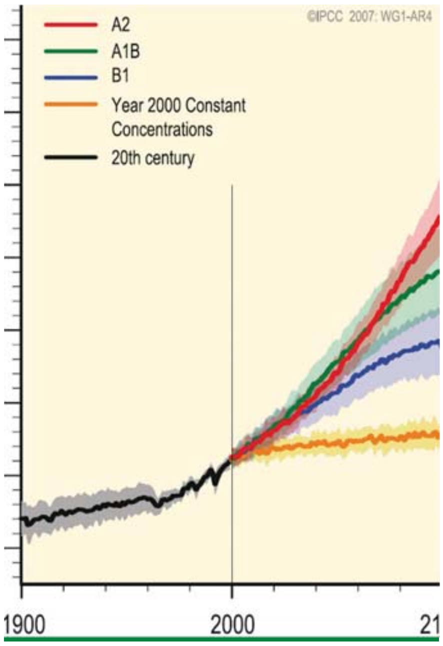


Climate Change

Dr.-Ing. Jörg Dietrich

Institute for Water Resources Management, Hydrology and Agricultural Hydraulic Engineering

Leibniz Universität Hannover

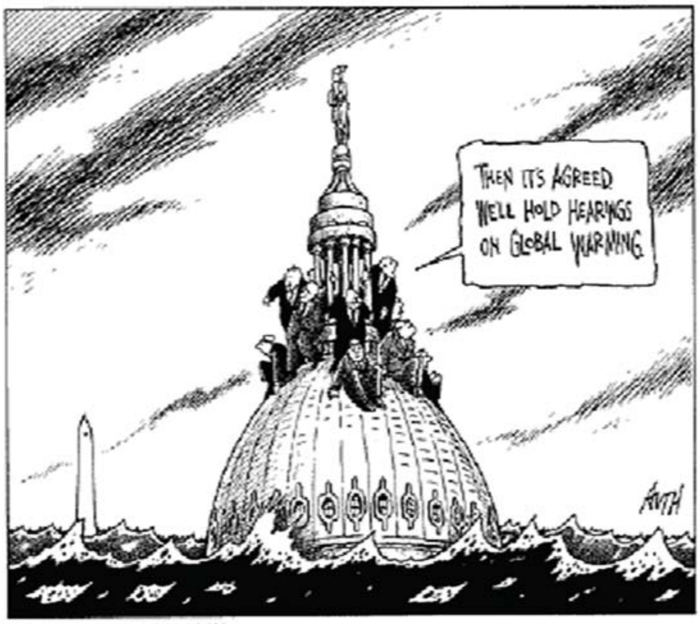
Course: Integrated Water Resources Management
Module: Ecology & Water Resources

WATENV International Master Programme

Lecture 3: Global Change

1 Climate Change
2 Impact of Global Change on Water Resources
3 Adaptation of Water Resources Management

1 Climate Change



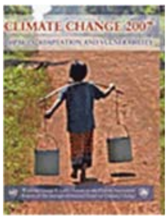
Climate Change

- Climate change: long-term global change caused by geological processes and anthropogenic emissions.
- The estimation of the impact of climate change on water resources is uncertain and depends on the region and the evaluated scenarios.
- However: most experts agree that climate change will have a significant impact on water availability.
- Other aspects of global change are at least as important for water management (population growth, socio-economic development, political changes).

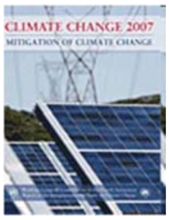
IPCC Reports about Climate Change

- IPCC: Intergovernmental Panel on Climate Change
- Founded by WMO and UNEP
- Elaborates political relevant assessments of the scientific literature about climate change
- Structure of the IPCC reports:

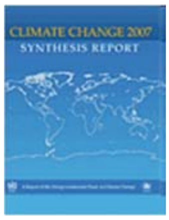
Working Group I Report **"The Physical Science Basis"**



Working Group II Report **"Impacts, Adaptation and Vulnerability"**

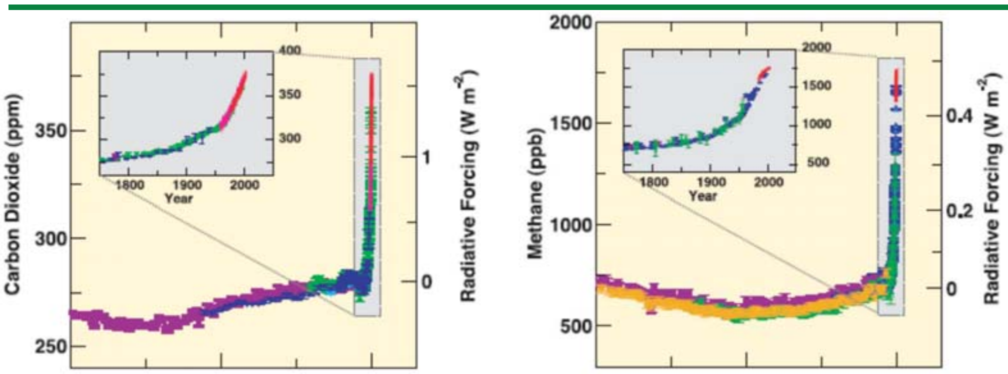


Working Group III Report **"Mitigation of Climate Change"**



The AR4 **Synthesis Report**

Change of Greenhouse Gas Emissions



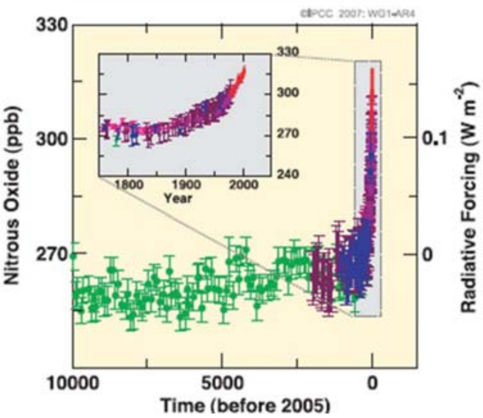


Fig. 1: *Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings are shown on the right hand axes of the large panels. {Figure 6.4}*

Fig. 1 (IPCC, 2007)

Change of Radiation

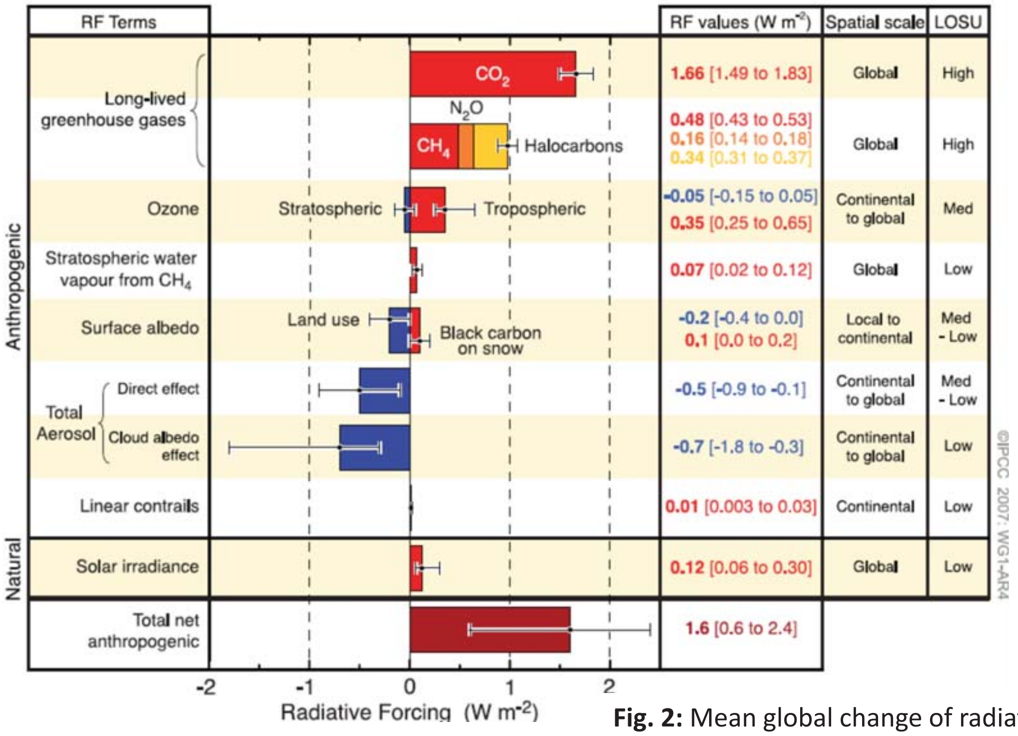


Fig. 2: Mean global change of radiative forcing caused by different factors (IPCC, 2007)

