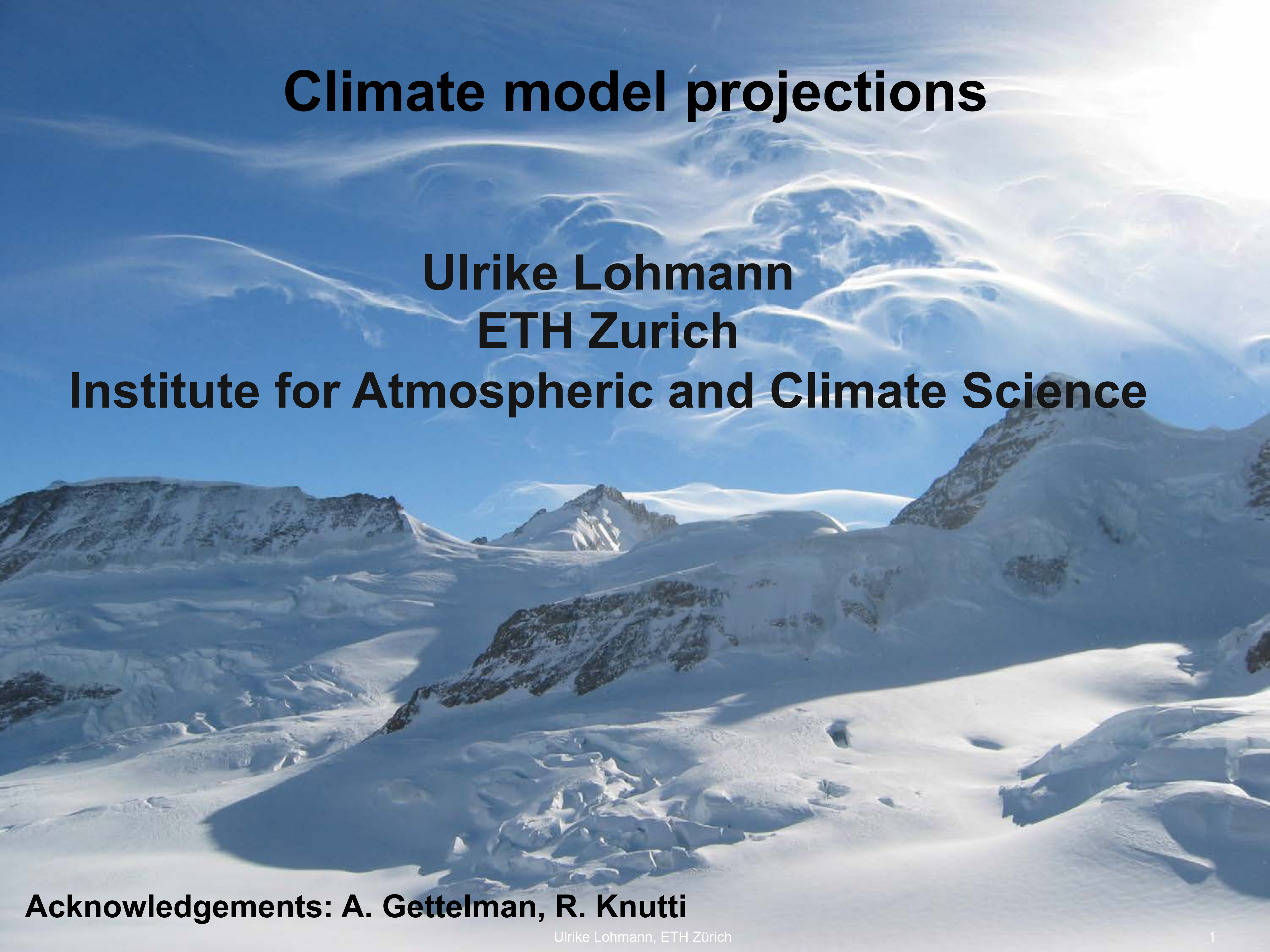

Climate model projections

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ETH Zurich
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Acknowledgements: A. Gettelman, R. Knutti

Outline of this lecture

- What is climate?
- Evaluation of Models: model uncertainty (structural and parametric)
- Predicting the past and near future: uncertainty due to internal variability
- Predicting the next century: boundary uncertainty
- Regional projections
- Summary

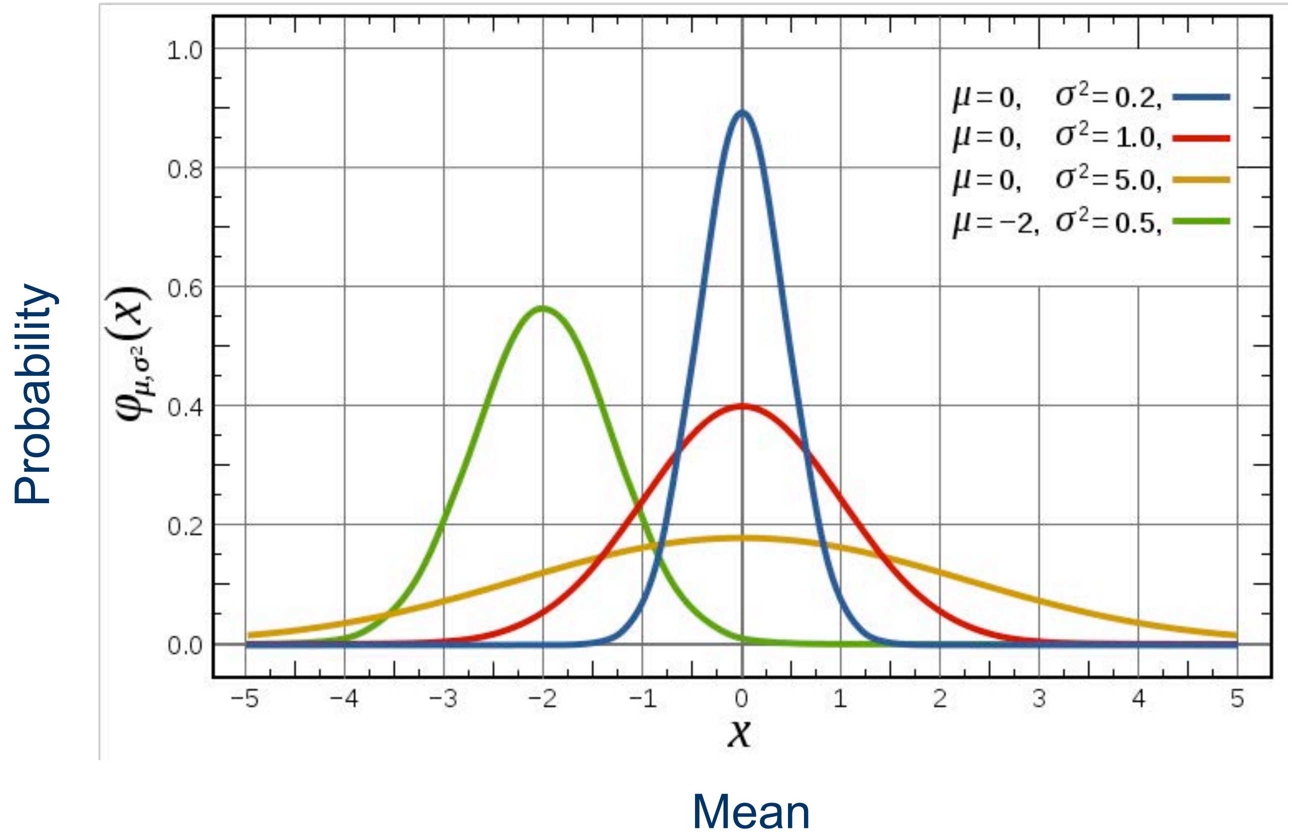
What is Climate?

A. Average Weather (a value)
B. Record high and low temperatures
C. The temperature range
D. Distribution of possible weather
E. Extreme events

How can we predict climate
if we cannot predict the weather?

‘Climate is what you expect, weather is what you get’

Climate is the probability distribution of weather states



Weather = Chaos

Deterministic Nonperiodic Flow[1]

EDWARD N. LORENZ

Massachusetts Institute of Technology

(Manuscript received 18 November 1962, in revised form 7 January 1963)

ABSTRACT

Finite systems of deterministic ordinary nonlinear differential equations may be designed to represent forced dissipative hydrodynamic flow. Solutions of these equations can be identified with trajectories in phase space. For those systems with bounded solutions, it is found that nonperiodic solutions are ordinarily unstable with respect to small modifications, so that slightly differing initial states can evolve into considerably different states. Systems with bounded solutions are shown to possess bounded numerical solutions.

A simple system representing cellular convection is solved numerically. All of the solutions are found to be unstable, and almost all of them are nonperiodic.

The feasibility of very-long-range weather prediction is examined in the light of these results.

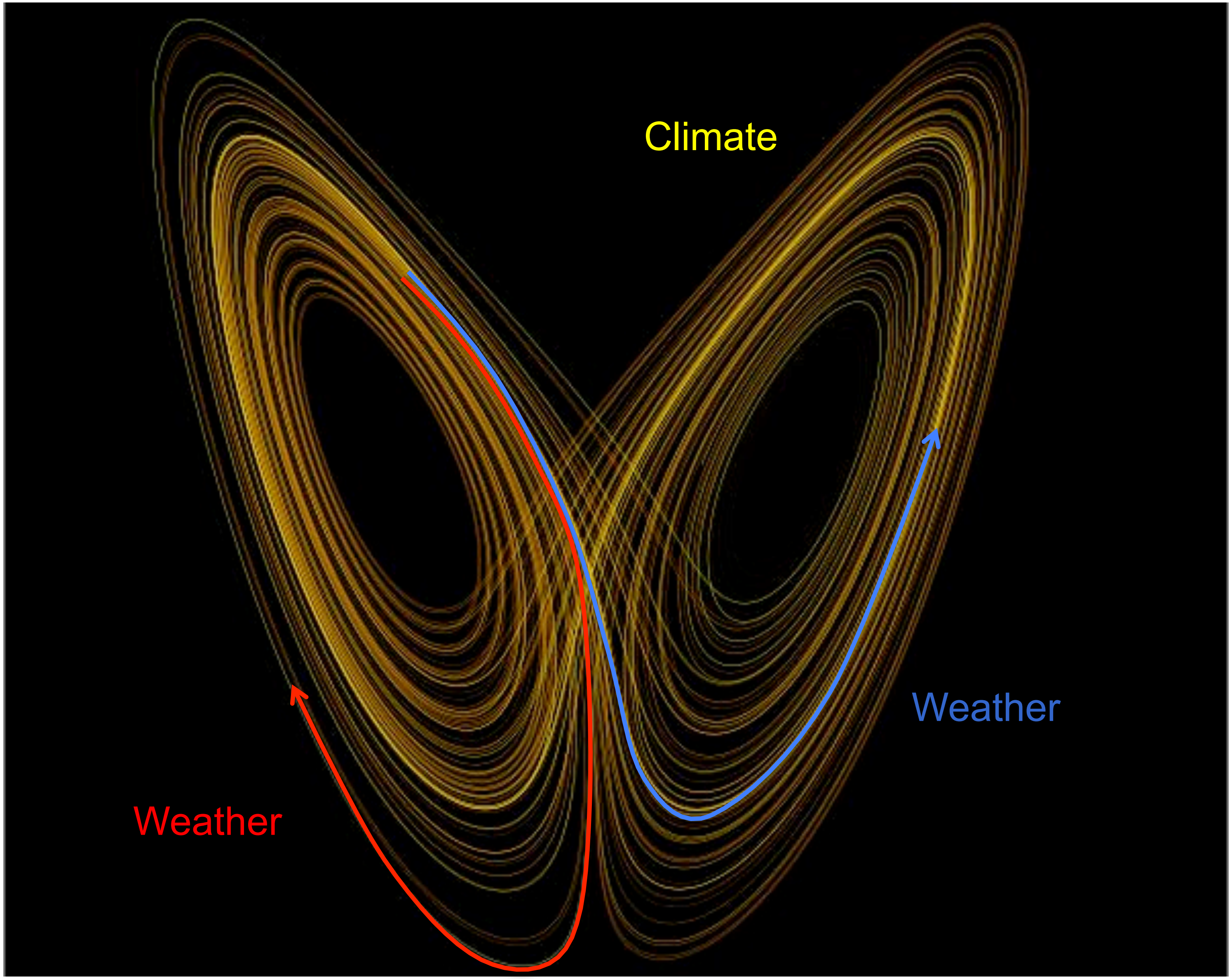
$$\frac{dx}{dt} = \sigma(y - x)$$

$$\frac{dy}{dt} = x(\rho - z) - y$$

$$\frac{dz}{dt} = xy - \beta z$$

When our results concerning the instability of nonperiodic flow are applied to the atmosphere, which is ostensibly nonperiodic, they indicate that prediction of the sufficiently distant future is impossible by any method, unless the present conditions are known exactly. In view of the inevitable inaccuracy and incompleteness of weather observations, precise very-long-range forecasting would seem to be non-existent.

