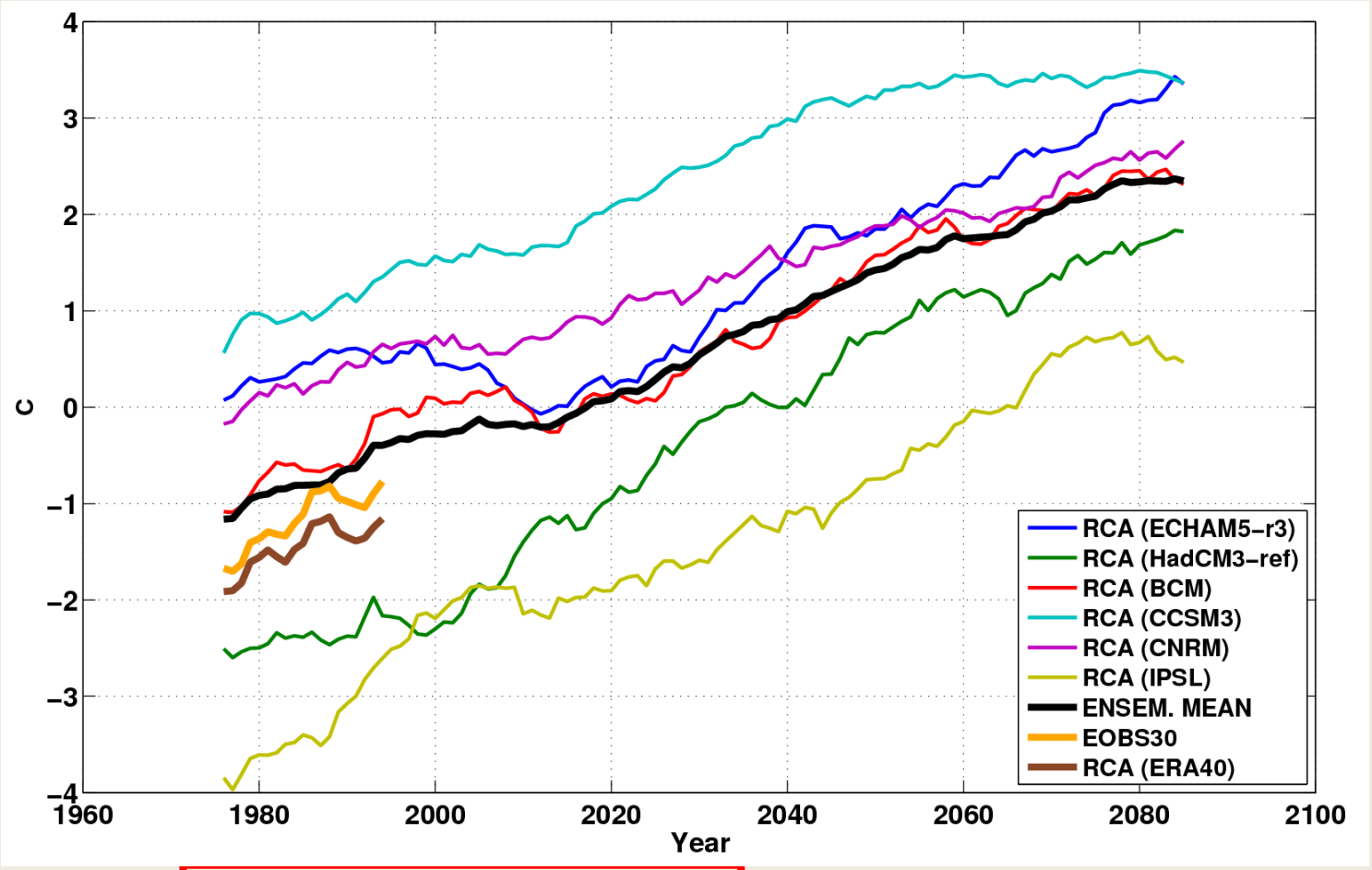


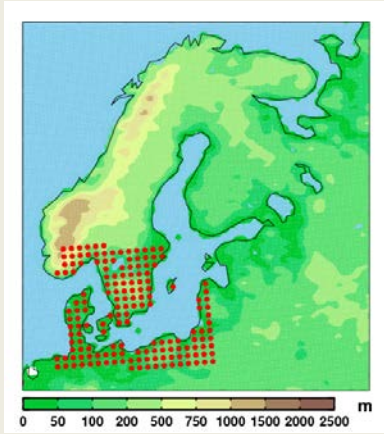




AIR TEMPERATURE

2m temperature Winter



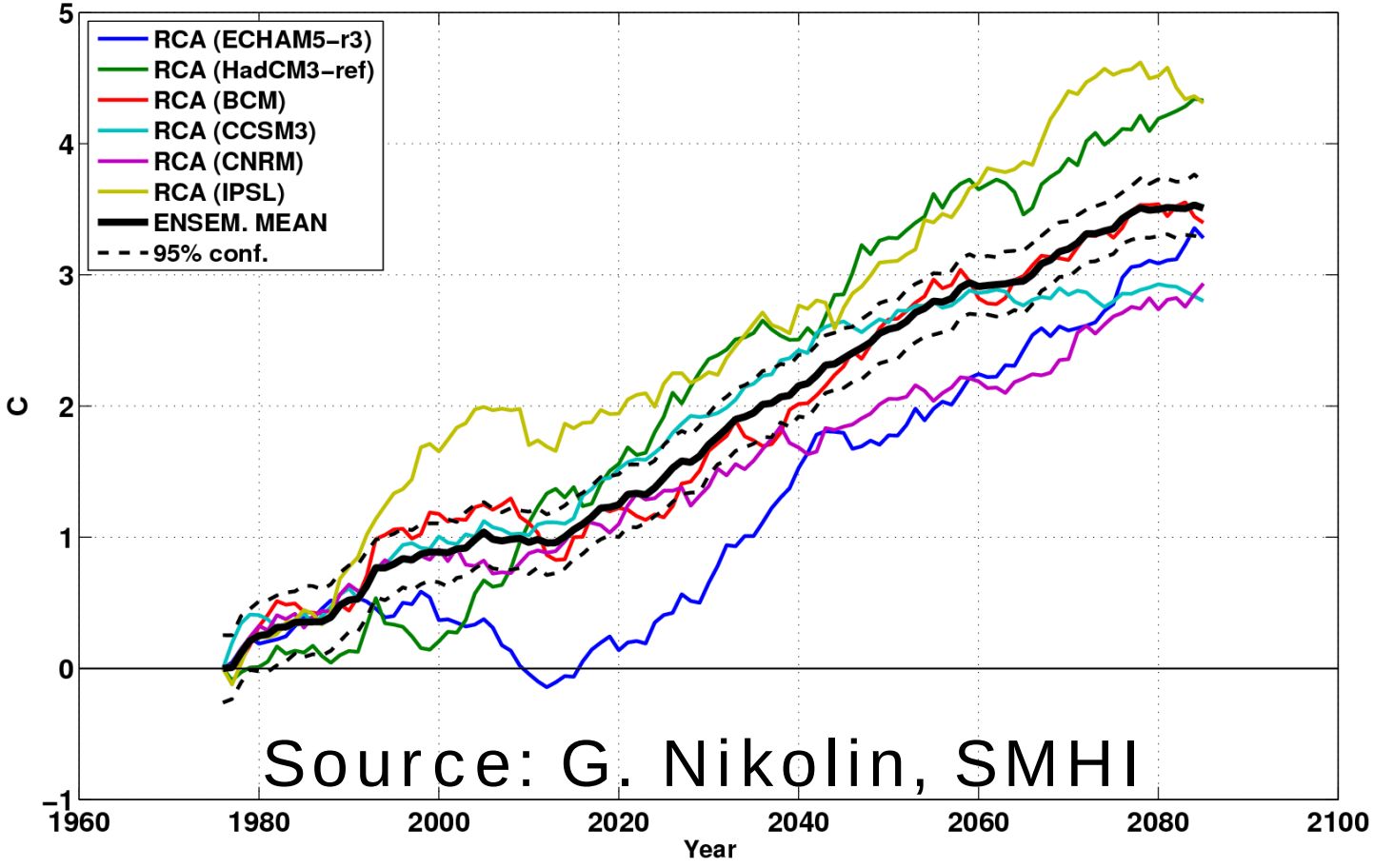


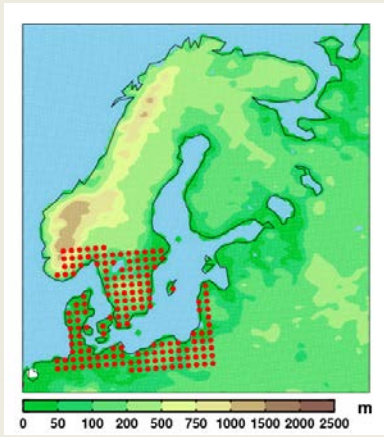
30-yr moving average of the red area average

common gradual increase

Source: G. Nikolin, SMHI

Winter 2m temperature (anomalies wrt the 1961-1990 mean)