Directly Observed Changes

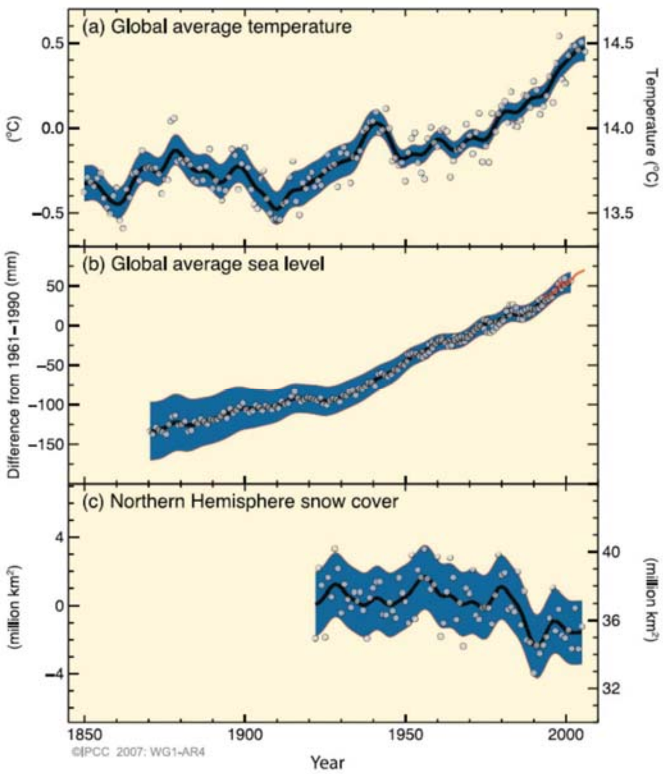


Fig. 3: Observed changes of global temperature, sea level and snow cover on the Northern hemisphere (IPCC, 2007)

Drivers of Change

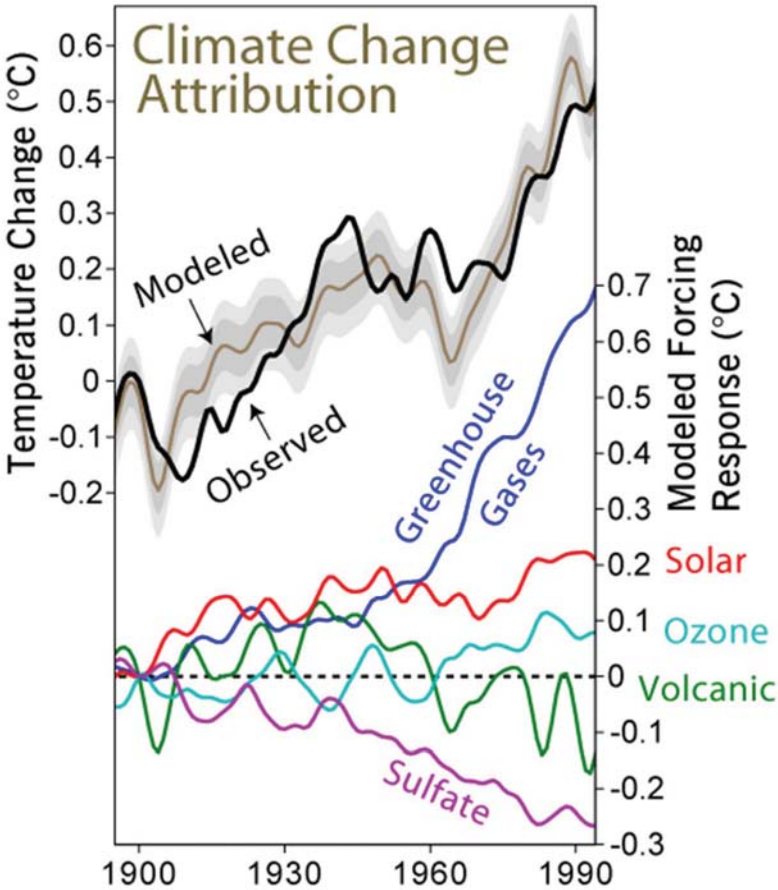


Fig. 4:

Provided by I. Cluckie

Paleoclimatic Analyses

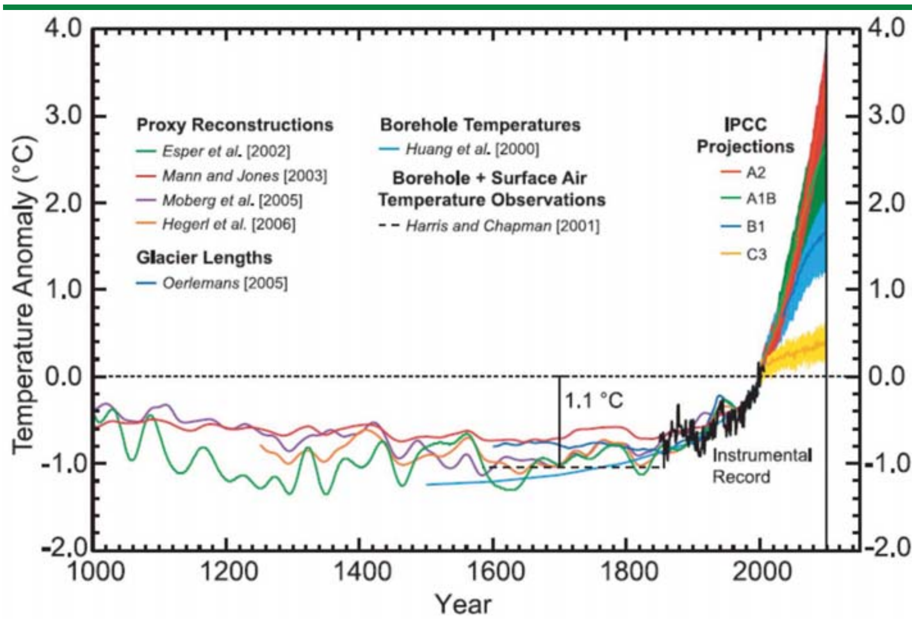


Fig. 5: *Views of temperature change in the next century are informed by temperature changes in the past. For illustrative and educational purposes, three sets of surface temperatures have been assembled: 1000-year reconstructions of past temperature change based on proxies (tree rings, corals, etc.), glacier lengths, and borehole temperatures; the instrumental record; and Intergovernmental Panel on Climate Change (IPCC) projections for temperature change from 2000 to 2100. Figure modified from* National Research Council *[2006] and* IPCC *[2007].*

Chapman, 2010

Expected Changes – More Hydrological Extremes!

