ECMWF Workshop on Atmospheric Reanalysis

Status and needs for reanalysis: Land-Surface Processes

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Outline

Introduction and motivation

Large-scale observations of terrestrial water storage variations

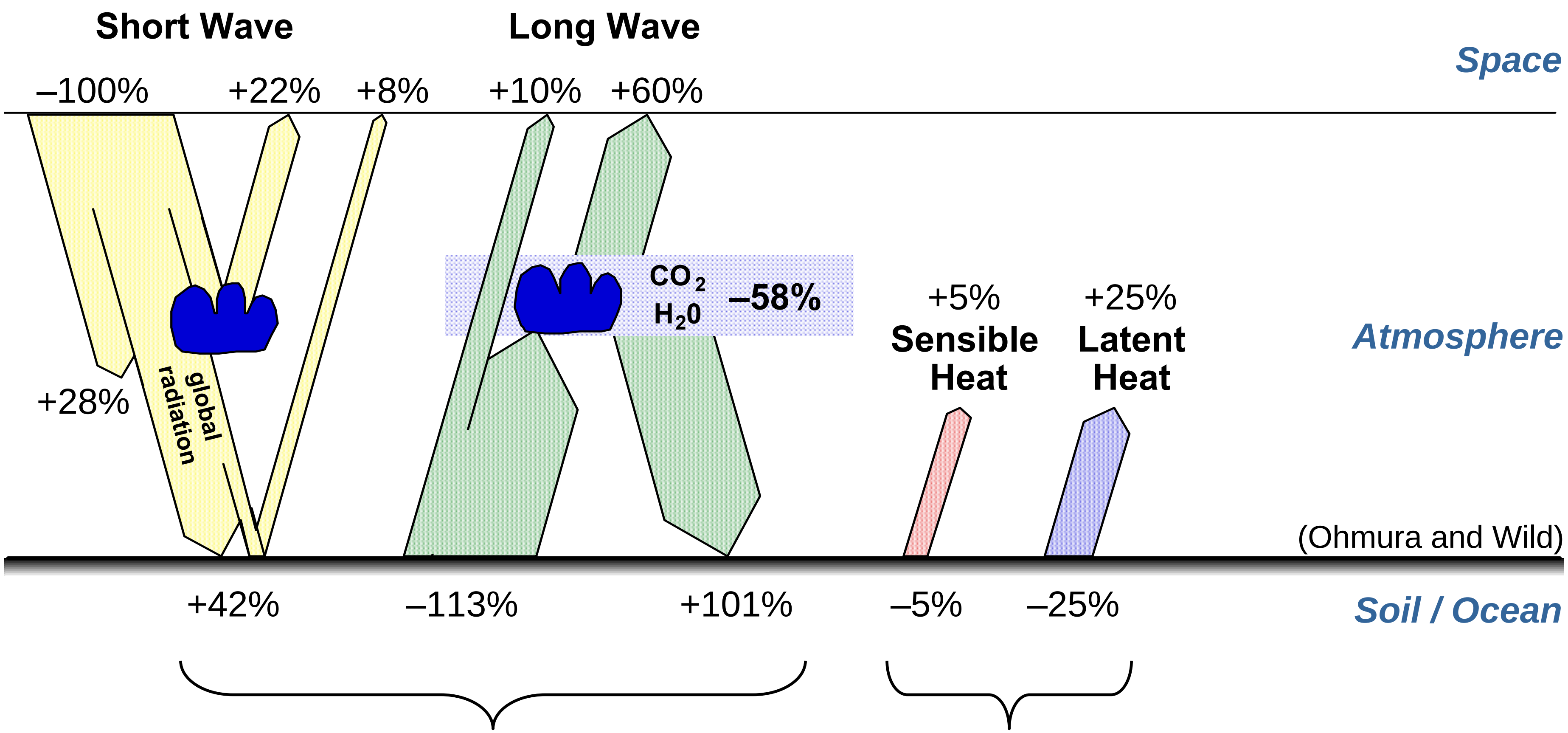
Sensitivity experiments of the European summer 2003