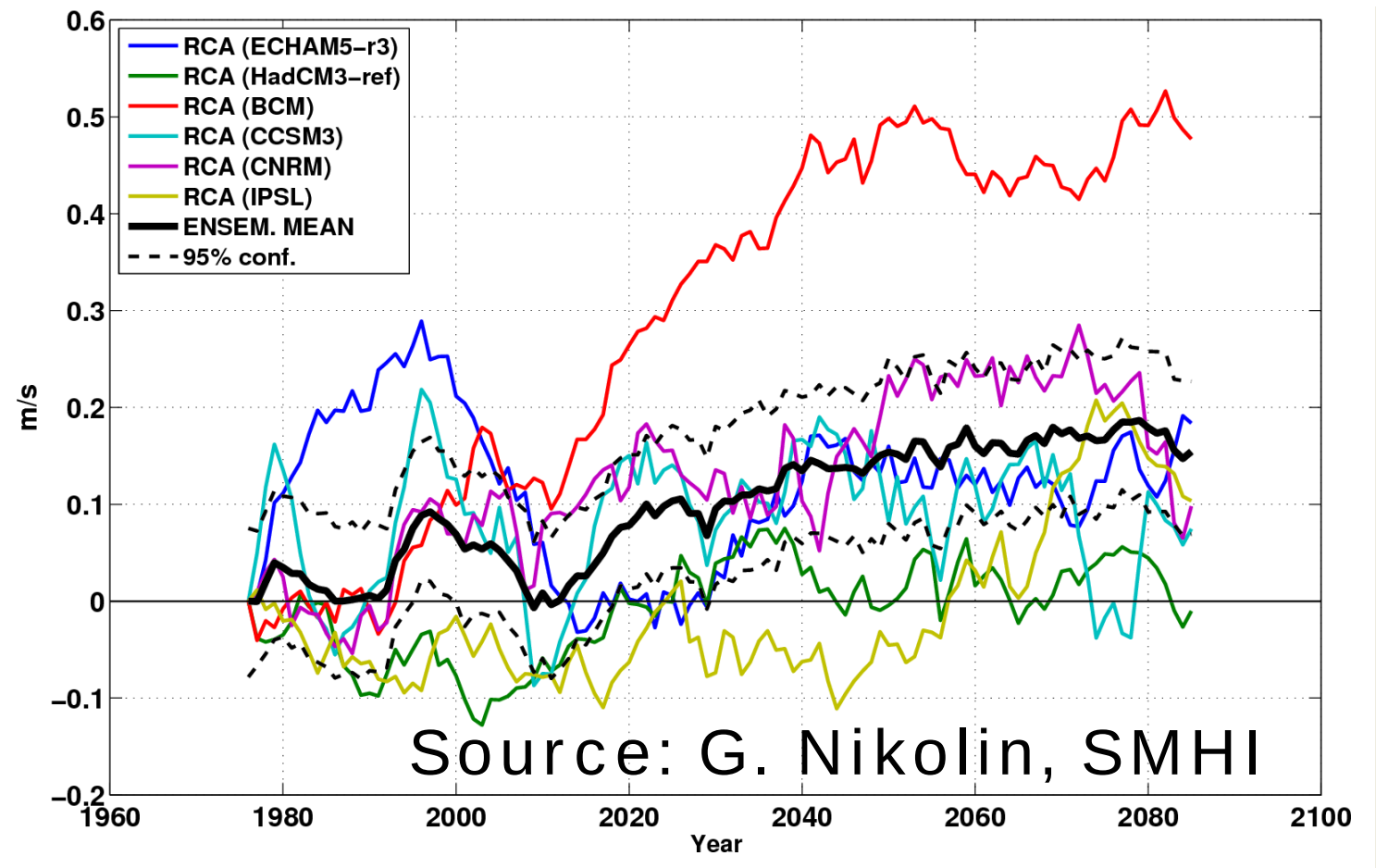


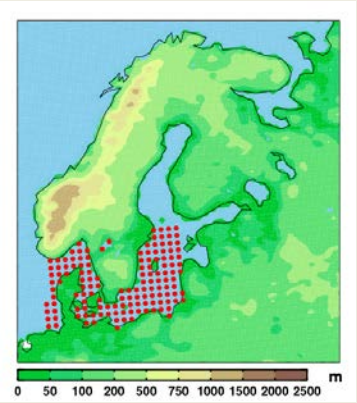
30-yr moving average of the red area average

similar tendency to higher temperature
decadal and multi-decadal variability is not so large
difference among the runs may be about 2°C