Table 1: *Recent trends, assessment of human influence on the trend and projections for extreme weather events for which there is an observed late-20th century trend. {Tables 3.7, 3.8, 9.4; Sections 3.8, 5.5, 9.7, 11.2–11.9}*

(IPCC, 2007)

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend[b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[d]	*Virtually certain*[d]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[e]	*Likely (nights)*[d]	*Virtually certain*[d]
Warm spells/heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*[f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f,h]	*Likely*[i]

IPCC Emission scenarios

(IPCC, 2007)

- **A2**: Per-capita economic growth slower, continuing population growth
- **A1B**: Fast economic growth, decline of population in the middle of the 21st century, balanced use of energy sources
- **B1**: Global solutions for social, ecologic and economic sustainability, decline of population in the middle of the 21st century

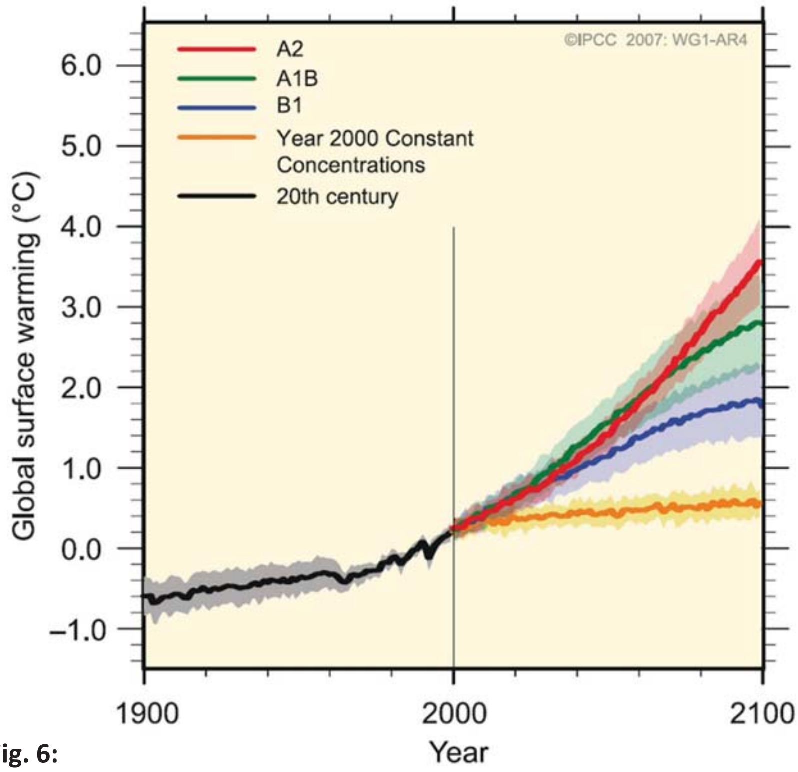


Fig. 6:

Regional Climate Projections

- Physical based climate modelling
  - Requires downscaling of global climate modelling results
  - Requires computation of impact models, e.g. hydrological models driven by the climate projection data
  - Uncertainty caused by a lack of knowledge about relevant processes, insufficient observation data, chaotic behaviour of the climate system.
- Statistical trend analyses
  - Analysis of trends within historical records, extrapolation of these trends into the future
  - Direct analysis of the desired variable (e.g. runoff) possible
  - Uncertainty caused by a lack of data (short time series), the inability of statistical methods to regard for changing processes, the chaotic behaviour of the climate system.

Regional Climate Projections

- Hydrological analyses need surface variables like precipitation and temperature in high spatial resolution.
- Global climate models: coarse resolution (100 to 200 km grid).
  - **Dynamical downscaling**: nested deterministic (physically based) modeling: global model drives regional model with 5 to 20 km grid.
  - **Statistical downscaling**: Projection of observed time series (from climate stations) into the future using statistical methods (relationship between global and local variables) or stochastic models dependent on global variables like large scale weather patterns.

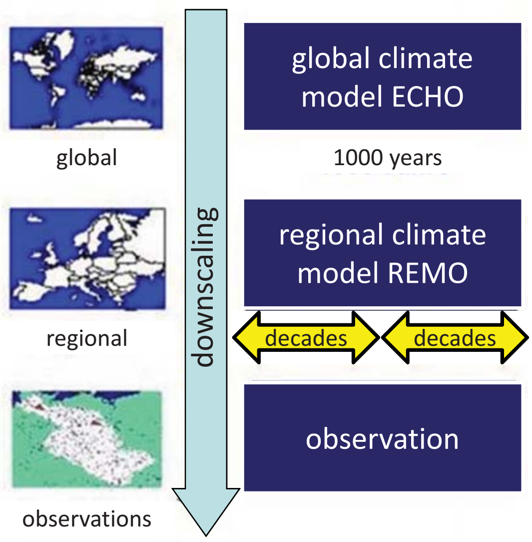


Fig. 7:

Regional Climate Projections

- Typical model scenarios:
  - Reanalysis run (driven by observation);
  - Control run (20^{th} century climate simulation);
  - Climate projection run (implementation of IPCC emission scenarios);
  - Control and projection: ensembles with different initial conditions!
- Examples (Central Europe):
  - Dynamic: REMO, CLM
  - Statistical: WETTREG, STAR
- Advantages and disadvantages of the downscaling methods:

	statistical downscaling	dynamic downscaling
+	regional precipitation characteristics	conservation of mass and energy, unobserved areas
-	observations required, extrapolation uncertain	high computational demand

Modeling of Feedbacks

- Feedbacks between components of the climate system: atmosphere, hydrosphere, cryosphere, lithosphere, biosphere.
- With a separate simulation (loose coupling) of the sub-systems one cannot simulate feedbacks.
- Researchers are developing dynamically coupled models, but it is open if we will get a “world model” in the near future.
- Examples for feedbacks:
  - temperature ↑, evaporation ↑, more water vapour, counter-radiation ↑, temperature ↑ [positive feedback]
  - temperature ↑, evaporation ↑, more clouds, global radiation ↓, temperature ↓ [negative feedback]
  - temperature ↑, ice and snow melts, albedo ↓, temperature ↑, [positive feedback]

Uncertainty

Table 2: Selected sources of uncertainty in the computation of climate projections (changed from Krahe, 2009)

No	Source	Cause	Solution
1	Internal climate variability	Deterministic-chaotic behaviour of the climate system, initial conditions	Several realizations of GCM, RCM
2	Emission scenario (SRES)	Uncertainty about future greenhouse gas emissions	Several alternative scenarios
3	Global climate model (GCM)	Different model approaches, sub-scale processes, incomplete knowledge	Ensemble of several GCM
4	Regional climate model (RCM)/Statistical downscaling	Like 3	Combination of several methods
5	Impact models (hydrology, hydraulics etc.)	Like 3	Combination of several models

Uncertainty of Trends (1)