Chaos Theory: Lorenz Attractor



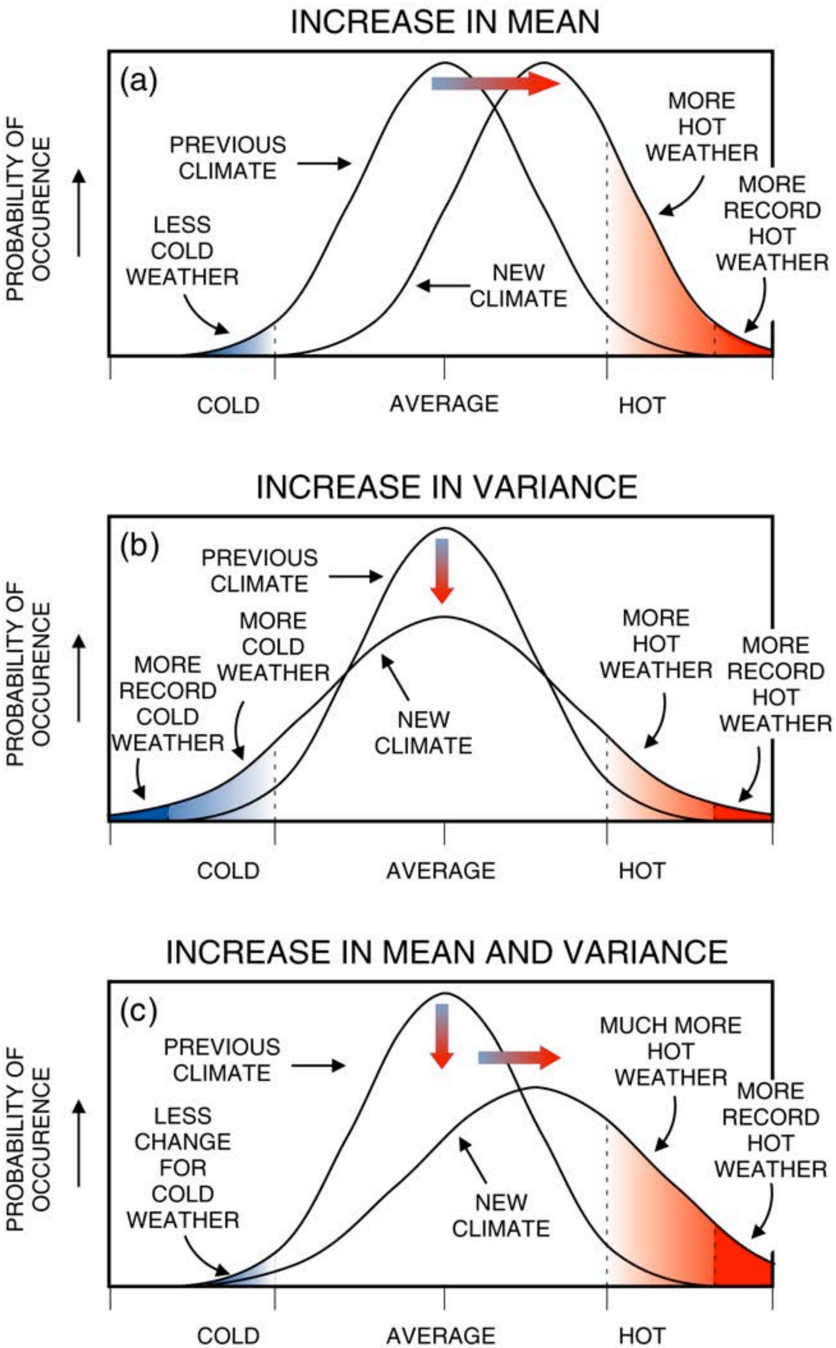
‘Climate Change’

- What does ‘Climate Change’ mean?
- More importantly: who cares if the climate changes by 1-3 ºC?
- The weather changed more than that since last week, or since last night
- What does it mean for weather extremes?

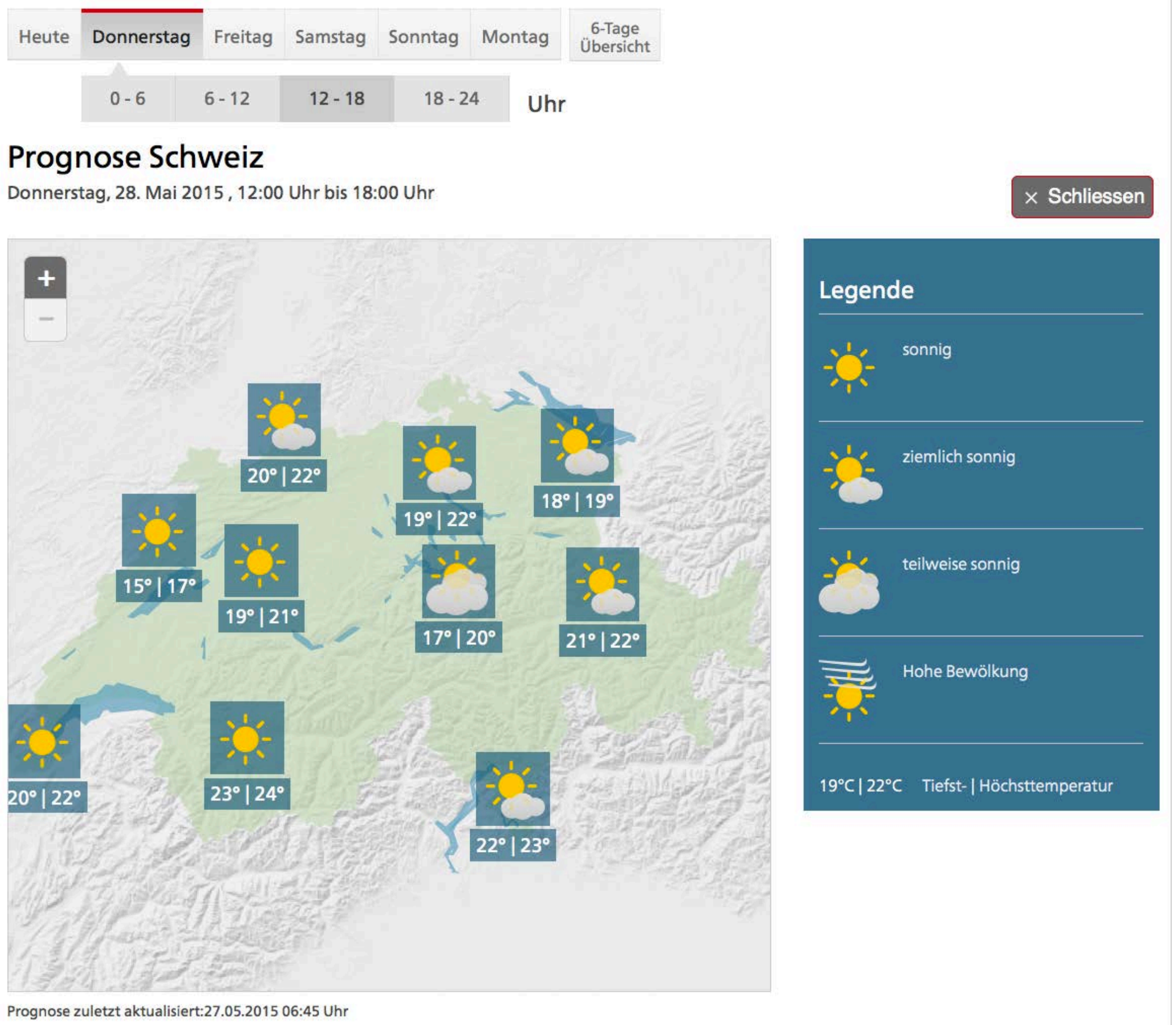
No one gets killed by the mean climate

What is Climate?

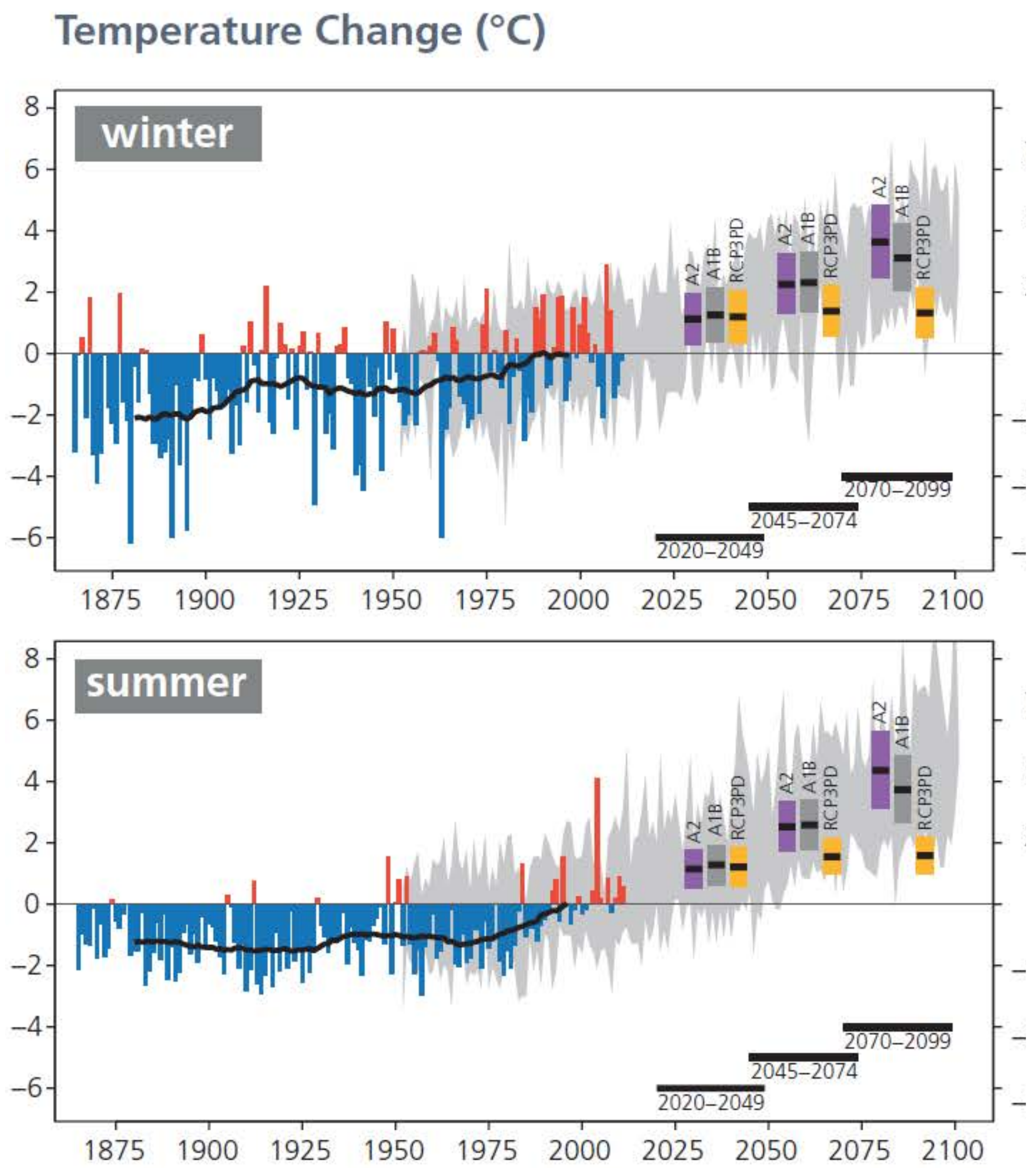
Climate change
and its manifestation
in terms of weather
(climate extremes)



Weather vs. climate (yesterday's weather forecast)



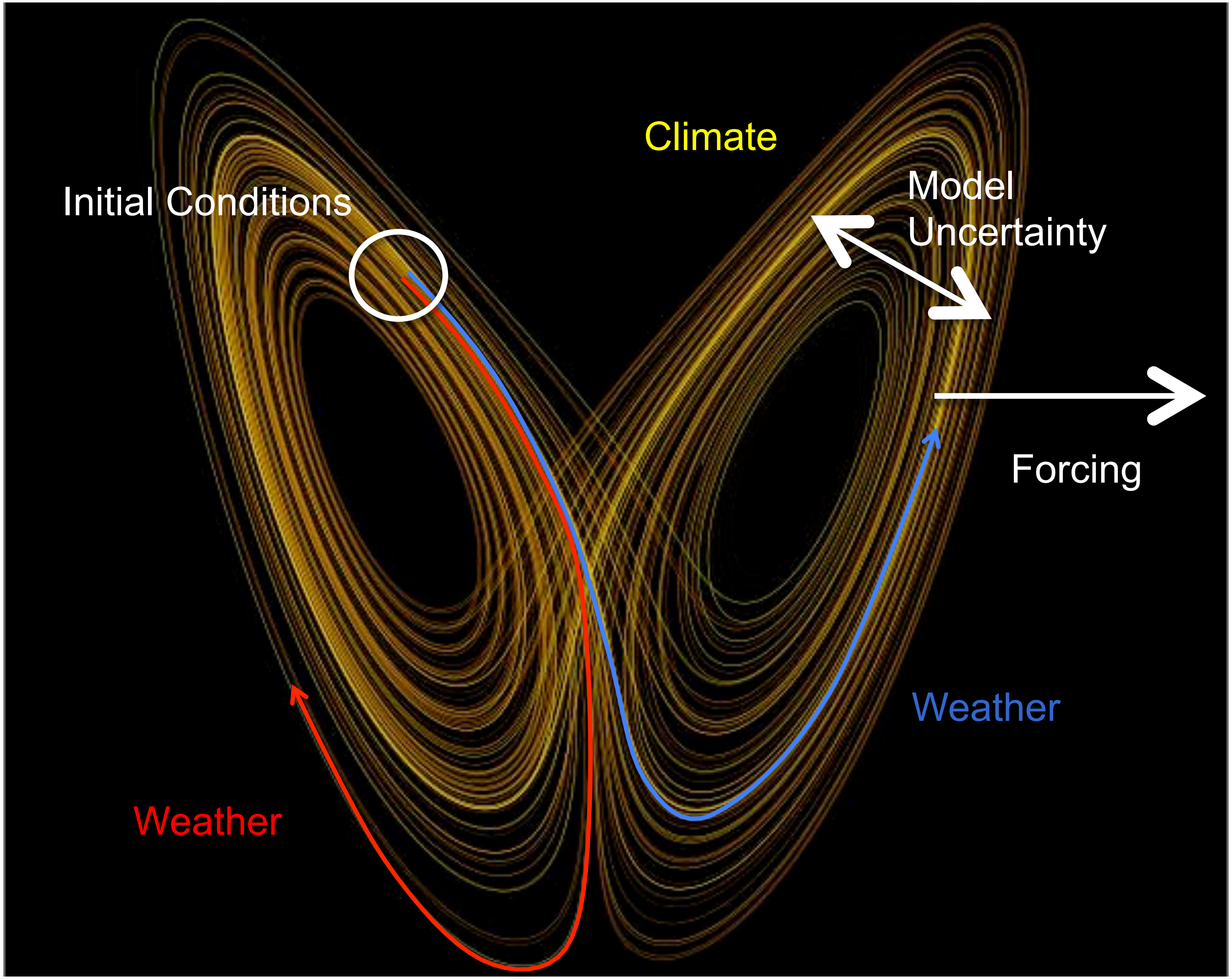
Weather vs. climate (Swiss climate projections)