WIND

Winter 10m Wind (anomalies wrt the 1961-1990 mean)



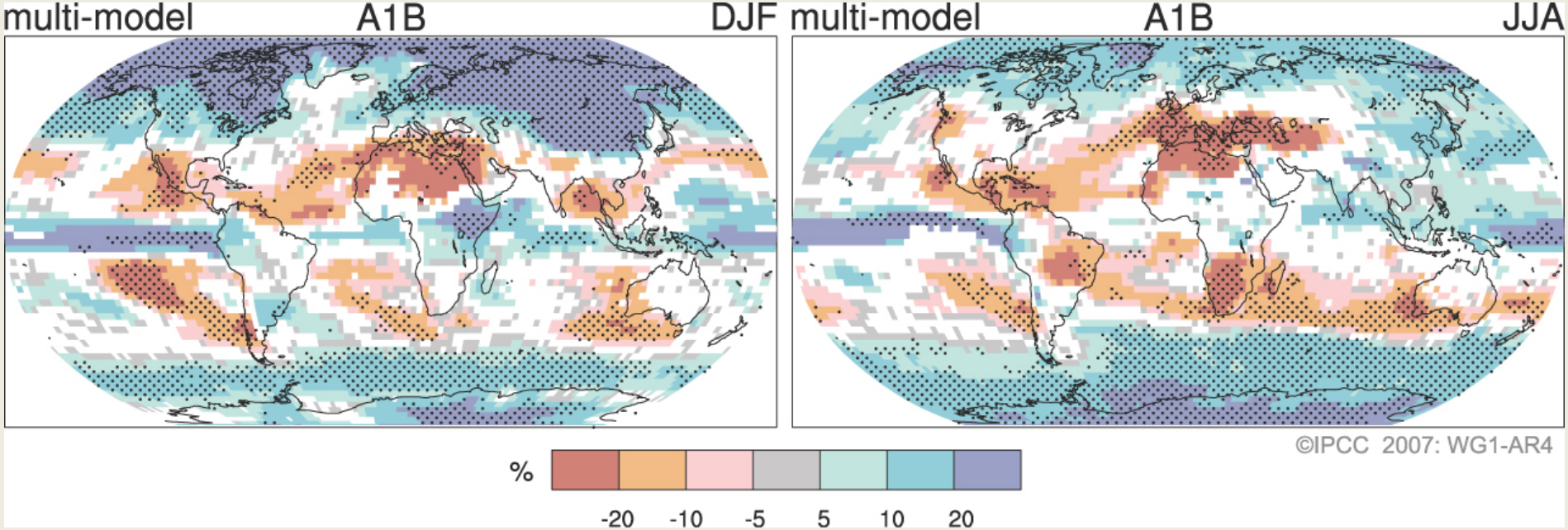


30-yr moving average of the red area average

strengthening of wind in the ensemble mean
strong influence of RCA3(BCM) on the ensemble mean