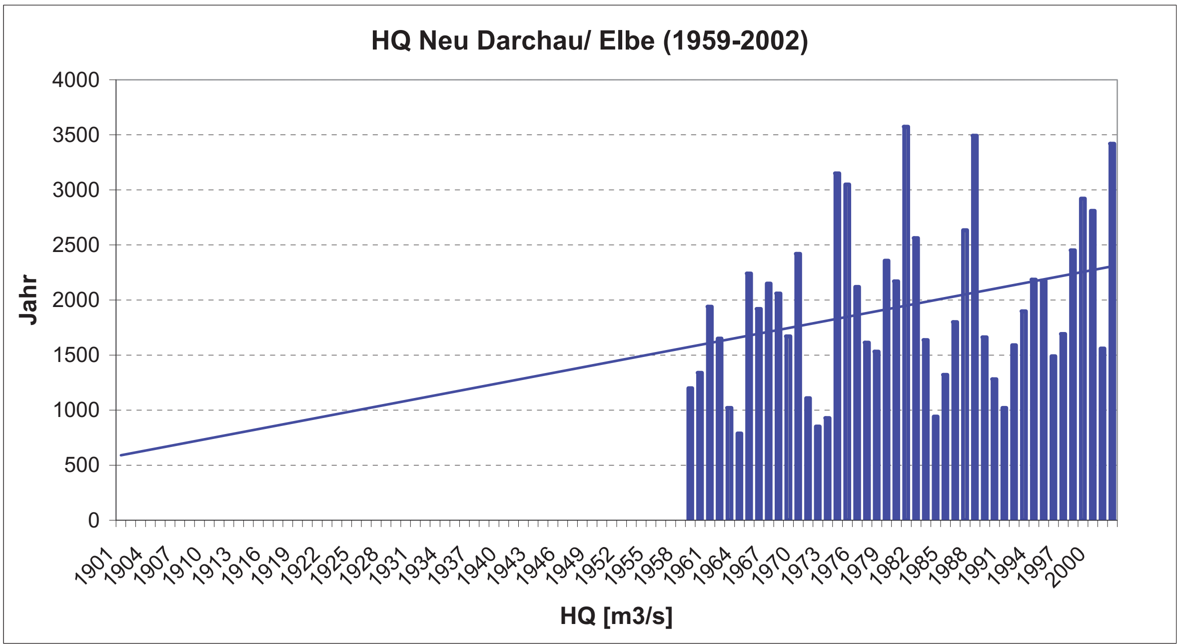


Fig 8: Uncertainty of trend estimation (sub period a)

Uncertainty of Trends (2)

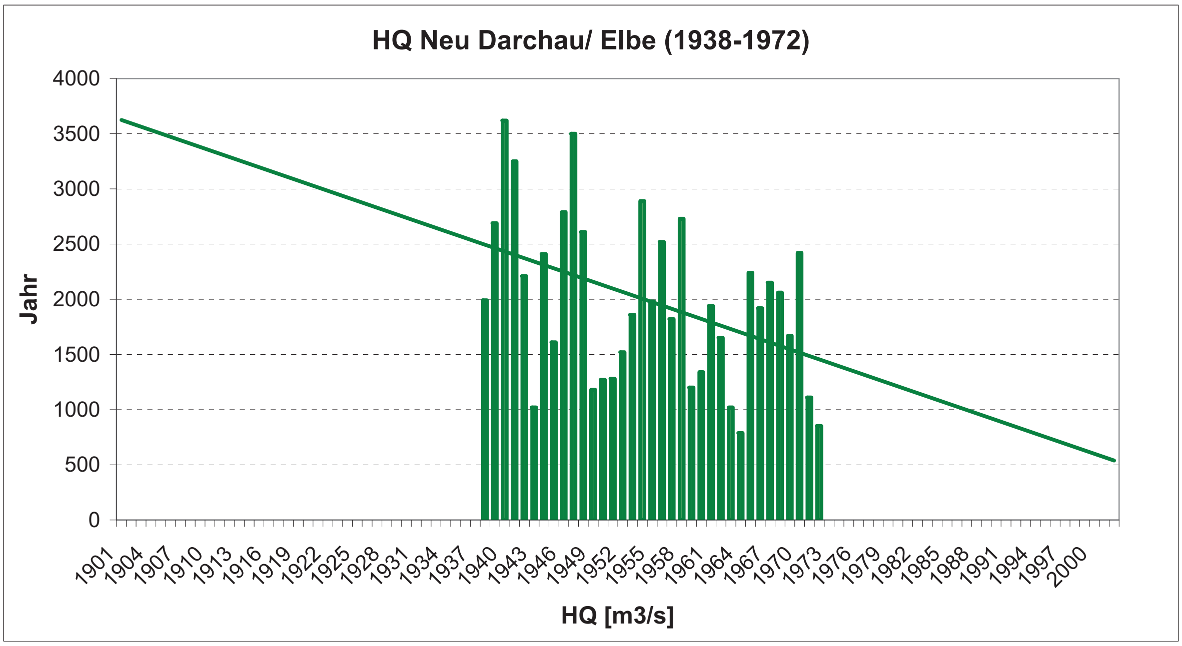


Fig 9: Uncertainty of trend estimation (sub period a)

Uncertainty of Trends (3)

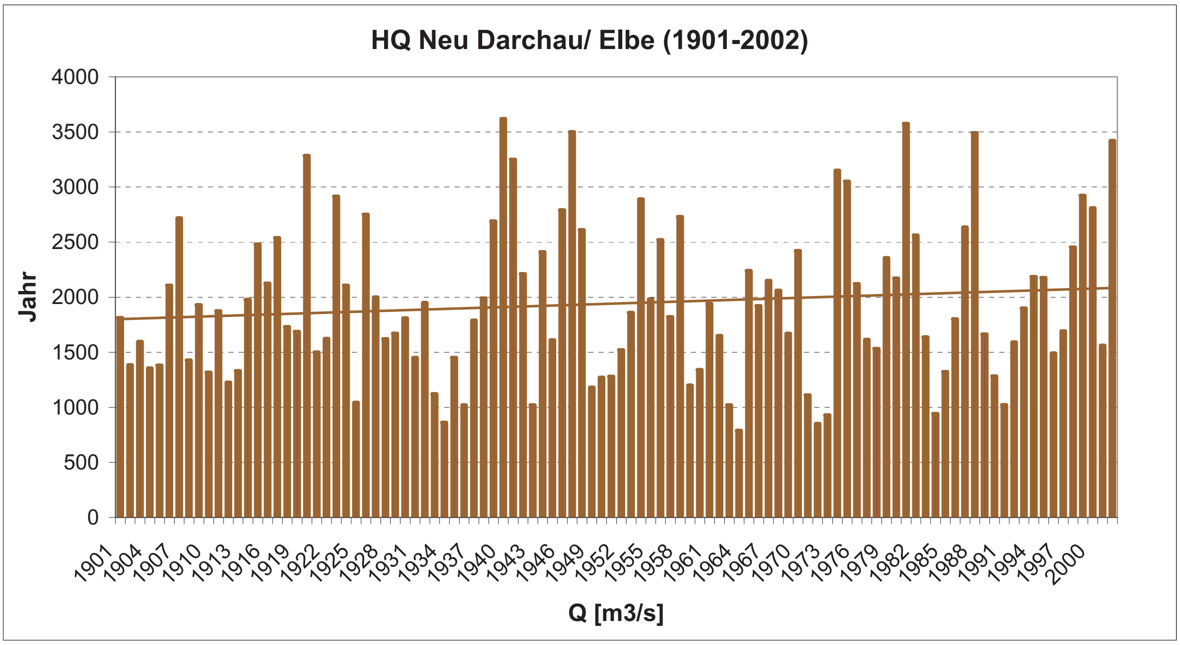


Fig 10: Uncertainty of trend estimation (complete time series)

2 Impact of Global Change on Water Resources

Grimma (Mulde), 2002-08-13. Source: dpa

Small river in the middle mountains 2003

IHP 7th Phase „Water Dependencies“ – Activities

- The development of monitoring networks and databases for change analysis
- Methods for change detection, attribution and prediction
- Prediction of changes in and vulnerability of groundwater, floods, low flows and droughts
- Prediction of groundwater quality degradation and restoration
- Assessment of snow, ice and glacier mass balances
- Assessment of the impact on sediment transport
- Integrated water management for adaptation to global change risk
- Policy-related interventions for adaptation

UNESCO IHP, 2011

Data Analysis: Change in runoff already observed?