- All predictions and projections have some dependence on model uncertainty (structural or parametric)
- Weather forecasts depend mostly on initial condition uncertainty (current state)
- Long term climate projections are independent of initial conditions, but depend on the boundary condition and forcing uncertainty

http://www.ch2011.ch/

Chaos Theory: Lorenz Attractor

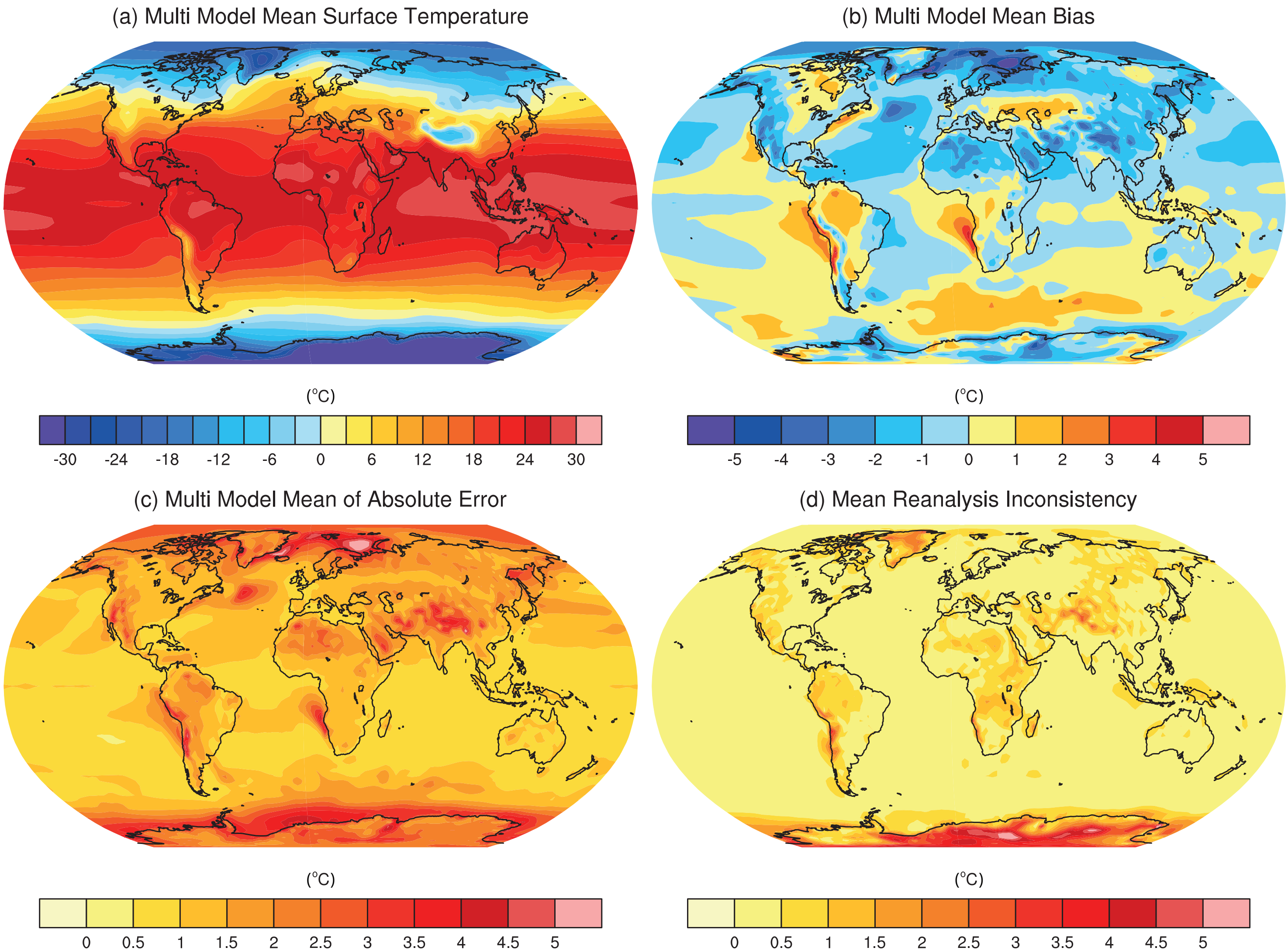


How do we test climate models?

- Compare to repeated observations (long term averages or ‘climatology’)
- Forecast the weather
- Reproduce the past

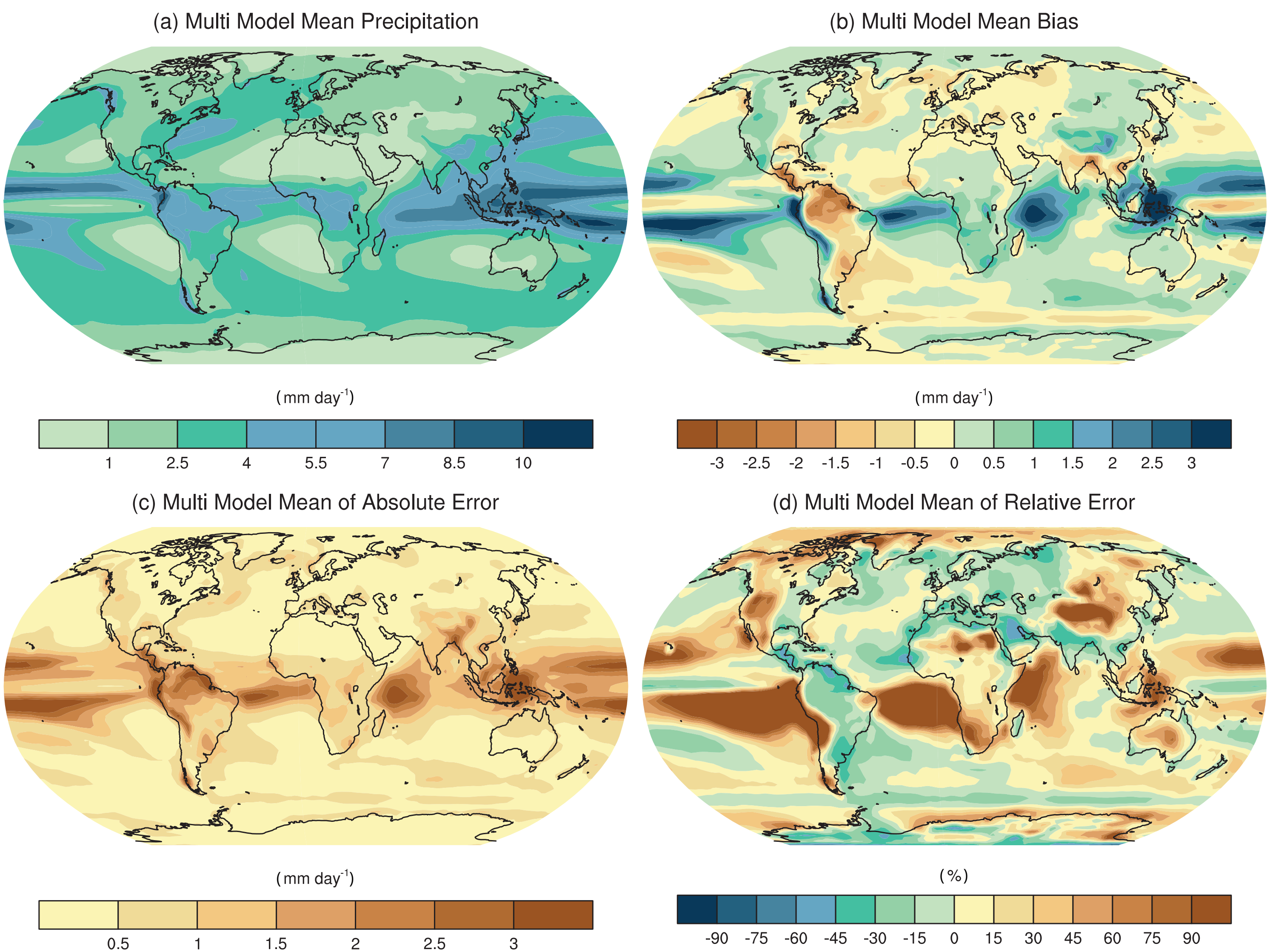
Goal: minimize “structural” or “parameter” errors in models by comparison to observations, in hindcast simulations