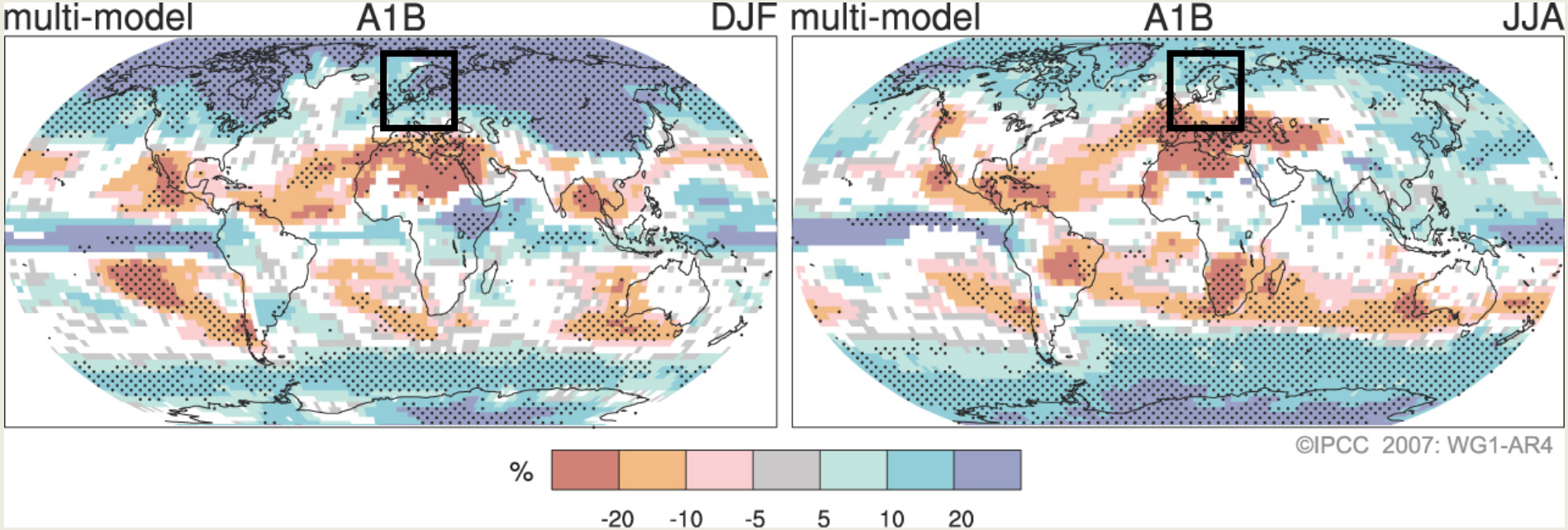
PRECIPITATION

Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right).



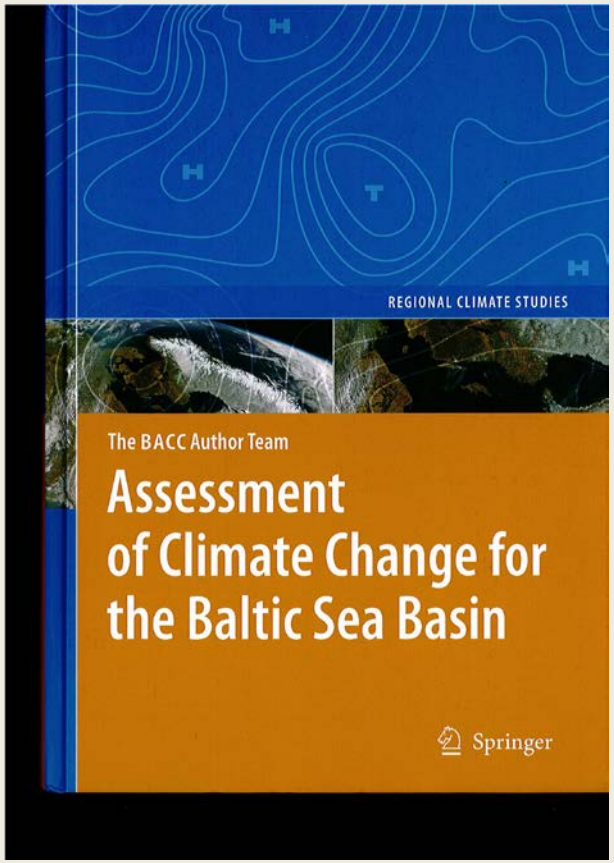
White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change.

Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right).



White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change.

Regional changes



Assessment of Climate Change for the Baltic Sea

The BACC Author Team (2008, 2015)

http://www.baltic.earth/BACC2/index.html

ECO SUPPORT

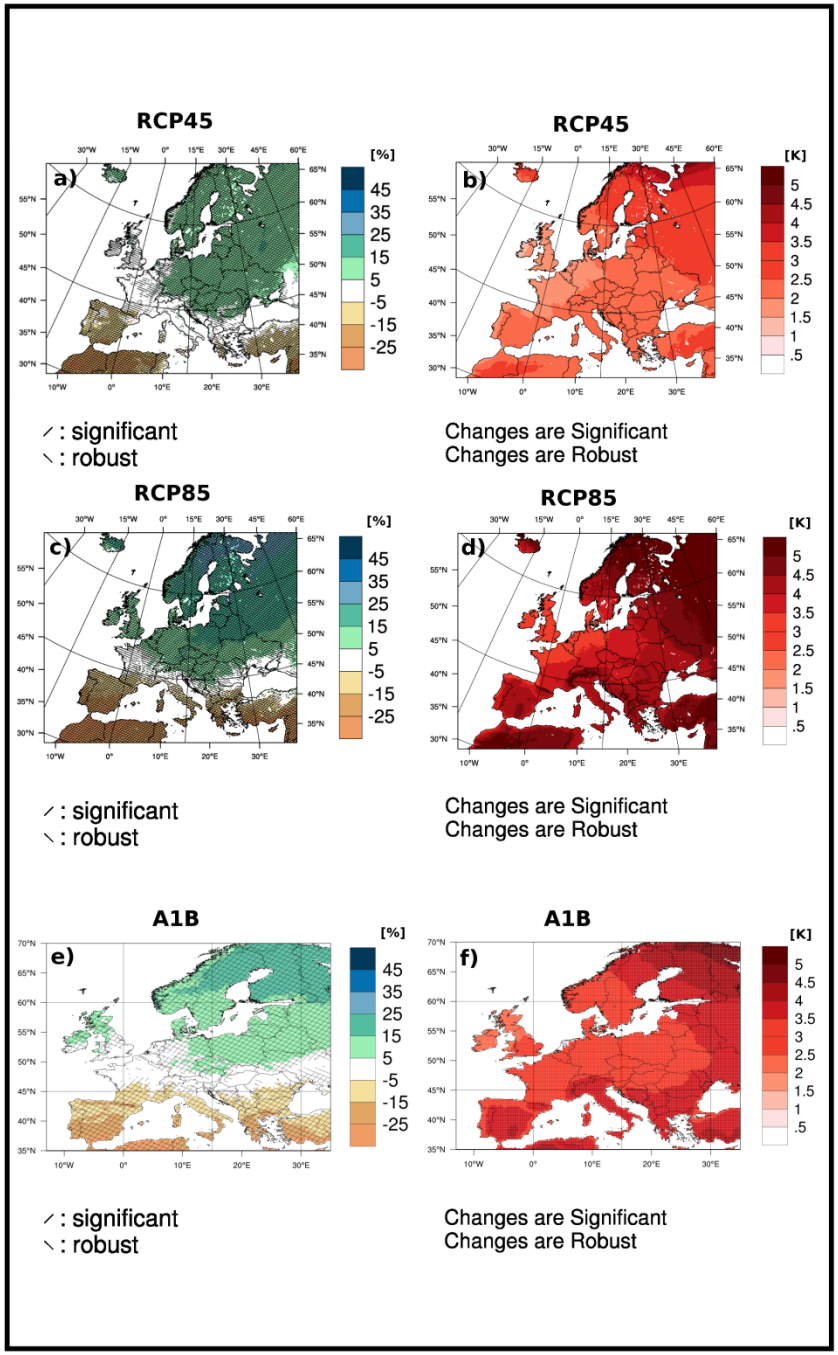
SMHI

North Sea Region Climate Change Assessment

http://noscca.hzg.de

Quante M, Colijn F (eds) (2016) North Sea Region Climate Change Assessment. Regional Climate Studies, Springer Verlag, Cham, Heidelberg, New York, Dordrecht, London