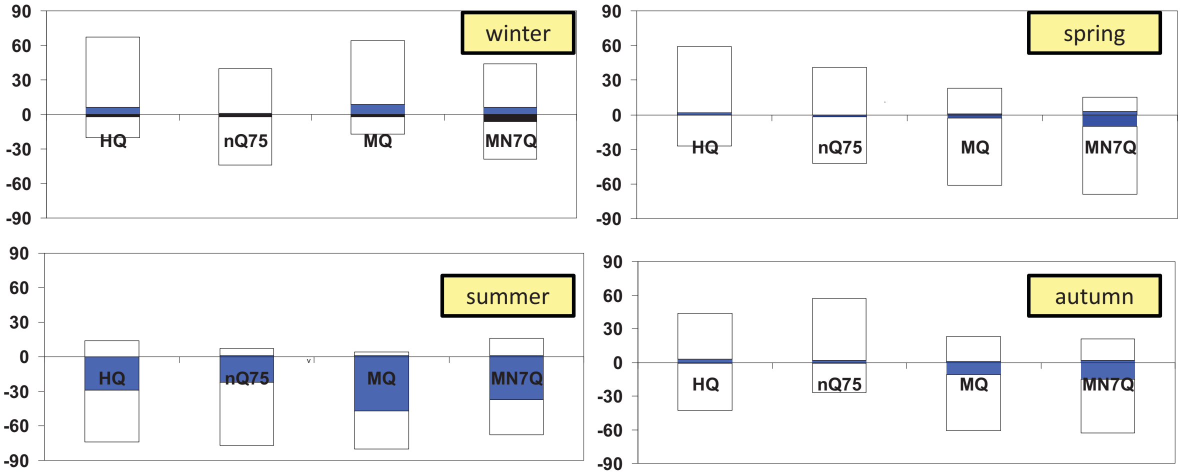


Fig. 11:

Number of gauging stations showing trends in Lower Saxony; period 1966-2005, 88 stations, daily values, (Mann-Kendall, blue significant, α = 0.05)

Observed Trends for Central Europe

- More extreme events e.g. heavy rainfall observed -> expected?
  - More local flash floods -> decentralized flood protection more efficient?

Statements about future extreme events are very uncertain! (Bronstert et al. 2007)

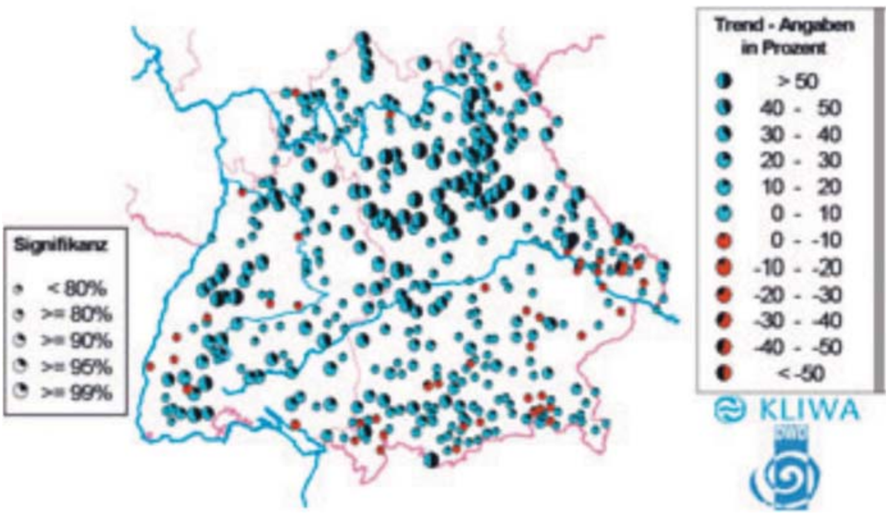


Fig. 12: Observation: heavy rainfall events of 24 h duration in the winter season for the period 1931–2000.

(Hennegriff et al. 2006)

Hydrological Scenarios

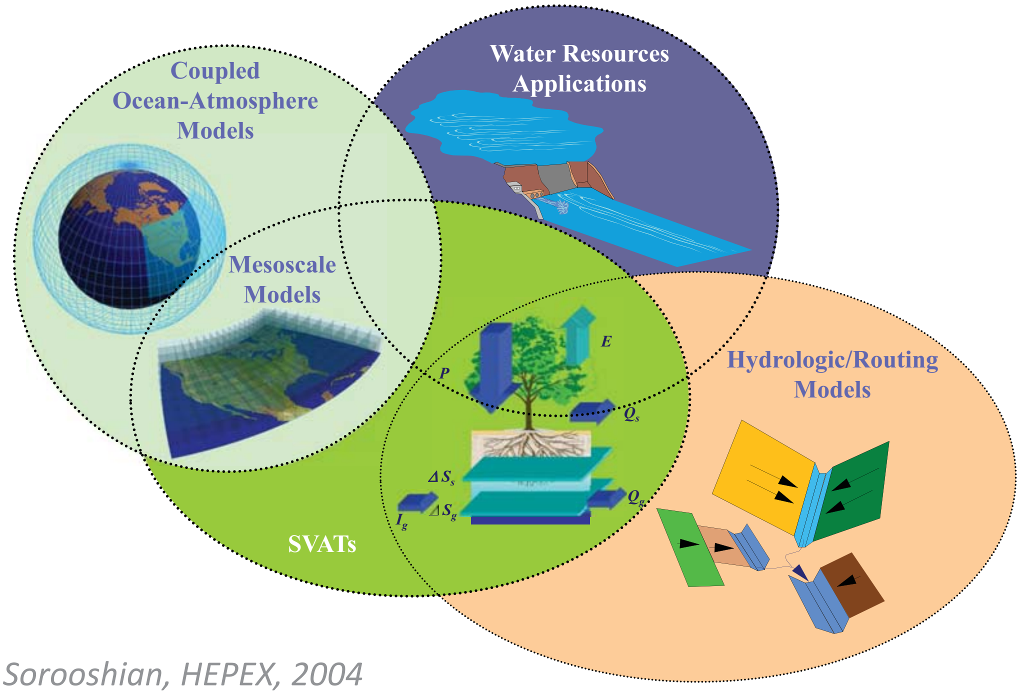


Fig. 13: *Sorooshian, HEPEX, 2004*

Hydrological Ensemble Prediction Experiment (provided by I. Cluckie)