Role of terrestrial water storage for interannual variability

Homogeneity of assimilation products

Outlook

Global Energy Balance



Global mean

Net radiation R_{net} = 30% of solar input

More than 80% of R_{net} is converted into *ET* rather than *heating!*

European Summer: $R_{net} \approx 120\ W/m^2$

$ET \approx 3$ **mm/d** $\approx 85\ W/m^2 \approx 70\%$ **of** R_{net}

Land-Atmosphere Coupling Strength

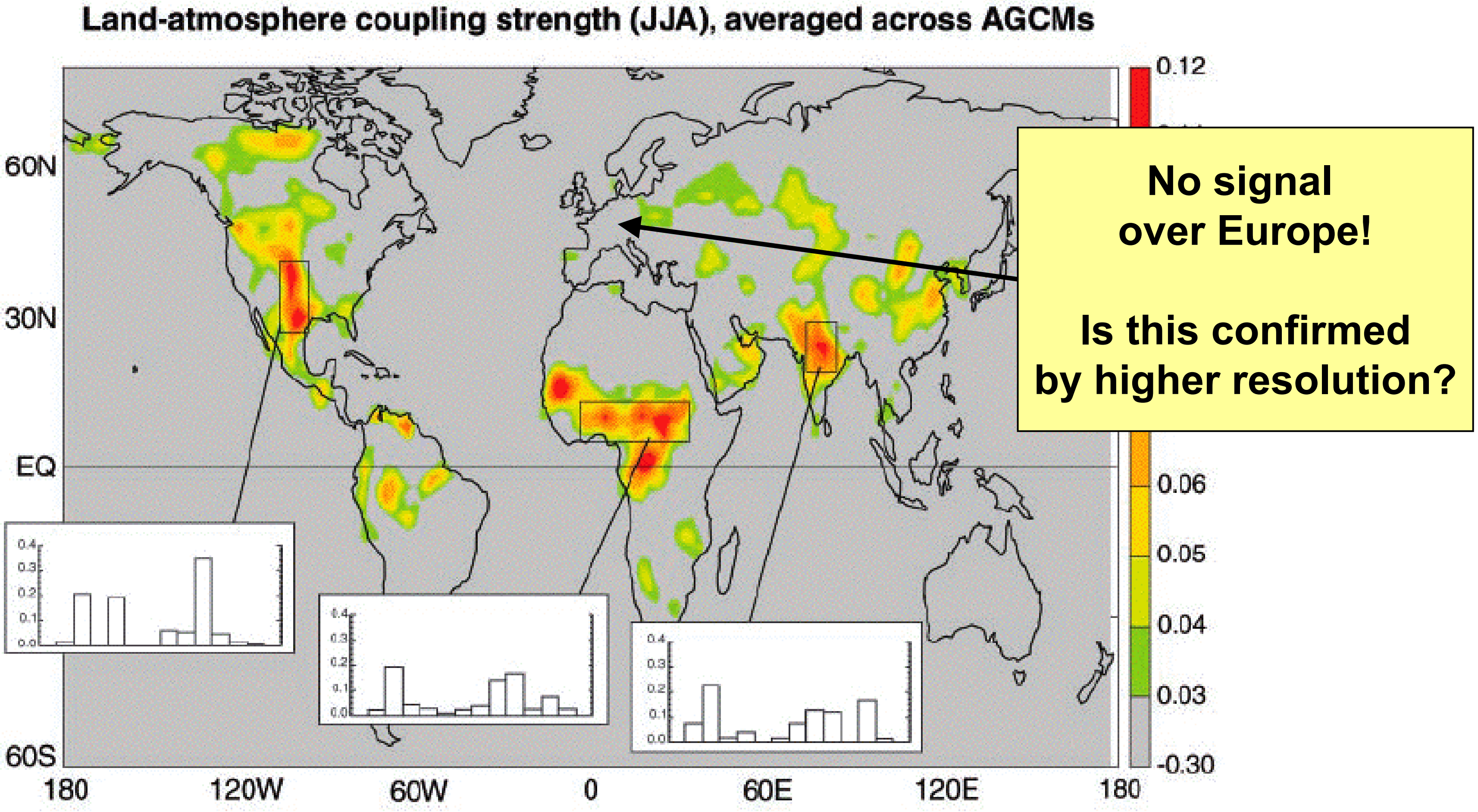


Fig. 1. The land-atmosphere coupling strength diagnostic for boreal summer (the Ω difference, dimensionless, describing the impact of soil moisture on precipitation), averaged across the 12 models participating in GLACE. **(Insets)** Areally averaged coupling strengths for the 12 individual models over the outlined, representative hotspot regions. No signal appears in southern South America or at the southern tip of Africa.

(Koster et al. 2004)