Comparison: temperature error



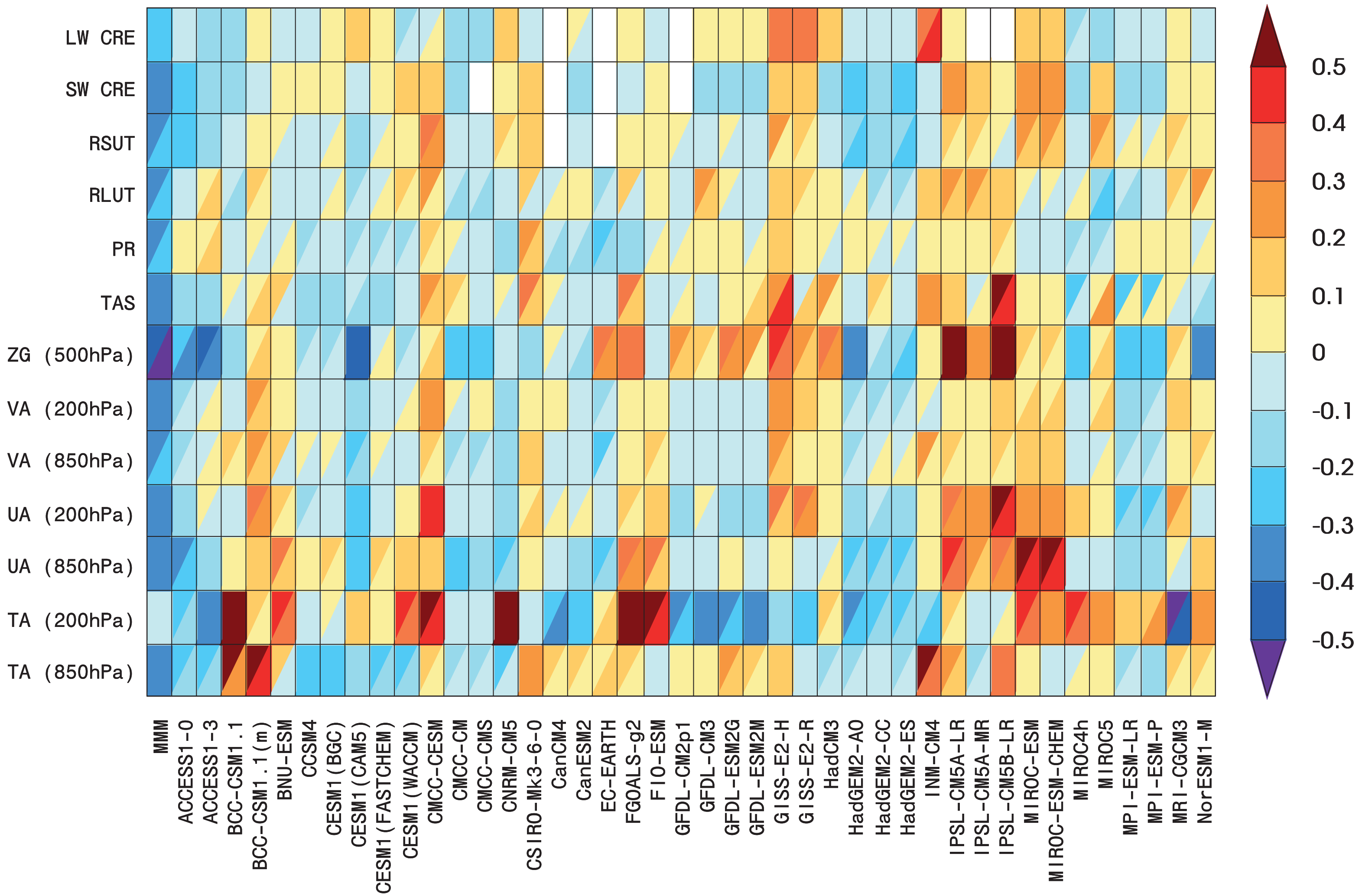
IPCC, 2013, Fig. 9.2

Comparison: precipitation error



IPCC, 2013, Fig. 9.4

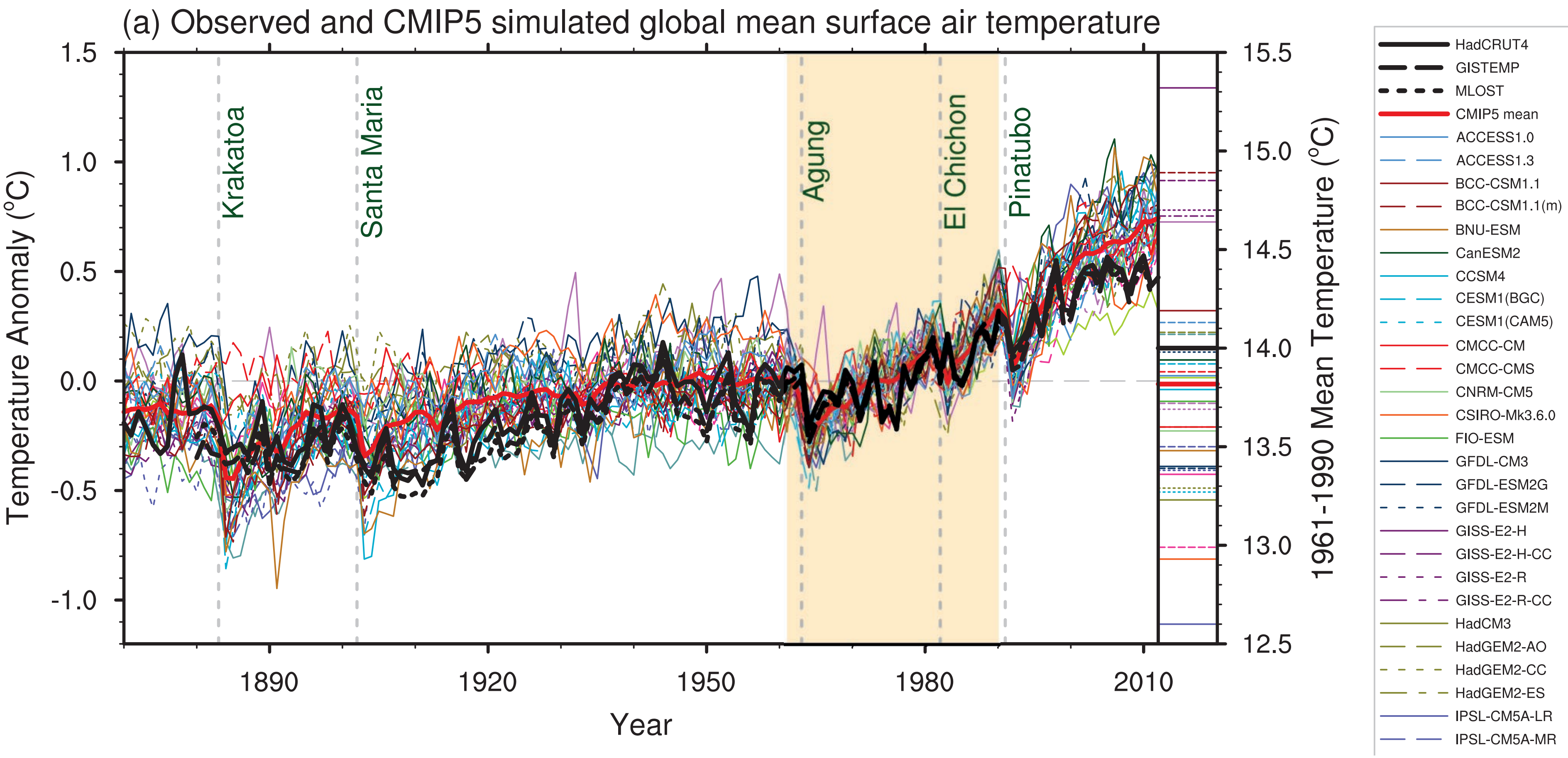
Root-mean square error



Root-mean square (RMS) error = $\sqrt{\mathrm{E}((\hat{\theta}-\theta)^2)}.$

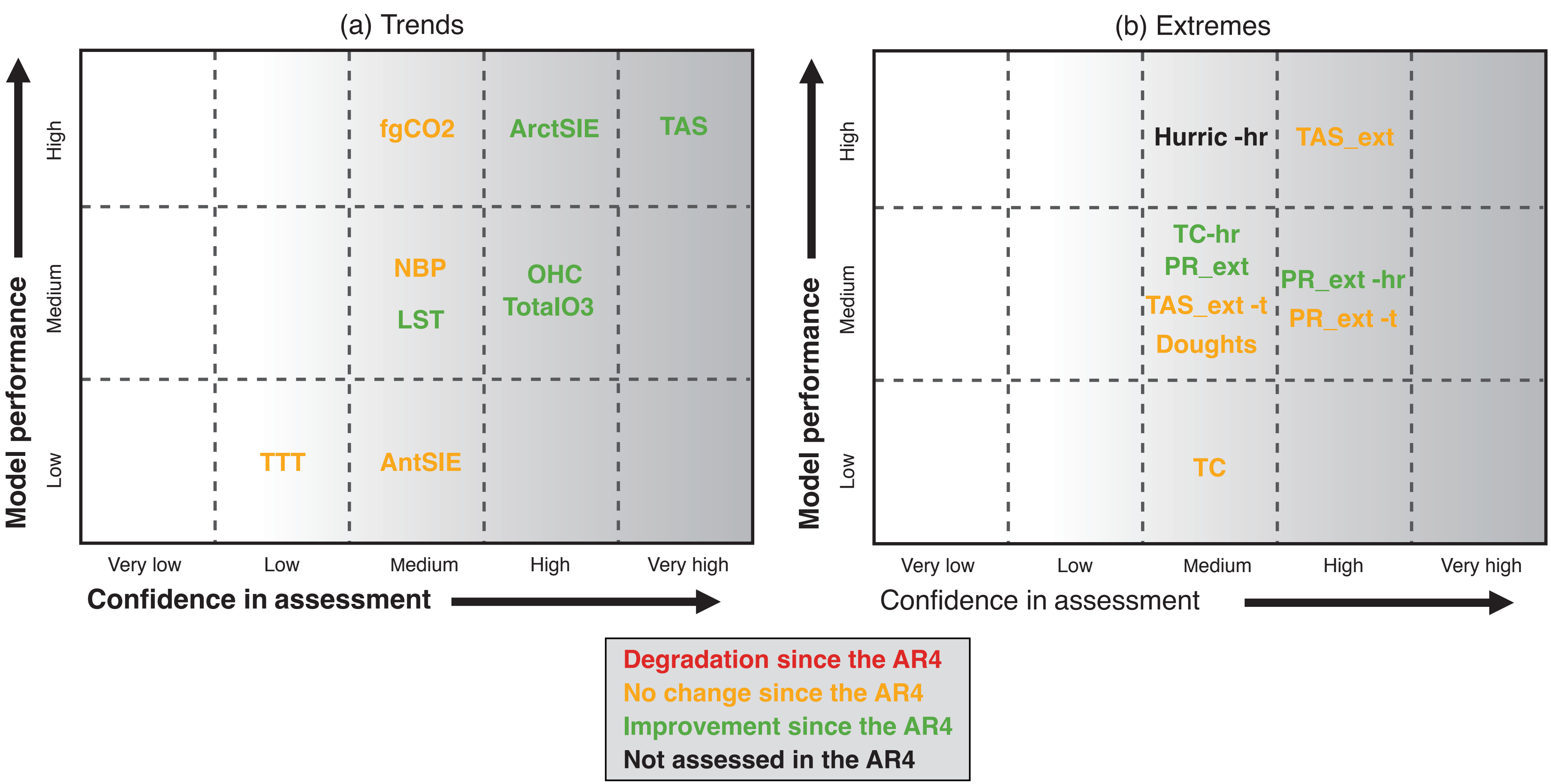
IPCC, 2013, Fig. 9.7

Hindcasts: Reproducing the past



IPCC, 2013, Fig. 9.8

Evaluation of climate models



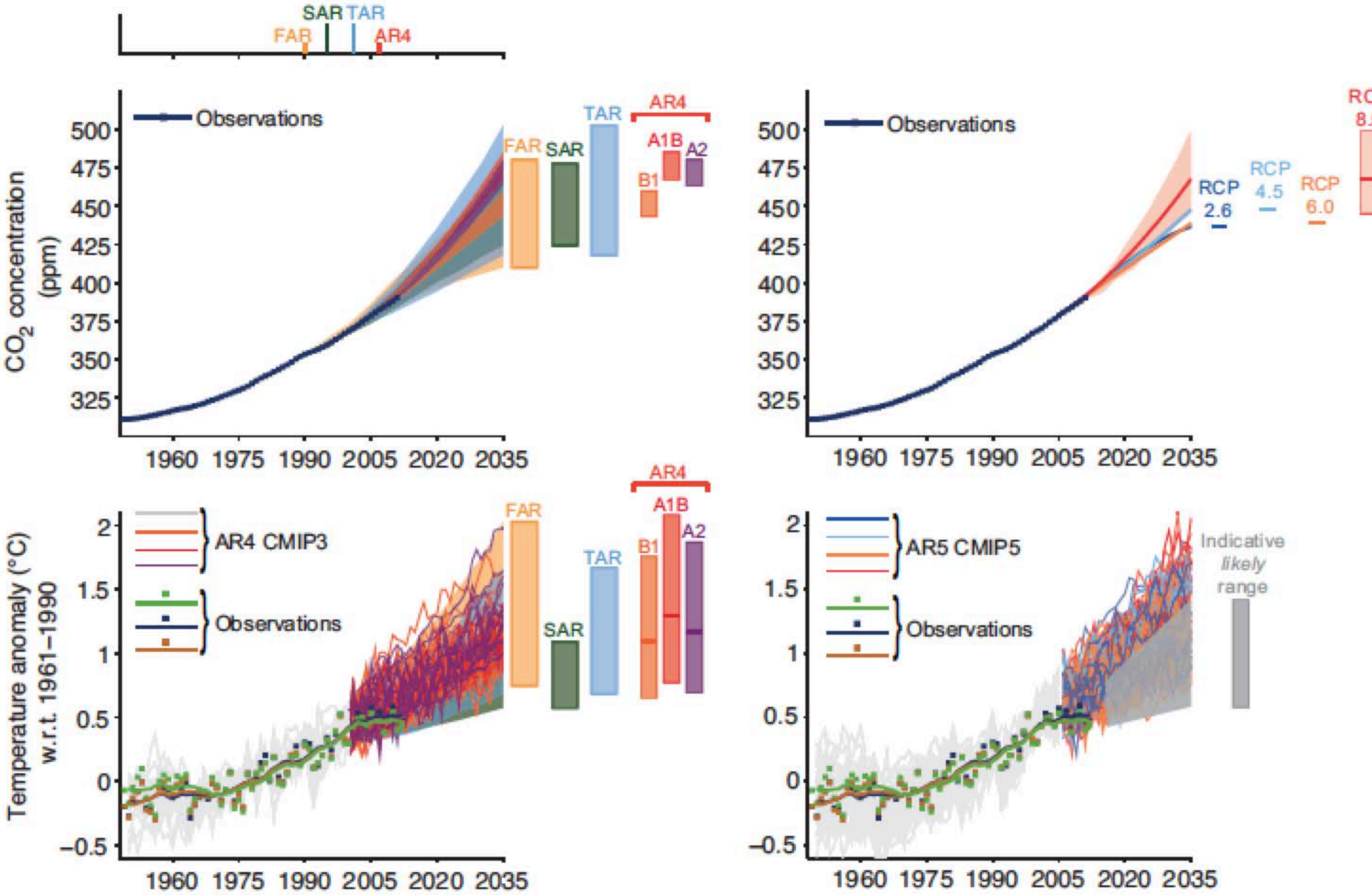
IPCC 2013, TS, Box 4, Fig. 1

What can we expect in future?

IPCC climate change scenarios

- Future greenhouse gas emissions include: demographical development, socio-economic changes, technological changes/renewals
- Their future development is very uncertain, so that scenarios need to be interpreted as different possibilities
- New in the IPCC AR5: express different scenarios in terms of representative concentration pathways (RCPs) of the radiative forcing in 2100 relative to pre-industrial values: e.g. RCP2.6 = 2.6 W/m^2

Evaluation of climate projections



IPCC 2013, TS, TFE3, Fig. 1

Why we should believe models

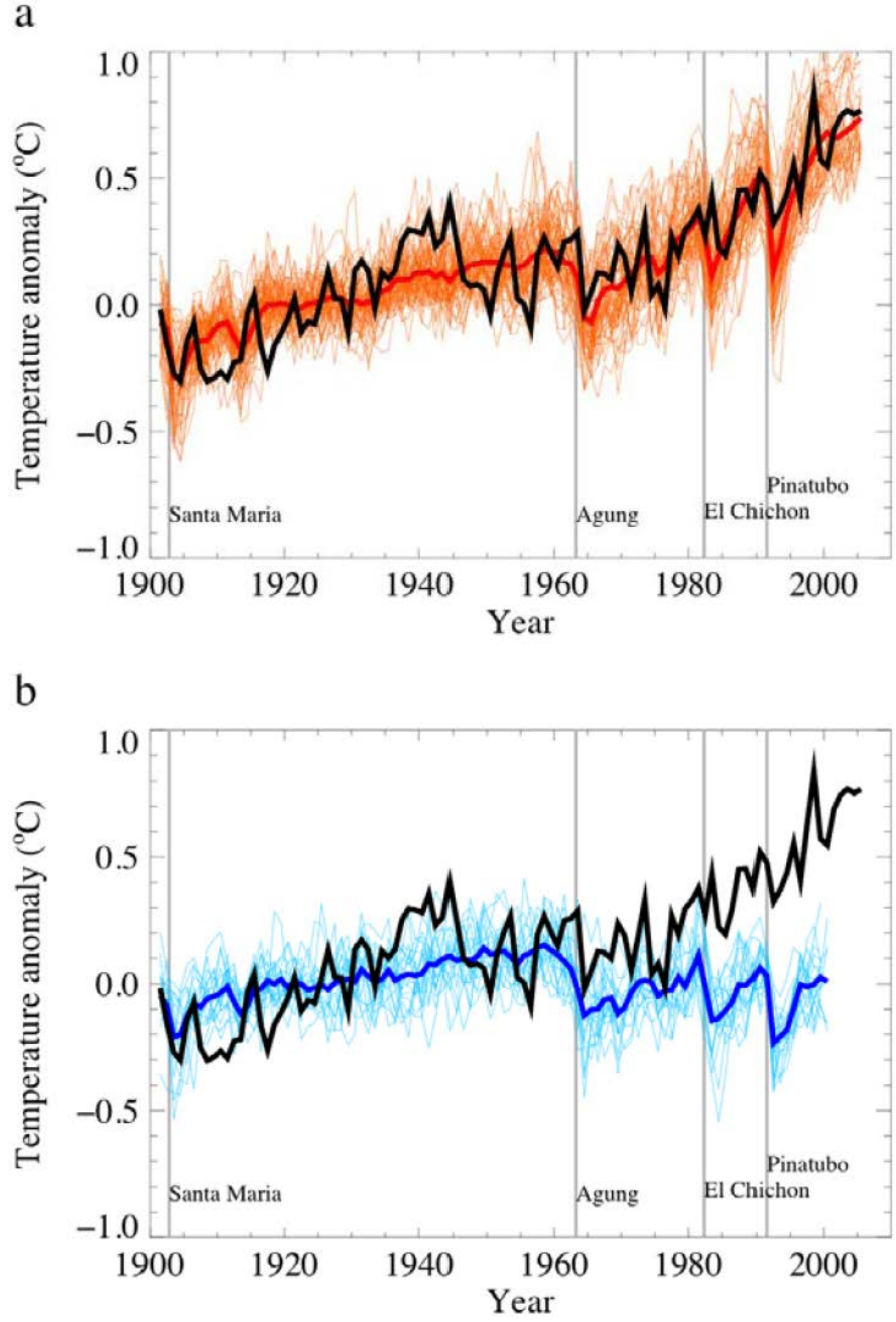
- Models reproduce processes (individual clouds) and global constraints (temperature records)
- Some constraints are good (temperature)
- Examples: Temperature record “wiggles”
  - Volcanoes
  - Variations in aerosols and greenhouse gases
- Can validate many broad scale processes
- What is uncertain?
  - precipitation less certain than temperature