Impact Model Chains / Cascades

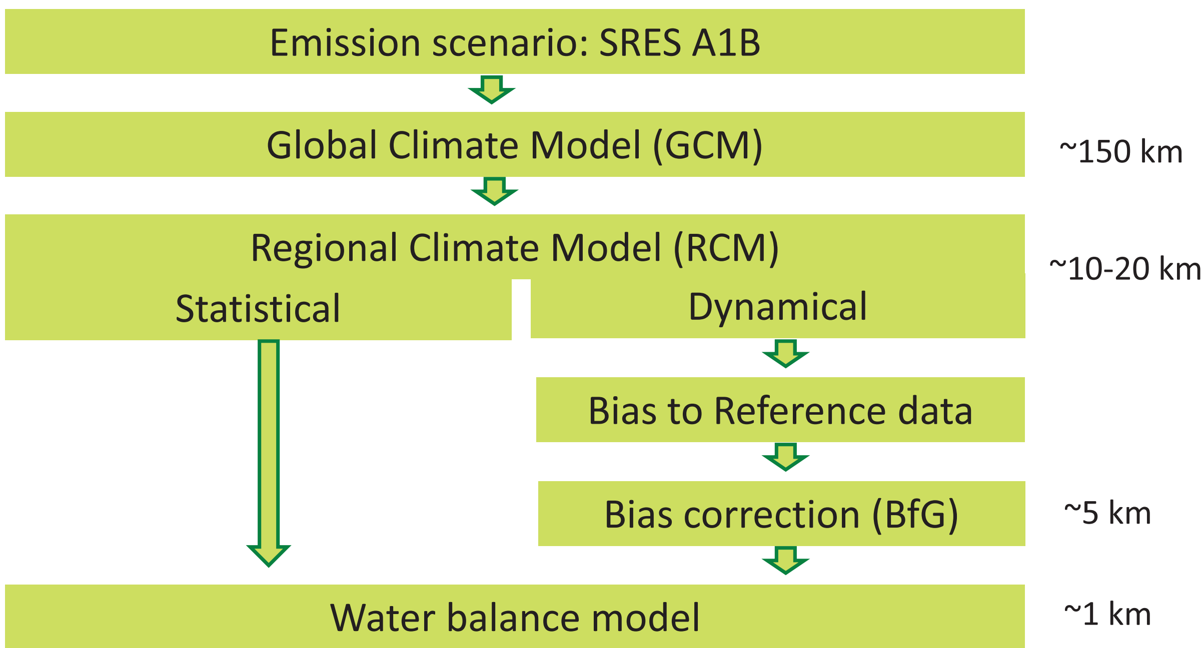


Fig. 14: *Provided by Willems, changed*

Problem of Climate Projections: Bias

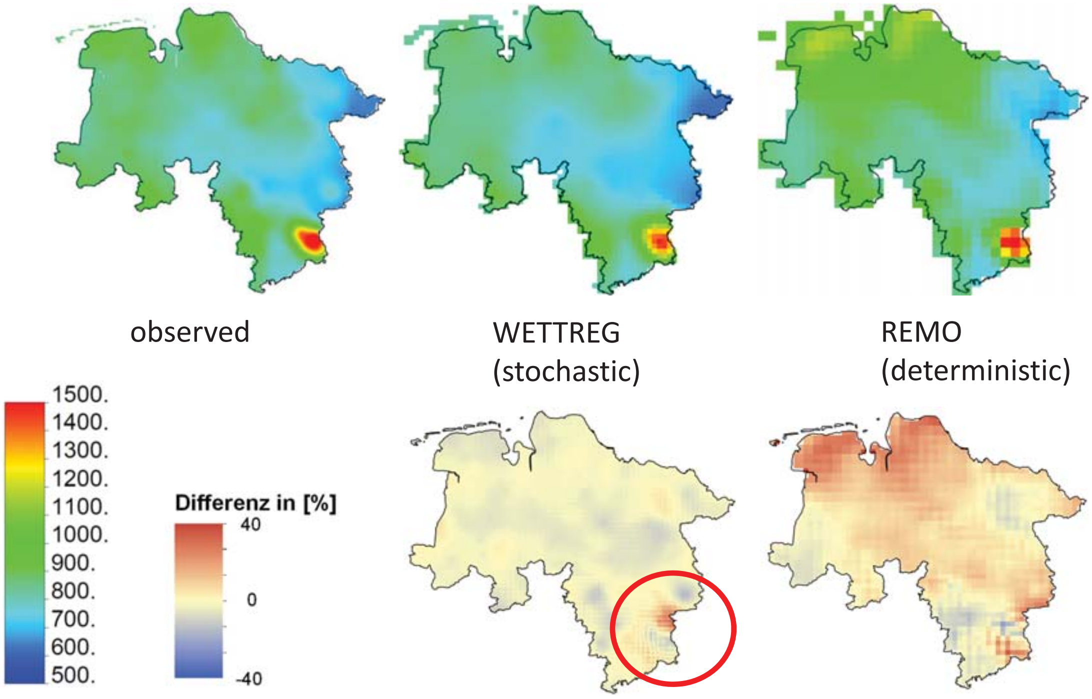


Fig. 15: Mean annual precipitation by control runs of two climate models 1961-2000 (interpolated)

Bias of climate projections

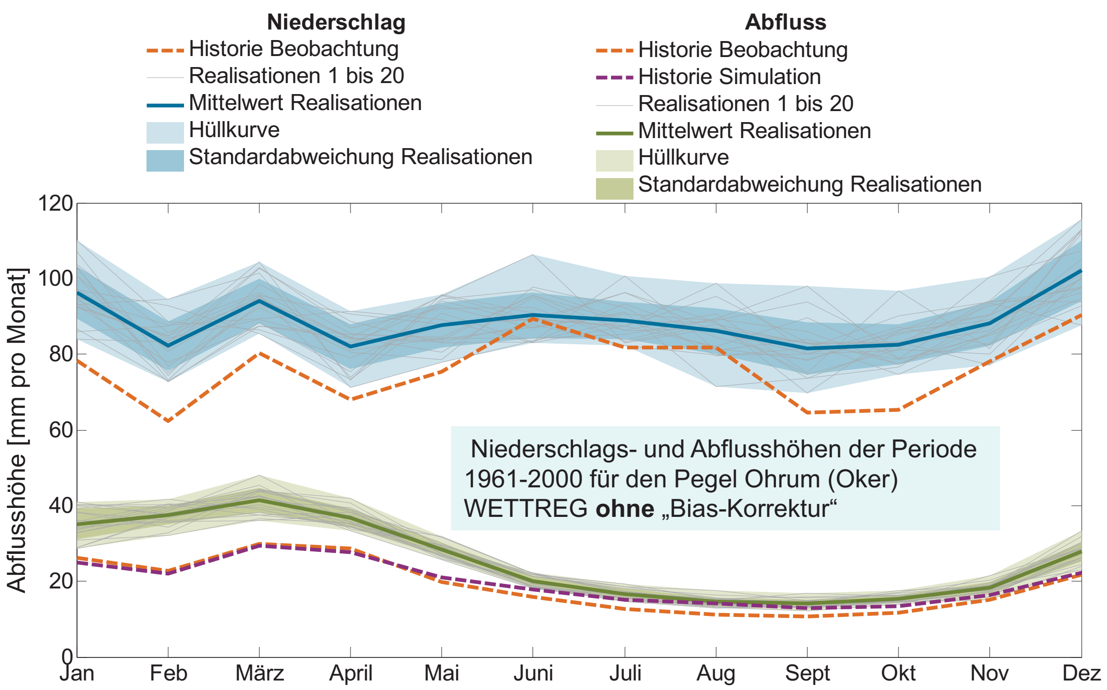


Fig. 16:

KLIFF/KliBiW : LU Hannover (climate data), TU Braunschweig (hydrology)

Bias of climate projections

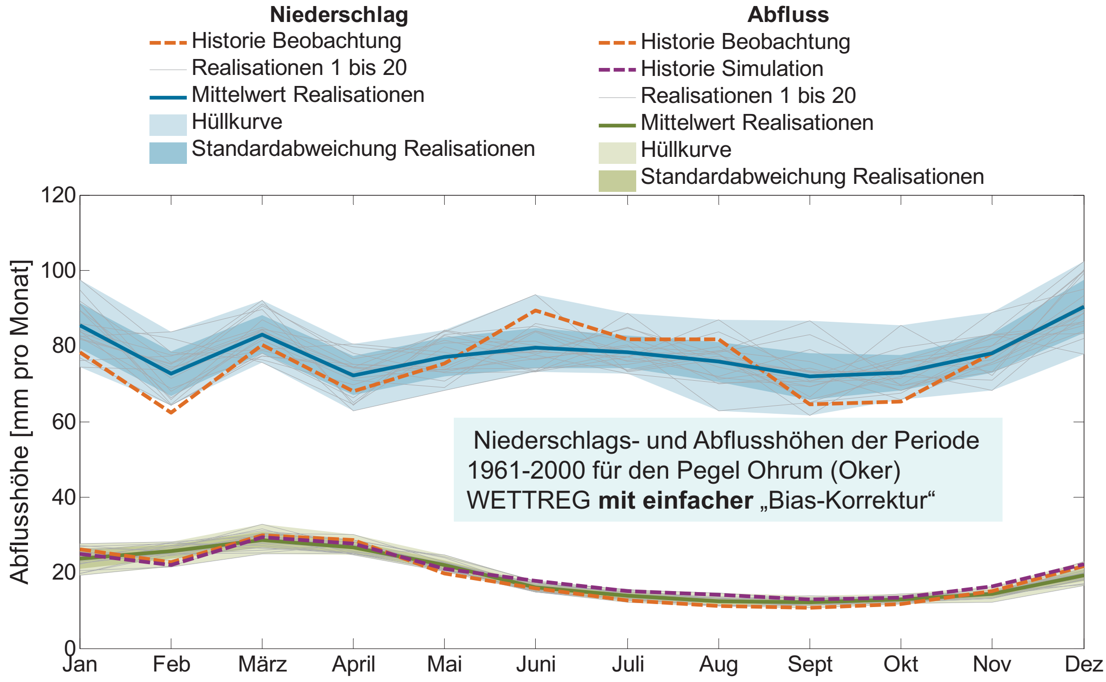


Fig. 17: *KLIFF/KliBiW Zwischenergebnis (unveröff.), Bearbeitung: LU Hannover (Klimadaten), TU Braunschweig (Wasserhaushalt)*