In press (will be published in August 2016)



SMHI

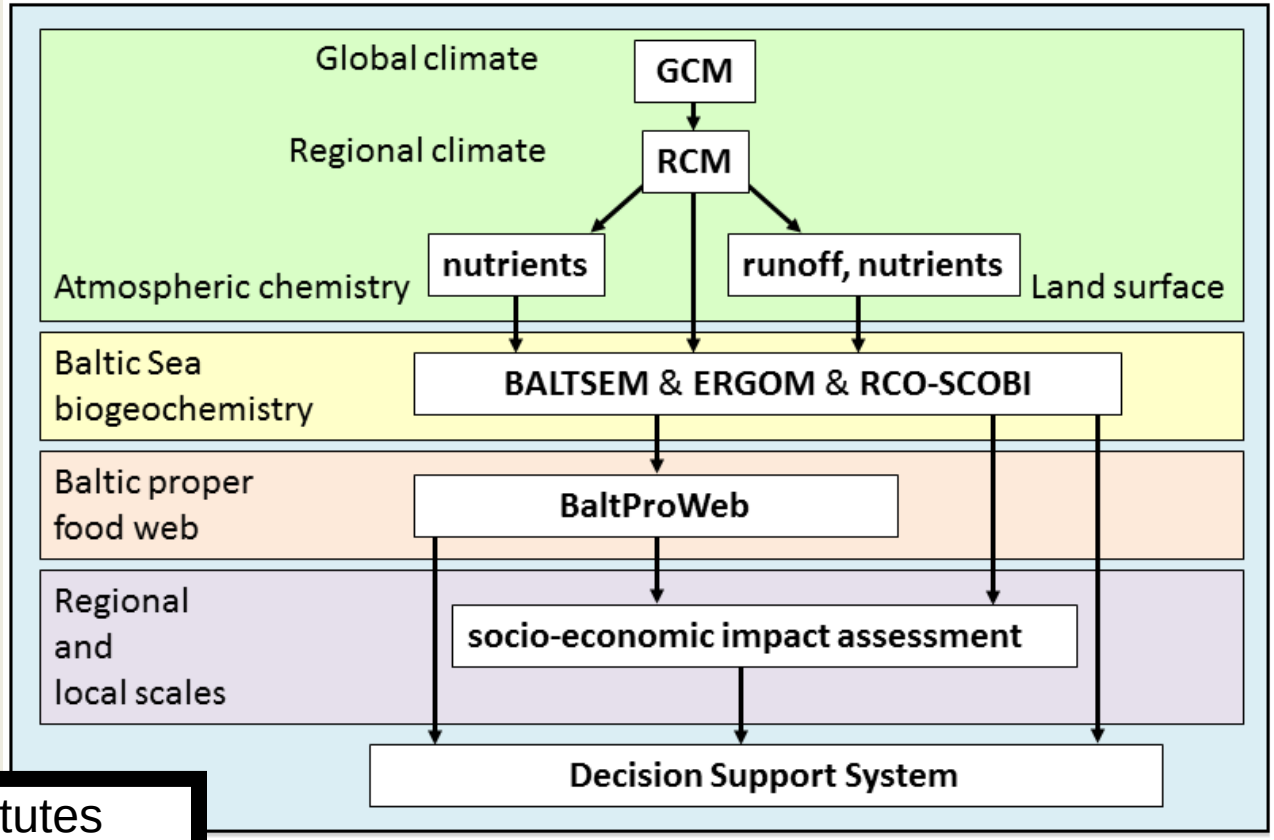
EURO-CORDEX: new high-resolution climate change projections for European impact research (Jacob et al., 2013)

SMHI

Regional climate system simulations (Earth System modeling)

Advanced modeling tool for scenarios of the Baltic Sea ECOsystem to SUPPORT decision making