Why we should distrust models

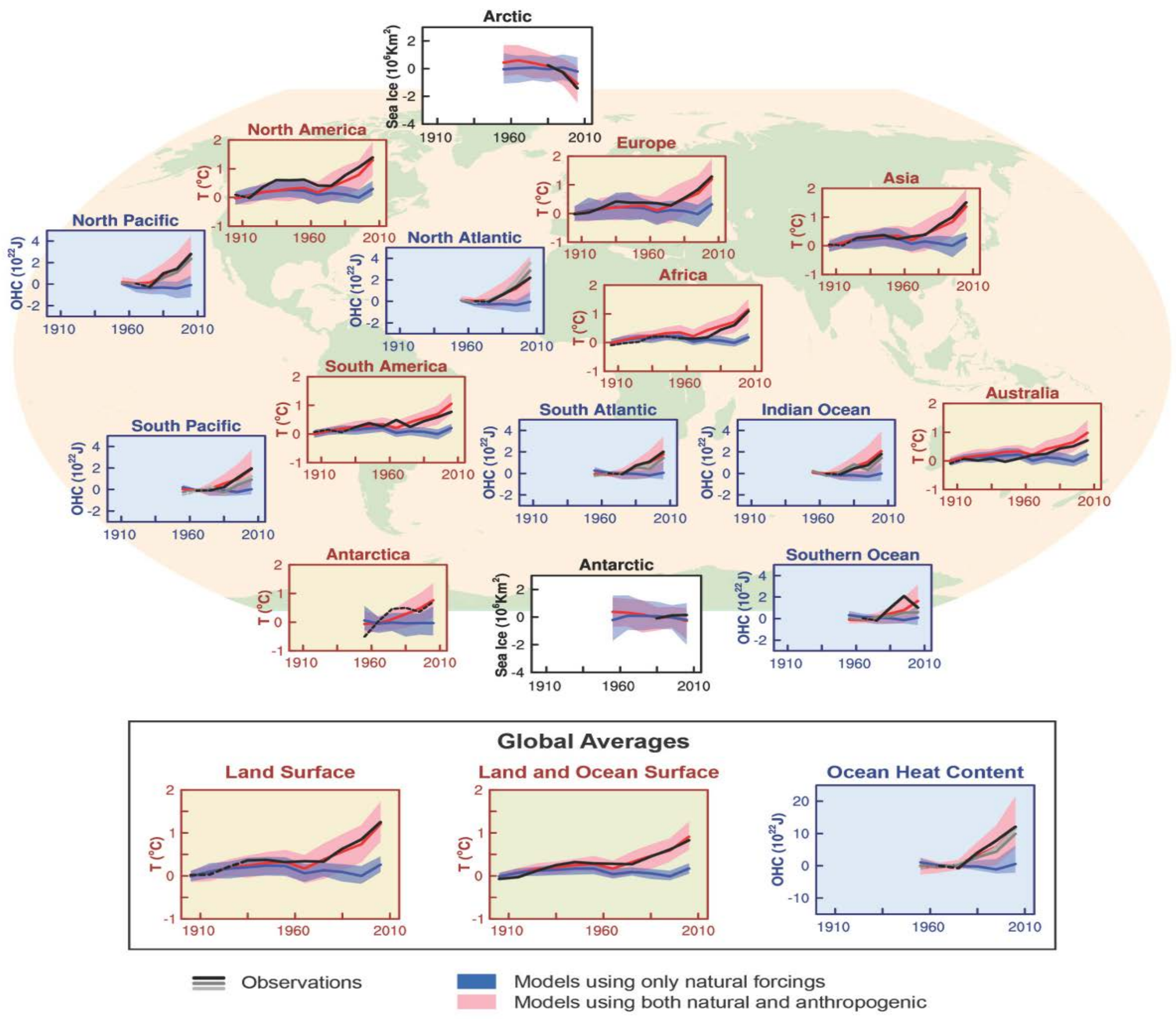
- Models have difficulty with parameterized processes:
  - precipitation and cloud physics
- Predictions of the past may not constrain the future:
  - necessary but not sufficient conditions
- Mechanisms that change climate operate differently in the past and present
  - Example: change in surface albedo
- Multi-model ensembles seem to have random errors: mean of many models seems to be ‘best’
  - But not if differences do not cancel (e.g. precipitation)

What models predict: The past

It is *extremely likely* (>95% probability) that human influence has been the dominant cause of the observed warming since the mid-20th century. (IPCC, 2014)

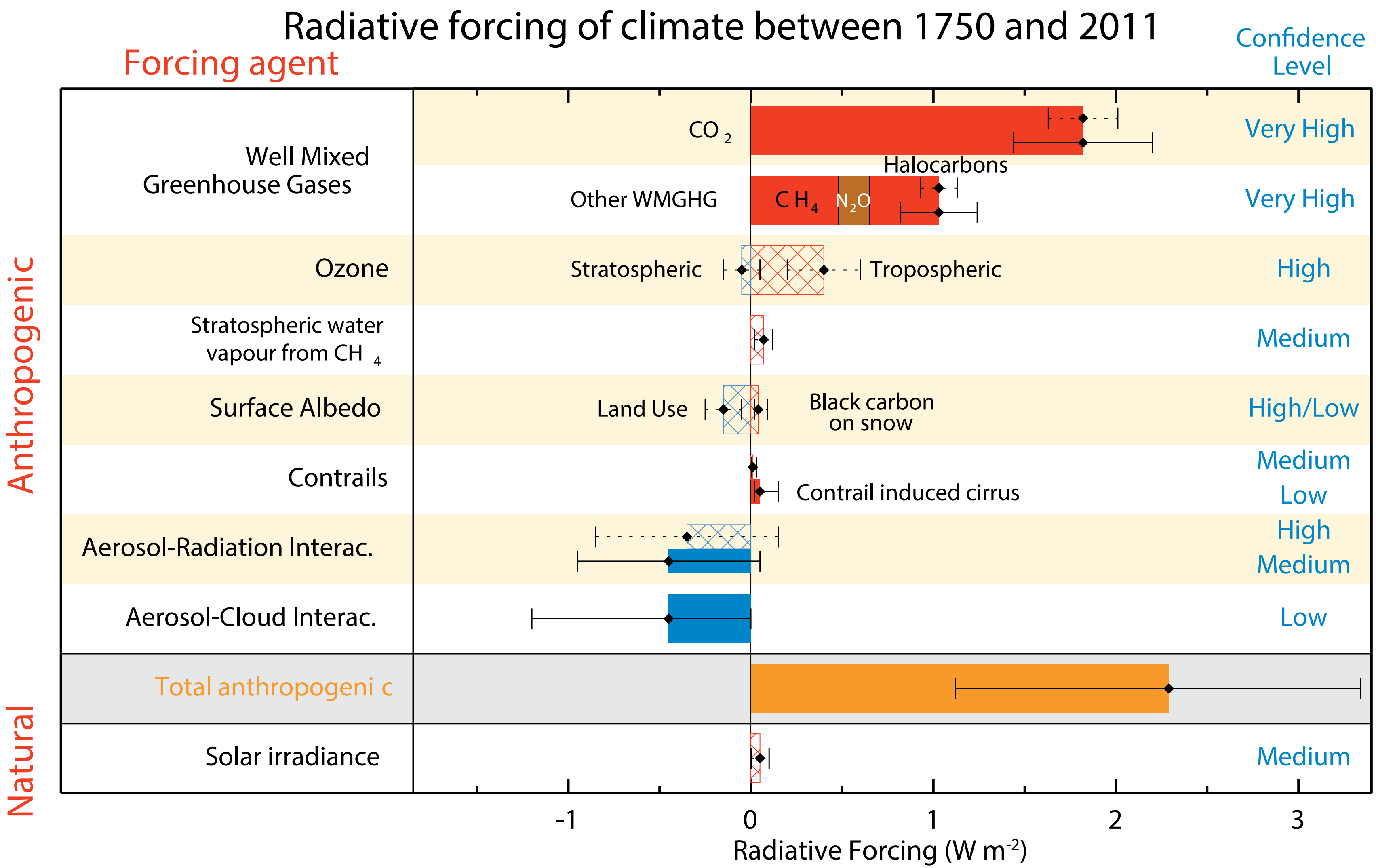


What models predict: The past



Physical causes of climate change

Radiative forcing of climate between 1750 and 2011



AR5, TS, Fig.6

IPCC AR5 Working Group I
Climate Change 2013: The Physical Science Basis

INTERGOVERNMENTAL PANEL ON climate change

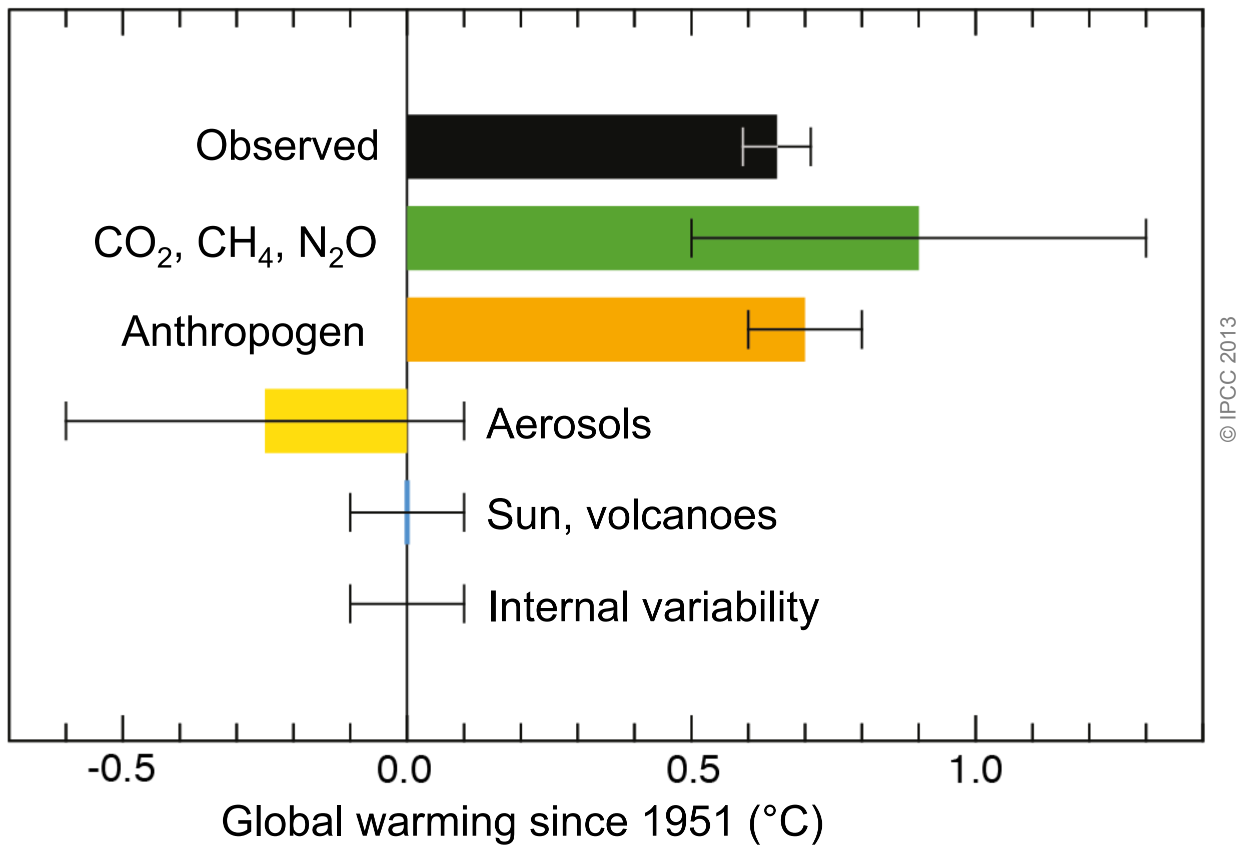
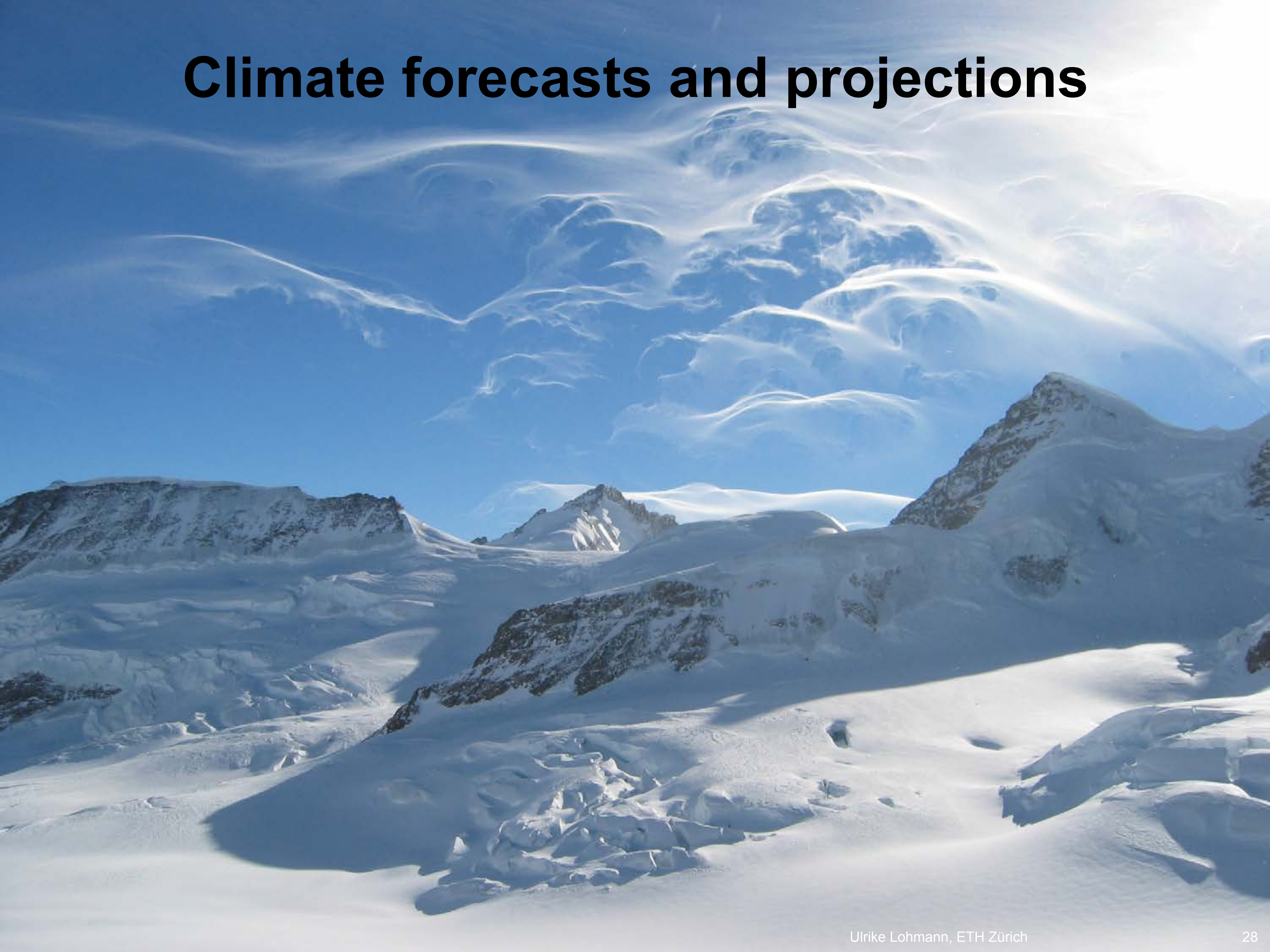