Possible Solutions

- Bias-correction of climate data
  - Simple approach: sub-basin correction factor, better: quantiles/seasons/regions
- Improvement of deterministic climate models
  - Pilot study Harz: non-hydrostatic REMO with 1km grid
  - Orography, snow accumulation/melt, convection
- Re-calibration of hydrological models
  - Flood simulations with 1h resolution – high rainfall intensities surprisingly good represented by REMO control period
- High resolution stochastic models
  - Sample size of climate projection too small for (rare) extreme events („only" 50 yrs past and 100 yrs future)

Uncertain Future: Winter

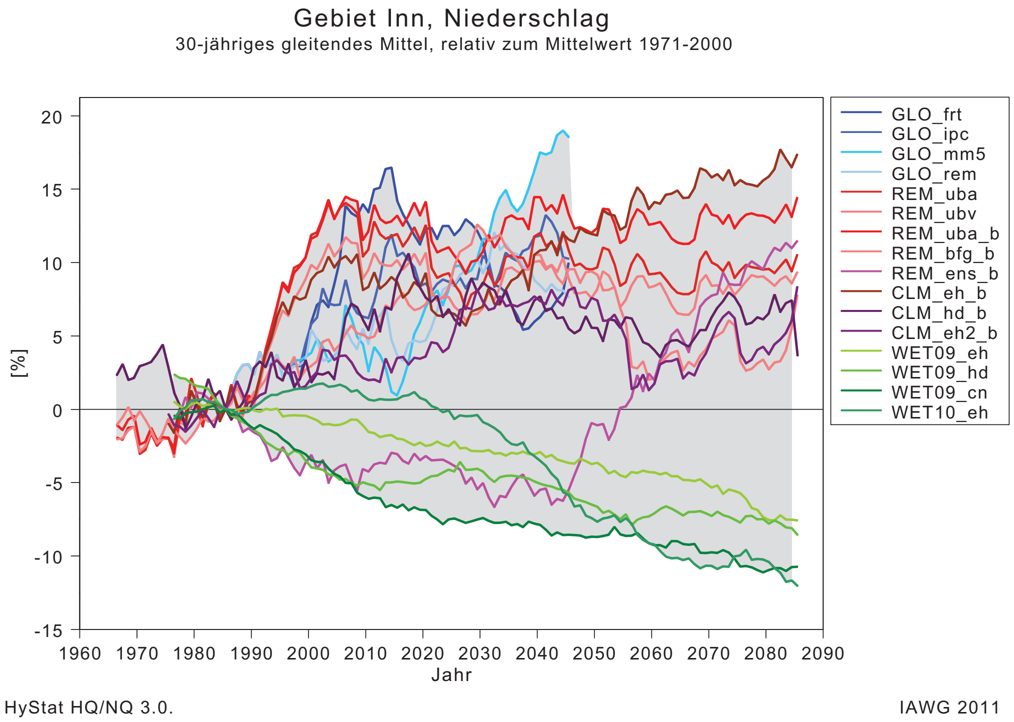


Fig. 17: *Provided by Willems, changed*

Uncertain Future: Summer

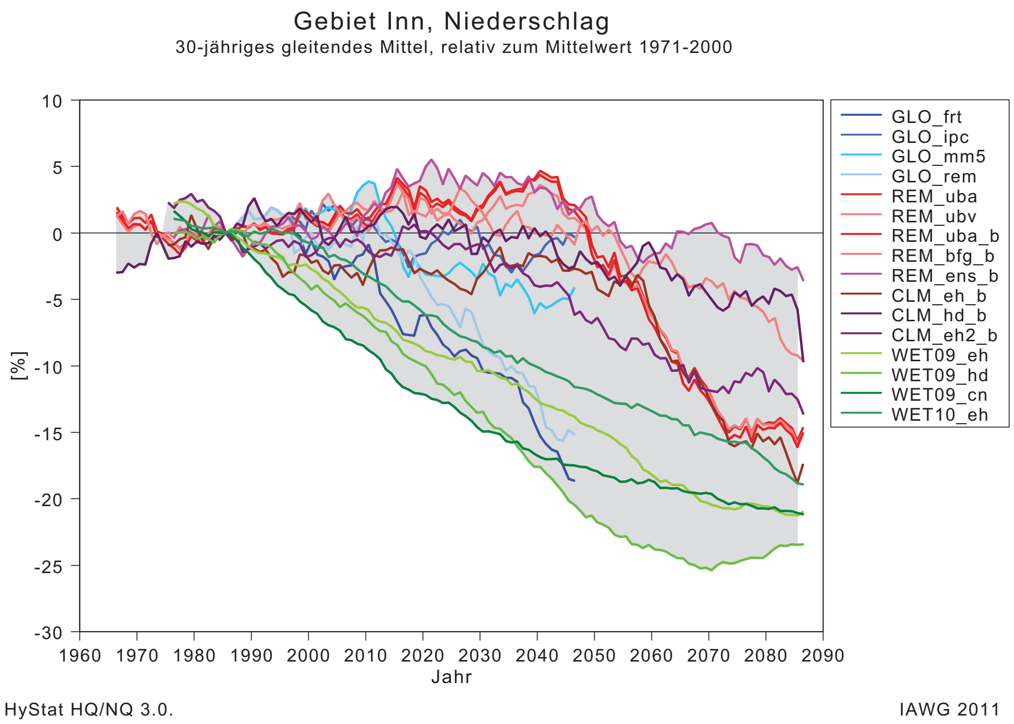


Fig. 18: *Provided by Willems, changed*

Expected Runoff Trends for Central Europe

- Seasonal shift in precipitation
  - Summer precipitation similar or slightly decreasing, about 10 % change;
  - Winter precipitation significantly increasing, up to more than 40 %.