Extreme Summers: 2002 … 2003 … 2005 …

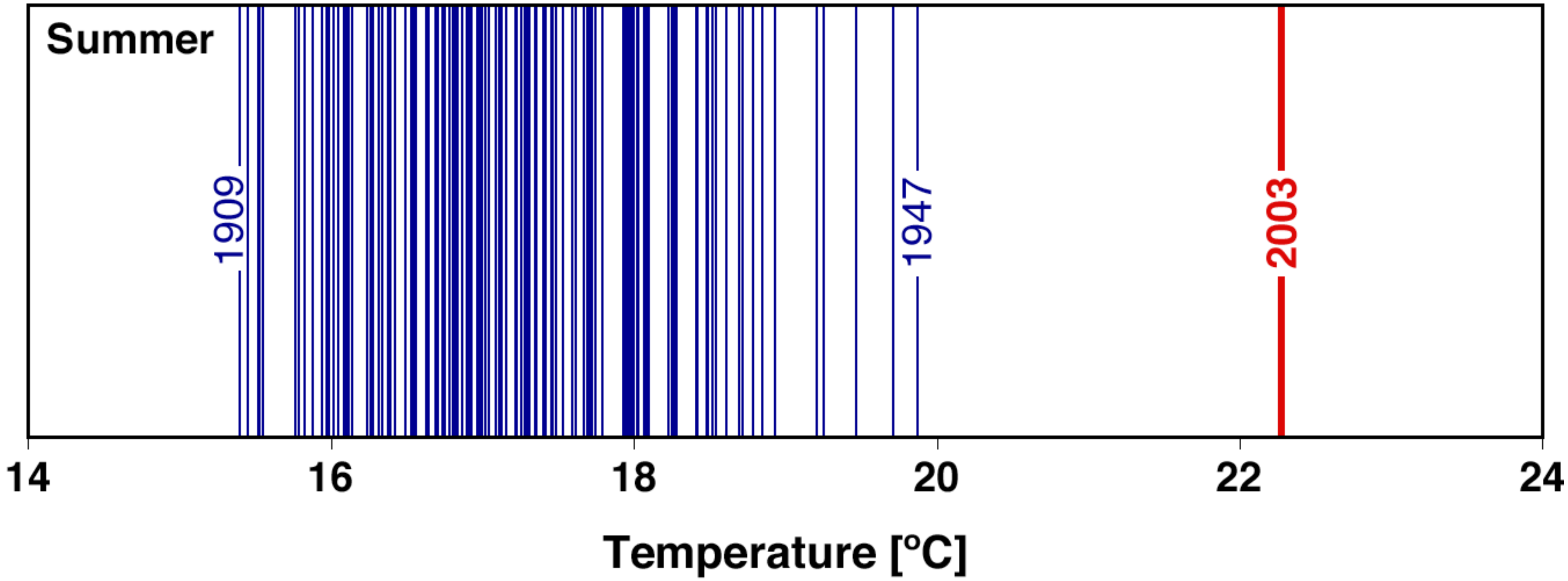
August 2002, Dresden, D

August 2003, Töss, CH

August 2005, Brienz, CH

Swiss Temperature Series 1864-2003

Average of 4 Stations: Zürich, Basel, Berne, Geneva