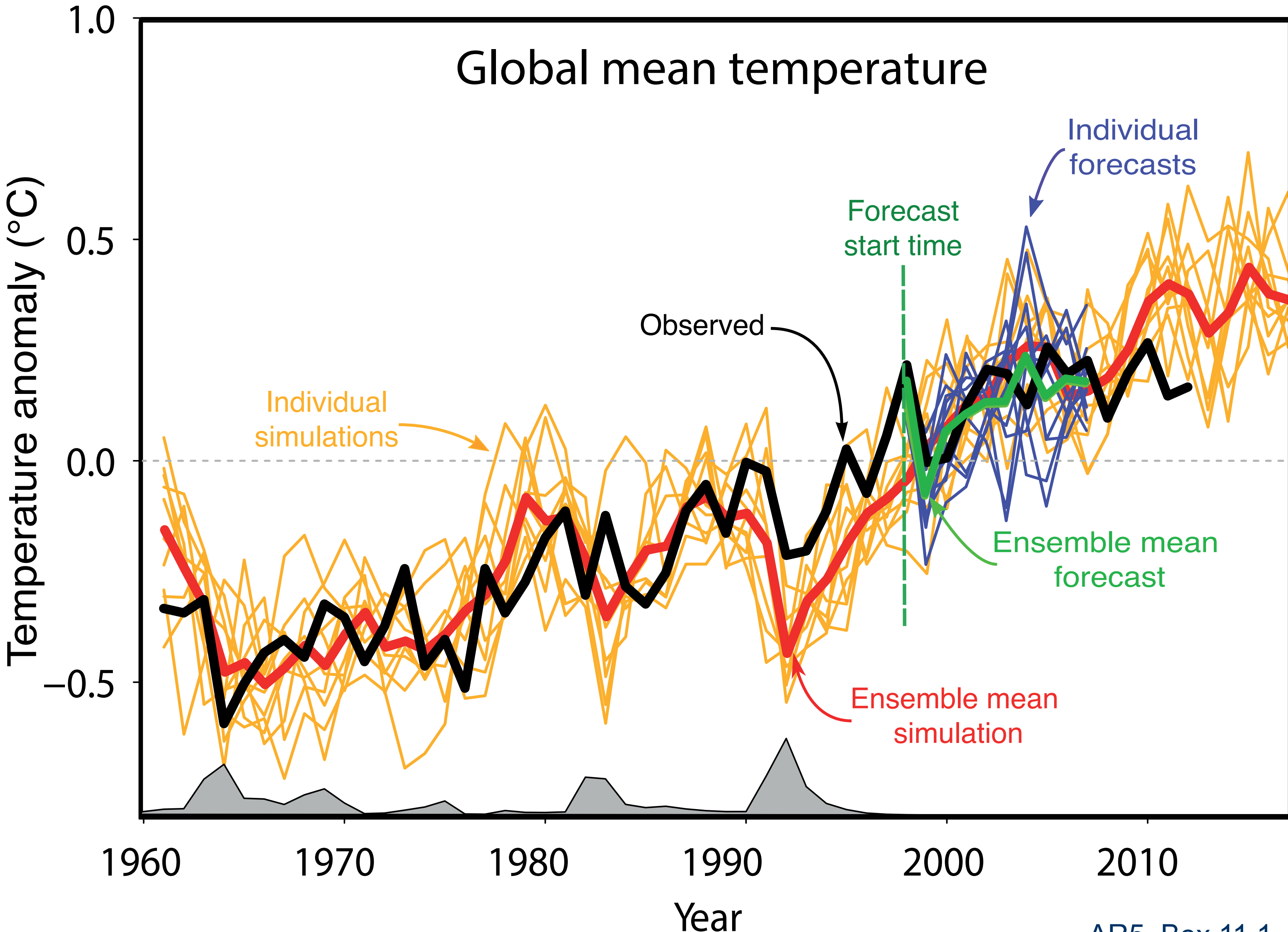
Fig. TS.10

Human influence on the climate system is clear

Climate forecasts and projections

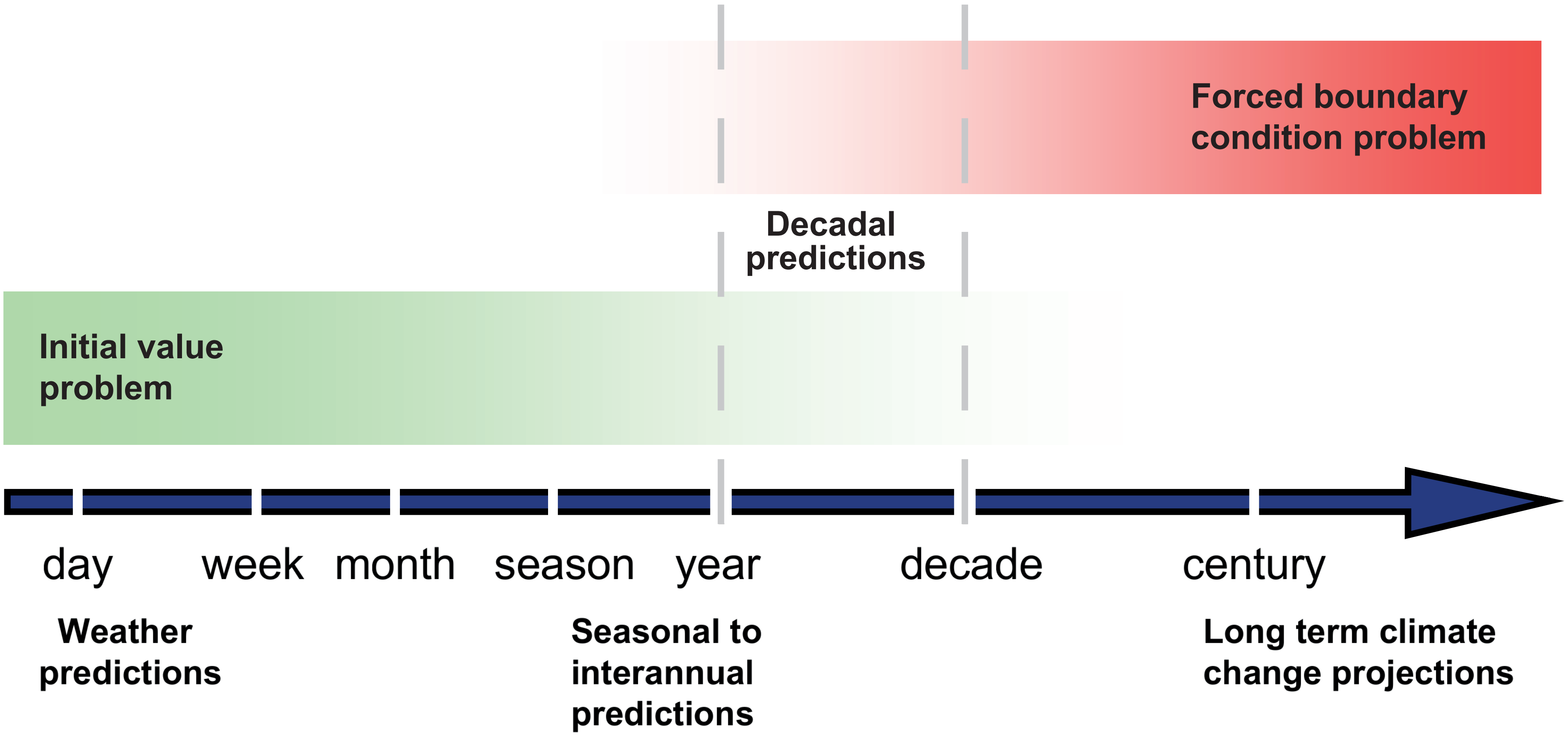


Climate simulations, forecasts and projections



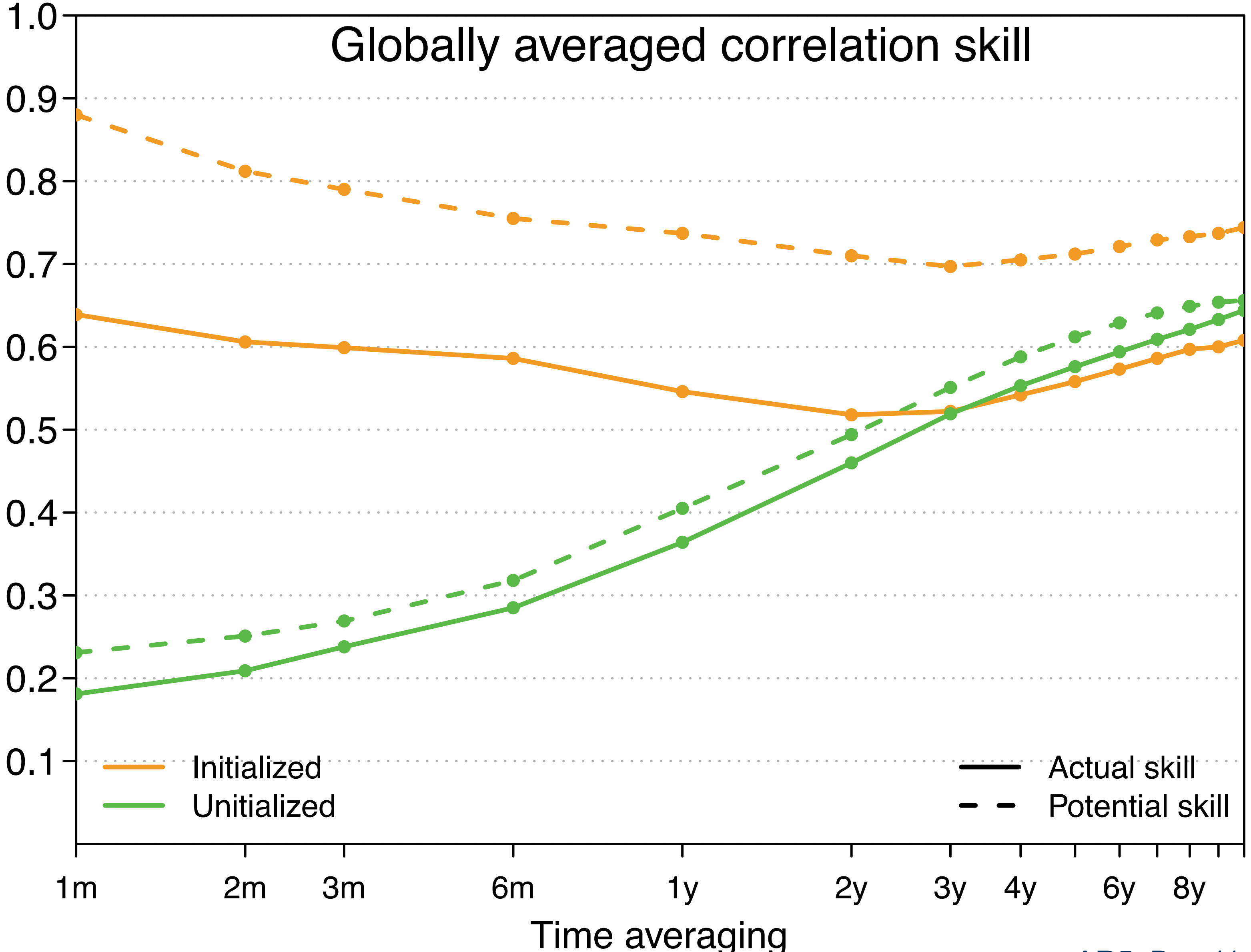
AR5, Box 11.1, Fig. 1

Climate simulations, forecasts and projections



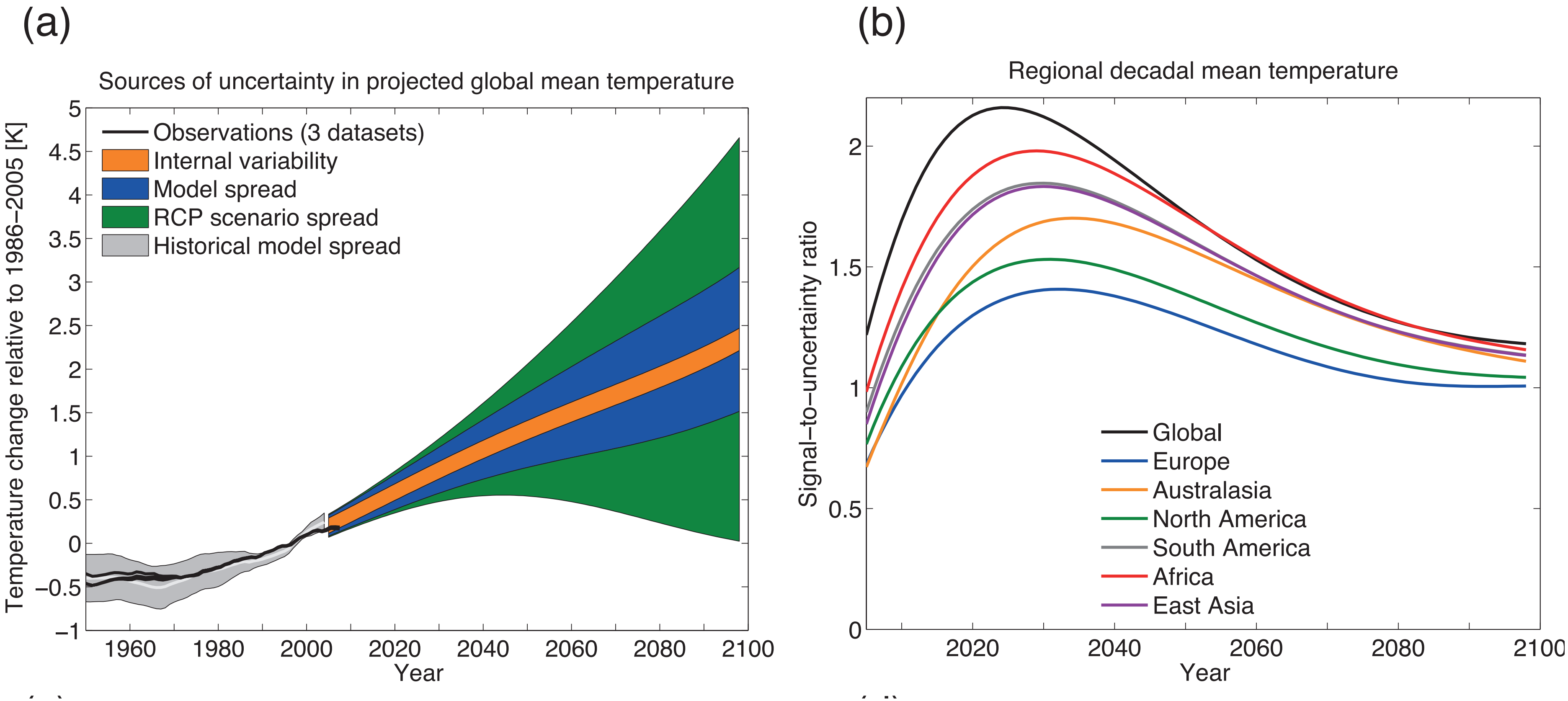
AR5, Box 11.1, Fig. 2

Climate simulations, forecasts and projections



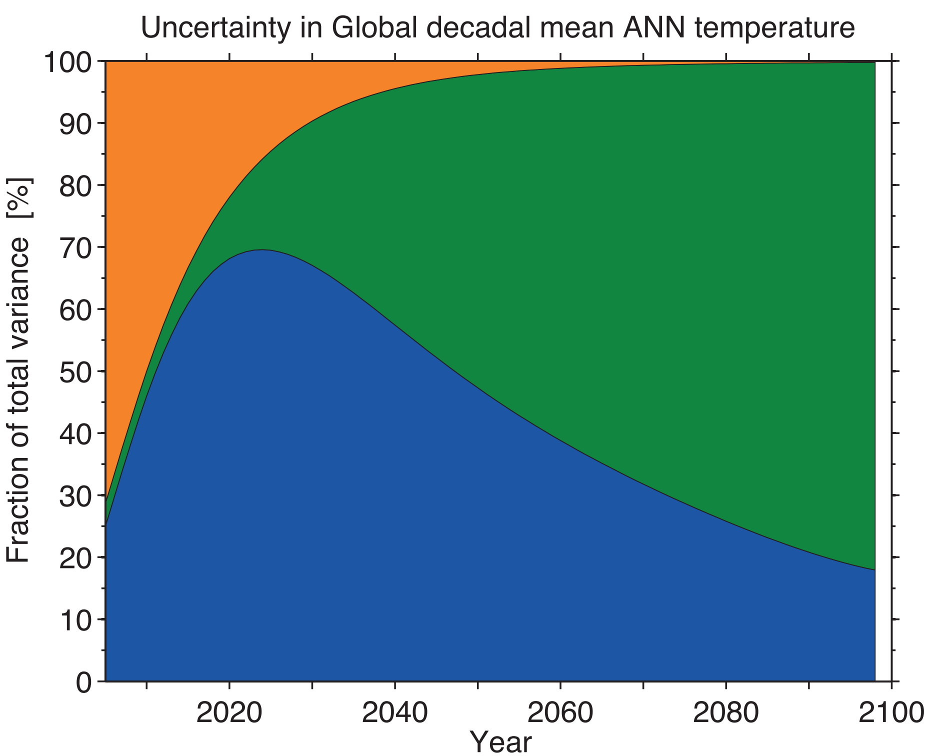
AR5, Box 11.1, Fig. 4

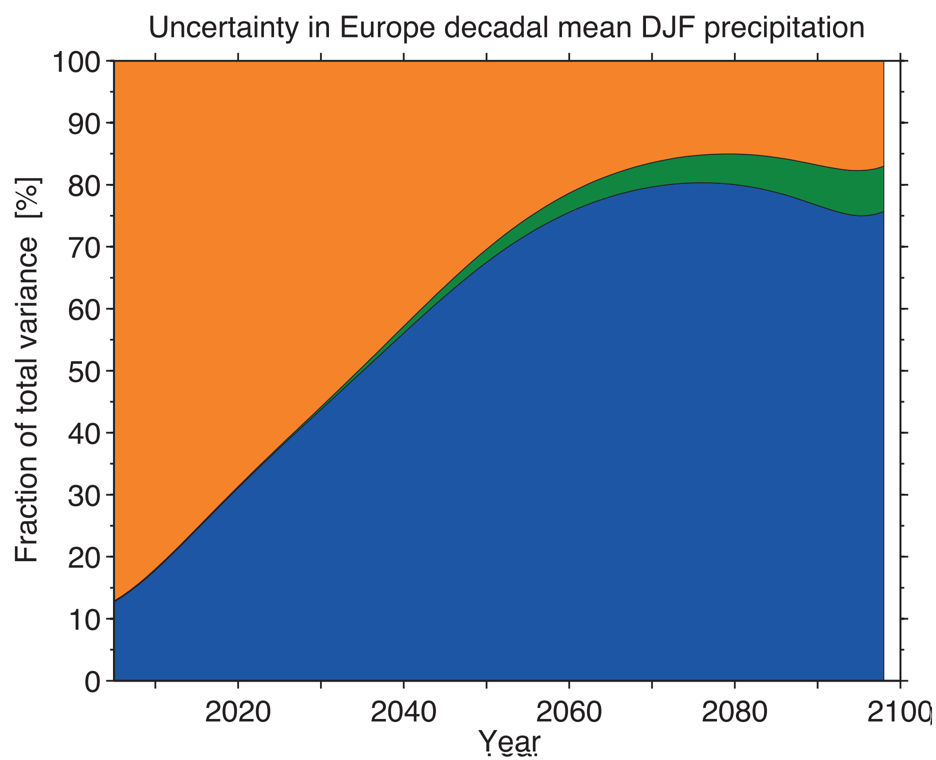
Sources of uncertainty in climate projections