ECO SUPPORT

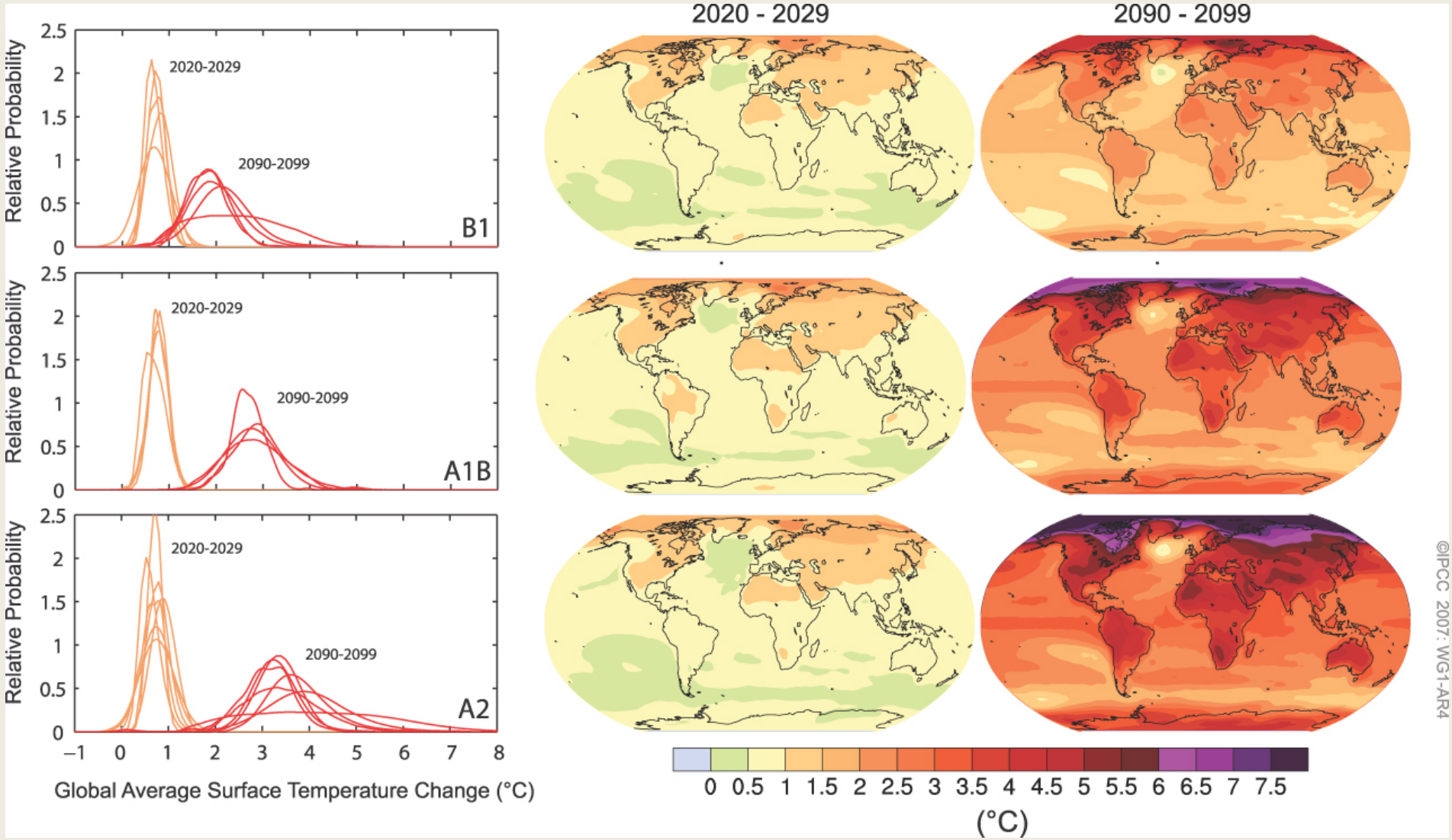


11 partner institutes from 7 Baltic Sea countries 2009-2011

www.baltex-research.eu/ecosupport

BONUS
SCIENCE FOR A BETTER FUTURE OF THE BALTIC SEA REGION

Thank you very much for your attention!


2020 - 2029
2090 - 2099
Relative Probability
2020-2029
2090-2099
B1
A1B
A2
Global Average Surface Temperature Change (°C)
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5
(°C)
©IPCC 2007: WG1-AR4