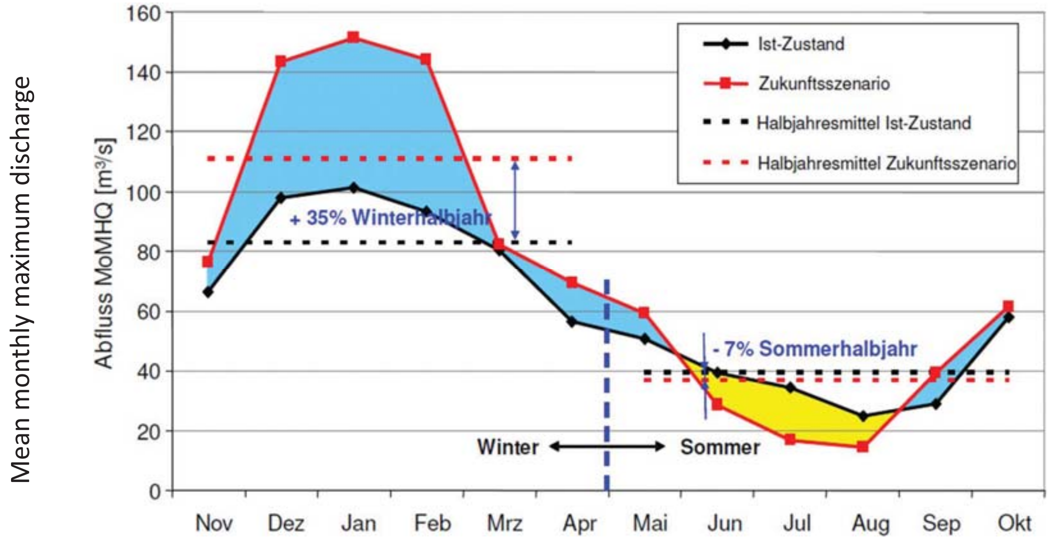


Fig. 19: Example Kinzig river (Schwarzwald, Germany), from Hennegriff & Reich (2007)

Floods: Need of high Resolution!

- Partial series of hourly precipitation for selected stations (REMO)
- High uncertainty of flood simulations in small catchments
- Extremes cannot be matched well
- Physics of the climate models does not cover convective thunder storms

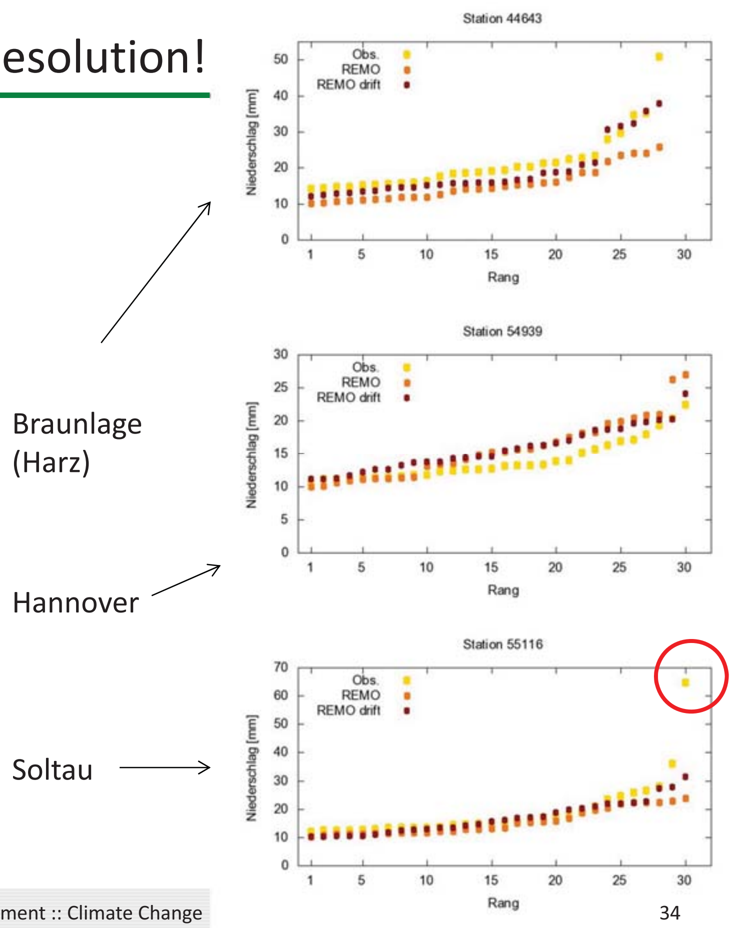


Fig. 20:

3 Adaptation of Water Resources Management (Examples)

Adaptation ex.: Climate Factors for Design Floods (1)

- Correction of design floods by application of a "climate factor".
- Procedure (KLIWA project, application in Baden-Württemberg/Germany):
  - Regional climate projections as drivers for:
  - Water balance models which:
  - Simulate scenarios of future runoff;
  - Extreme value statistics;
  - Comparison of status quo with projections of the future;
  - Definition of climate factors for recurrence intervals T_n of runoff.
- Discussion:
  - Practical approach, which can be implemented at local scale (flood protection planning).
  - Still high uncertainty, which is not reflected (better: ensembles, probabilistic appraoches, complete risk analysis).

Adaptation ex.: Climate Factors for Design Floods (2)

- $HQ_{Tn,K} = f_{T,K} * HQ_{Tn}$
  - $HQ_{Tn,K}$: runoff (with climate change correction)
  - $f_{T,K}$: climate factor
  - HQ_{Tn}: runoff (status quo) from modelling or regionalization

Table 3:

T [a]	Klimaänderungsfaktoren $f_{T,K}$				
	1	2	3	4	5
2	1,25	1,50	1,75	1,50	1,75
5	1,24	1,45	1,65	1,45	1,67
10	1,23	1,40	1,55	1,43	1,60
20	1,21	1,33	1,42	1,40	1,50
50	1,18	1,23	1,25	1,31	1,35
100	1,15	1,15	1,15	1,25	1,25
200	1,12	1,08	1,07	1,18	1,15
500	1,06	1,03	1,00	1,08	1,05
1 000*)	1,00	1,00	1,00	1,00	1,00

*) For return periods above T>1000 a the factor is 1,00

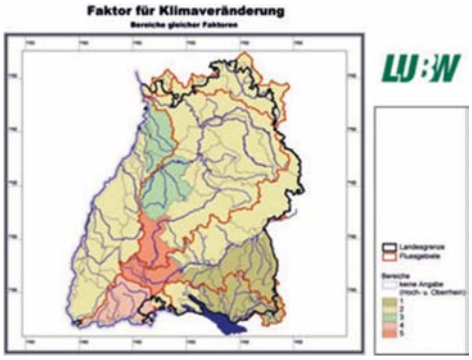


Fig. 21: Hennegriff et al. 2006

Tackling Uncertainty

- Ensemble simulations
  - Bandwidth of uncertainty by combination of different global and/or regional models, different emission scenarios etc.
- Adequate interpretation of model results
  - Climate projections do not allow a forecast for a single point at the time axis, they are designed to reproduce trends of long-term mean values.
  - Systematic errors of the model chain can be corrected if recognized (bias correction or other model output statistics).
- Adaptive planning processes
  - dynamic improvement of climate models and correction methods
  - continuous extension of observation time series
    -> learning process
  - iterations: re-compute model chain when new data or better sub-models are available

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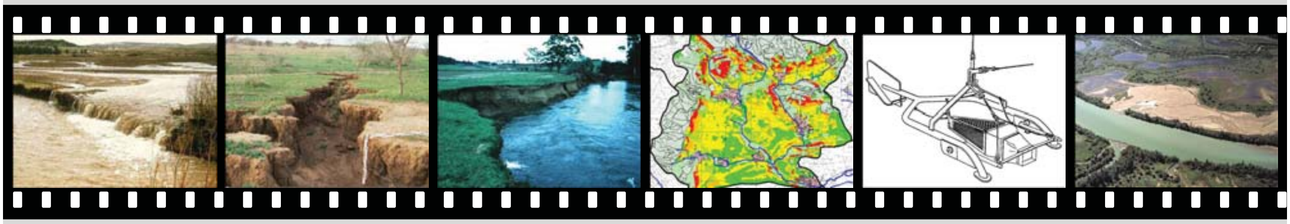
Thank you for your attention!

Global Change

Contacts: Jörg Dietrich
dietrich@iww.uni-hannover.de, Tel. 762-2309

Matthias Beyer
beyer@iww.uni-hannover.de, Tel. 762-5378



Institute for Water Resources Management, Hydrology and Agricultural Hydraulic Engineering, Appelstr. 9A, 7th floor

Leibniz Universität Hannover