AR5, Fig. 11.8

Sources of uncertainty in climate projections



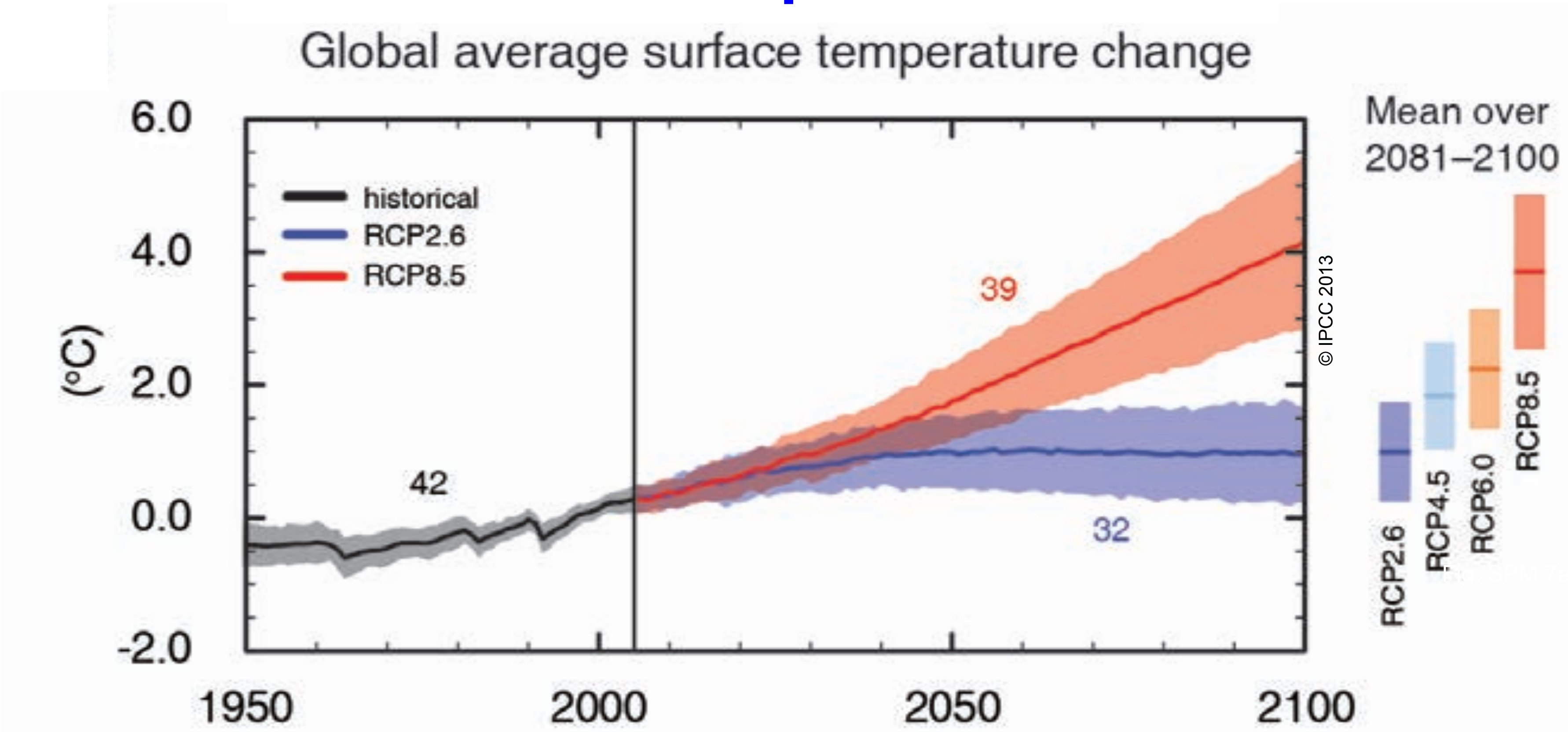


The relative importance of the different sources of uncertainty depends on the variables (temperature, precipitation), the scale considered and the time horizon

AR5, Fig. 11.8

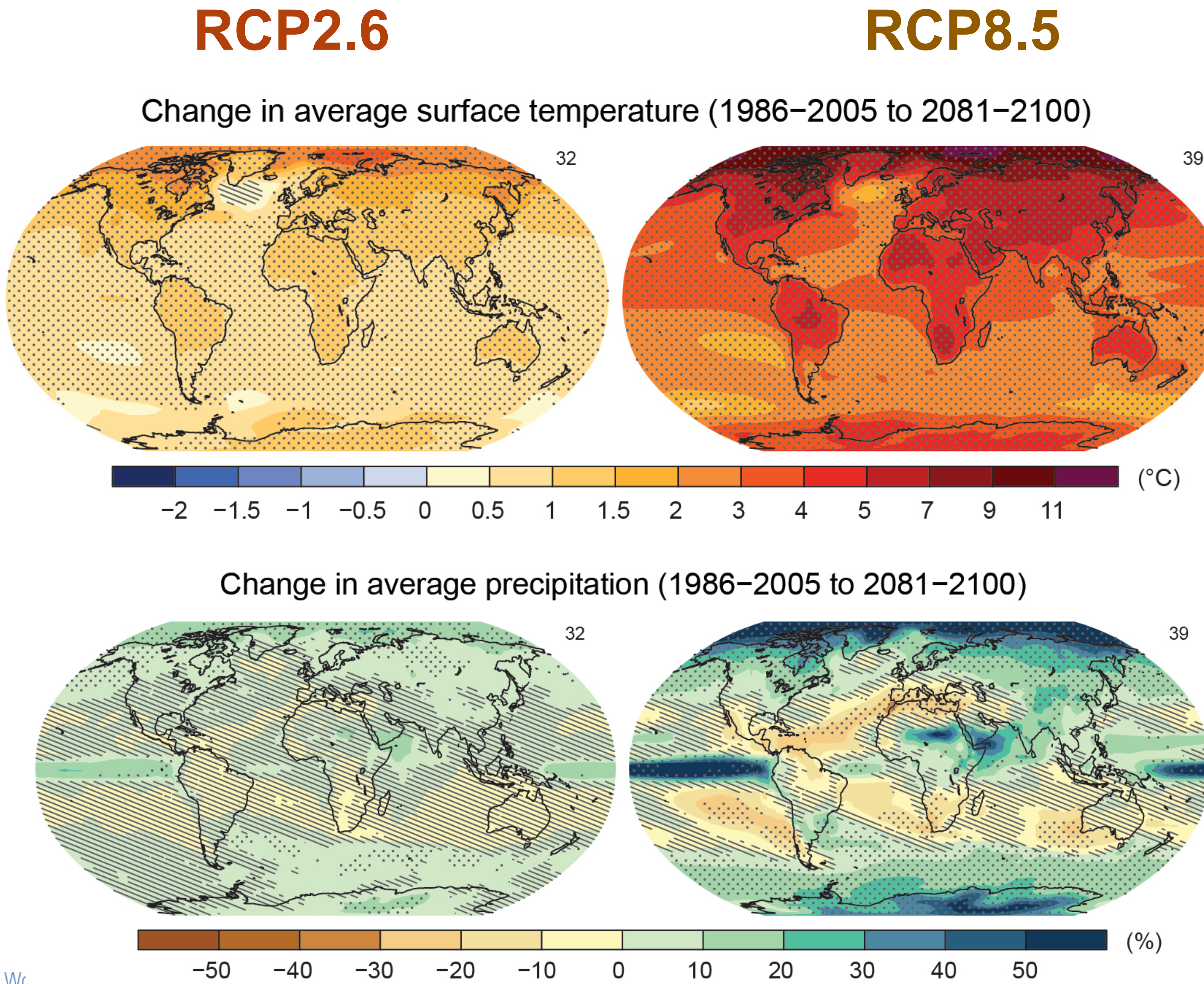
Long-term climate projections

Global mean surface temperature w.r.t. 1986-2005

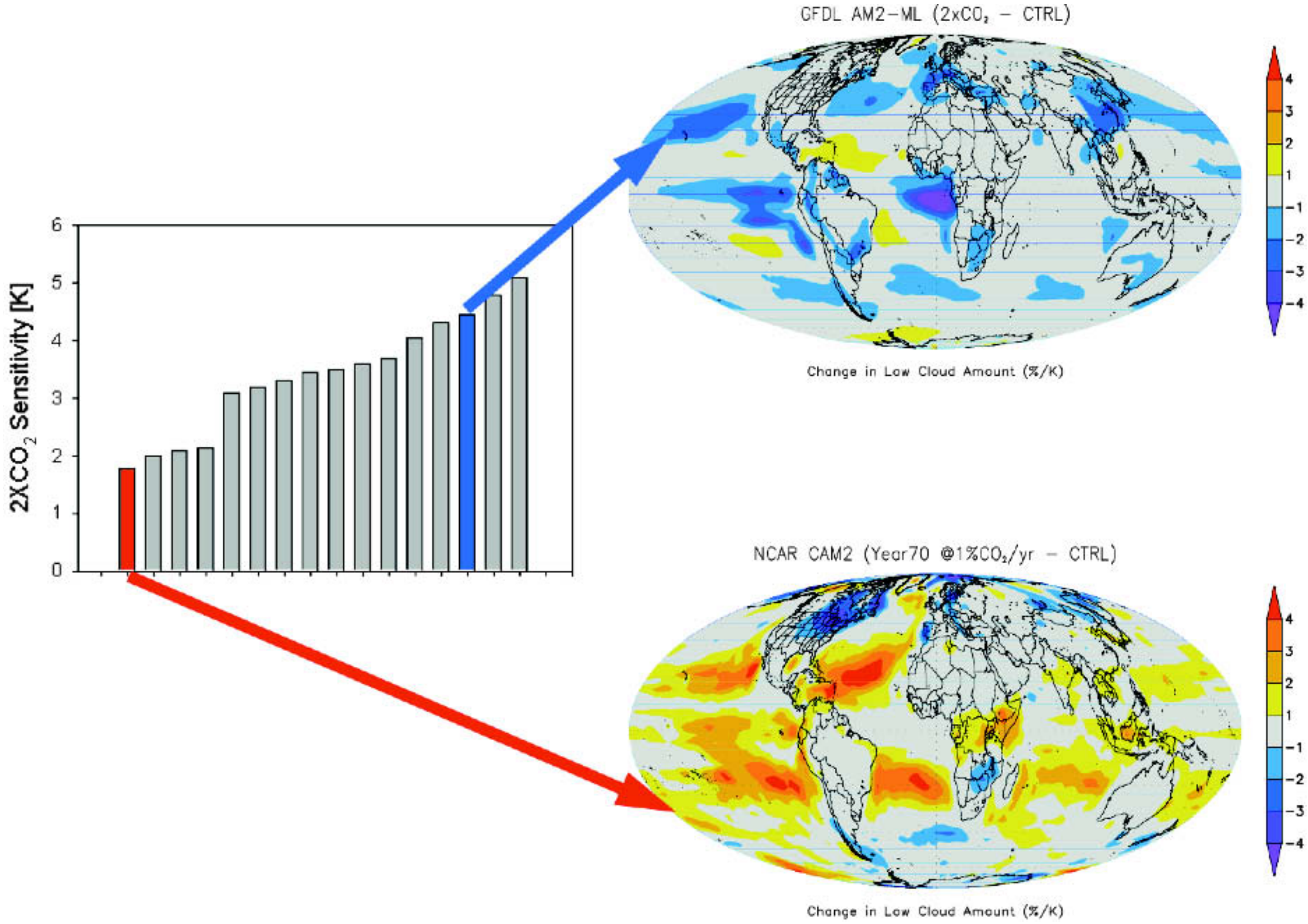


Global surface temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850−1900 for all scenarios except RCP2.6

Fig. SPM.8

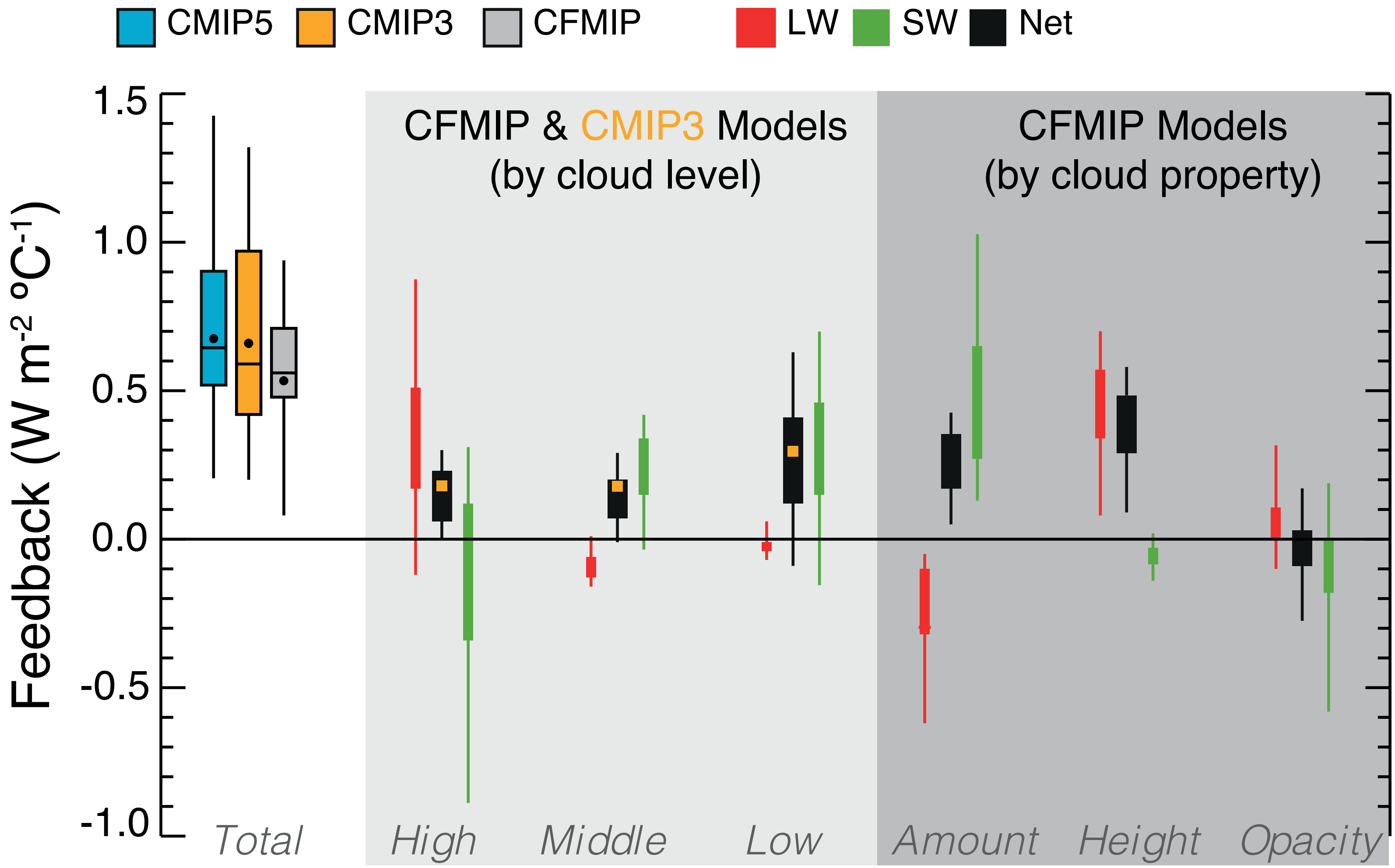

RCP2.6
RCP8.5
Change in average surface temperature (1986−2005 to 2081−2100)
32
39
−2 −1.5 −1 −0.5 0 0.5 1 1.5 2 3 4 5 7 9 11
(°C)
Change in average precipitation (1986−2005 to 2081−2100)
32
39
−50 −40 −30 −20 −10 0 10 20 30 40 50
(%)

Example of a parametric uncertainty: clouds



Stephens et al., JC, 2005

Response of clouds to CO_2 doubling



IPCC (2013), chapter 7

What we know

- It is hard for temperature not to increase. The magnitude of warming also depends on total forcing (GHG release).
  - High latitude temperatures increase more. Big impacts on the Arctic (Antarctic is too cold to see much change)
- Changes in the hydrologic cycle will occur: rainfall patterns (deserts) may shift poleward.
- Intensification of rain and drought.
  - We can hypothesize changes in rainfall, but they are uncertain
- Some threshold effects are known:
  - Sea ice is going away fast.
  - Ice sheets are melting fast. This could be up to 1-2m of sea level rise by the end of the century or it could be 0.2m.

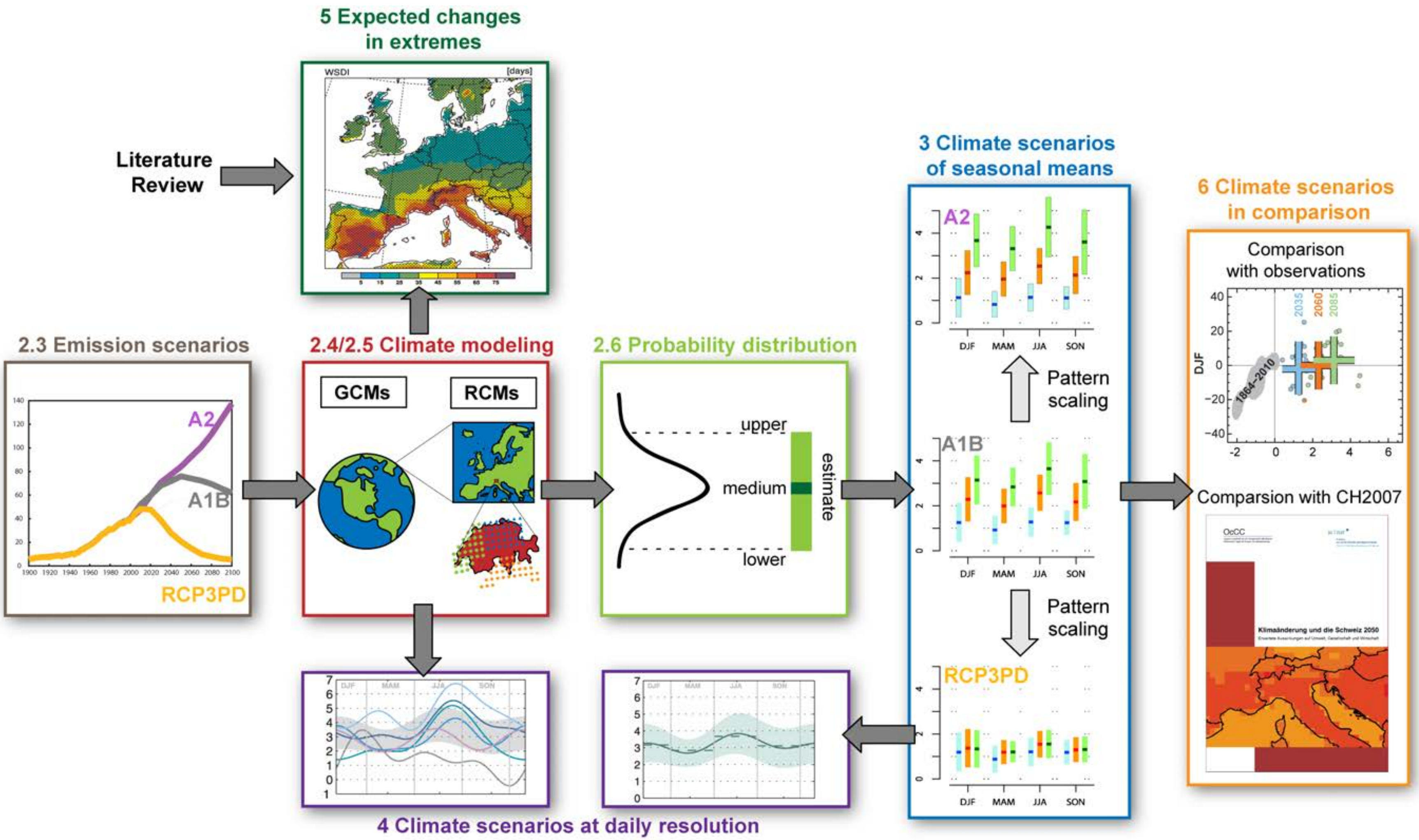
Where is the uncertainty?

- Temperature: clouds
- Regional precipitation: clouds, storm tracks, precipitation processes (extremes)
- Land surface: carbon storage and response of ecosystems
- Ocean: circulation changes, carbon storage
- Humans: how much we choose to emit.

Regional Changes

- How do we predict small scale regional change?
  - Global models are necessary for energy balance
  - Global models cannot get the details right
- Use ‘regional climate’ models or ‘downscaling’
- Regional climate models: weather model with boundary conditions from climate model (run 1-25km over a region)
- ‘Downscaling’ or statistical methods to relate present climate models to present observations (local) then use statistics in the future
- Example: Swiss Climate Change Scenarios combine these methods

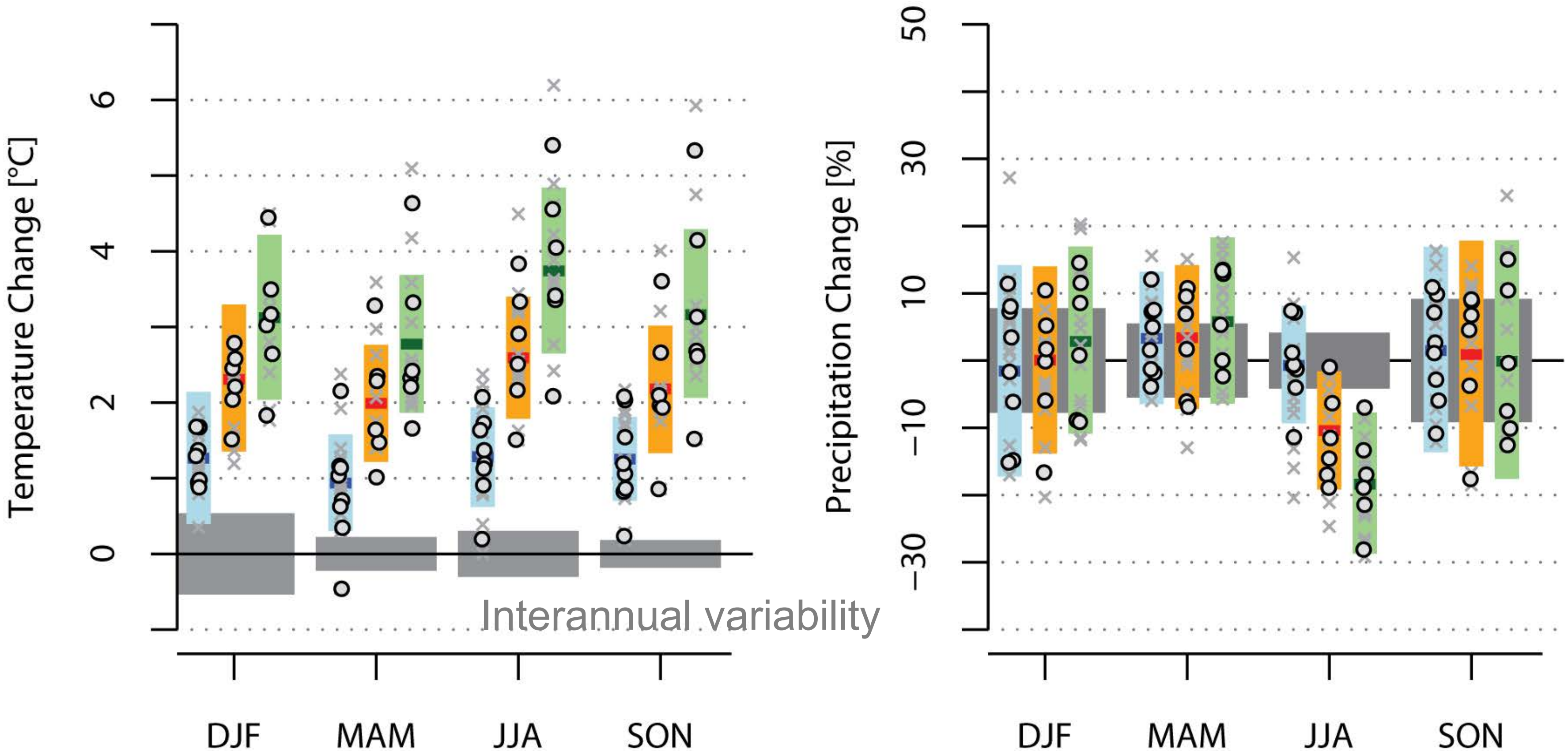
Swiss Climate Change Scenarios



CH2011: Fig 2.1

http://www.ch2011.ch/

Results: NE Switzerland



Seasonal Changes: A1B scenario

CH2011: Fig 2.6

X = GCM-RCM
O = all RCM for 1 GCM

2020-49
2045-74
2070-99

Conclusions: climate change

- Is based on physical laws: The heat has to go somewhere
- We can simulate the climate of the recent past
- Many aspects we do well (temperature, response to forcing)
- Some things we need to do better (clouds, precipitation)
- Still lots of uncertainties from the complexity of the system
- Hard for uncertainties to change the basic answer

Conclusions: weather vs. climate

- Weather forecasts (initial conditions, model uncertainty)
- Climate projections: 3 uncertainties
  - Initial conditions (internal variability)
  - Model (parametric & structural)
  - Boundary condition (forcing or scenario)