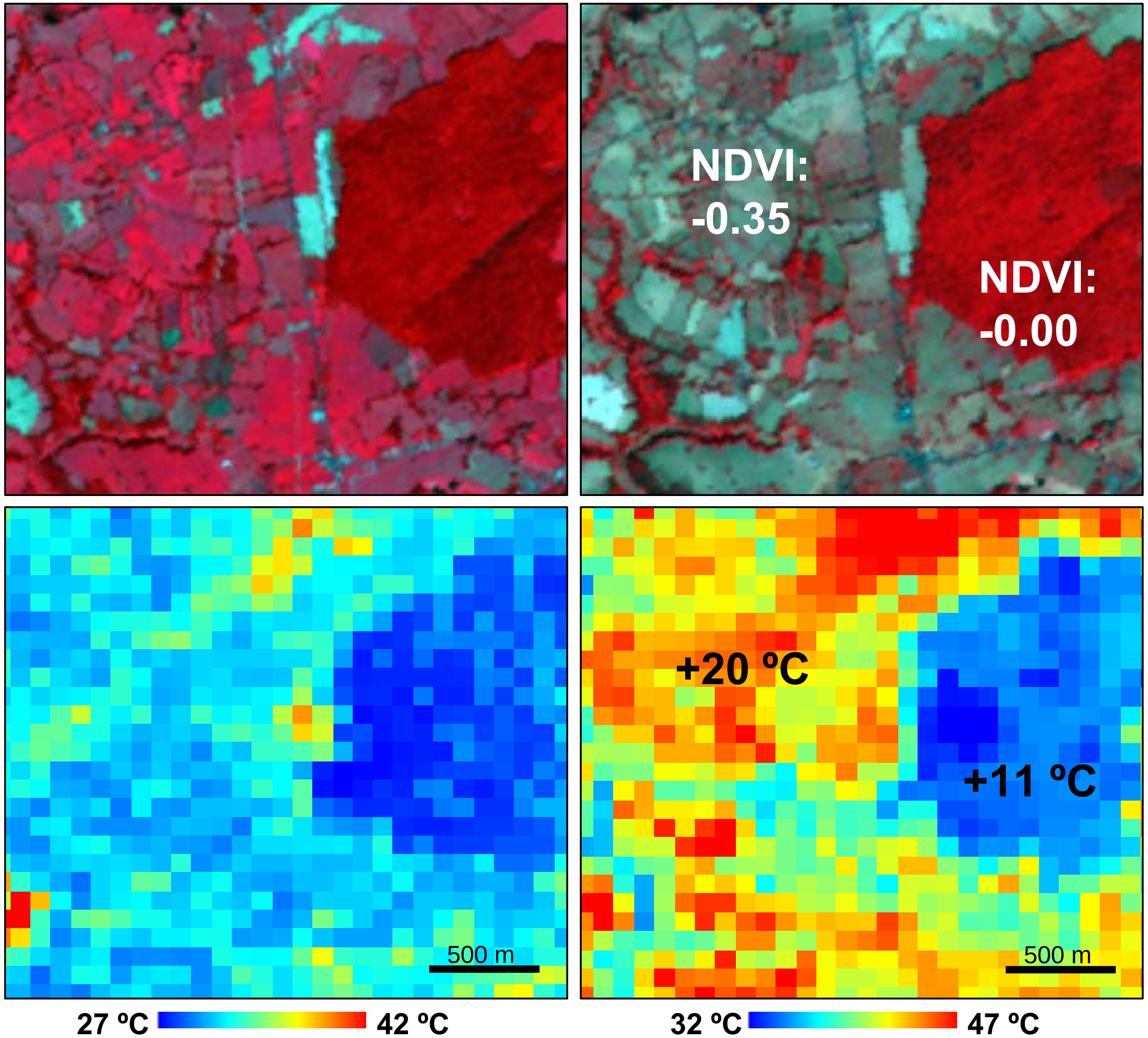
(Schär et al. 2004, *Nature*, **427**, 332-336)

High-resolution temperature analysis

August 1, 2000 | **August 10, 2003**

NDVI: active vegetation

IR: skin temperature

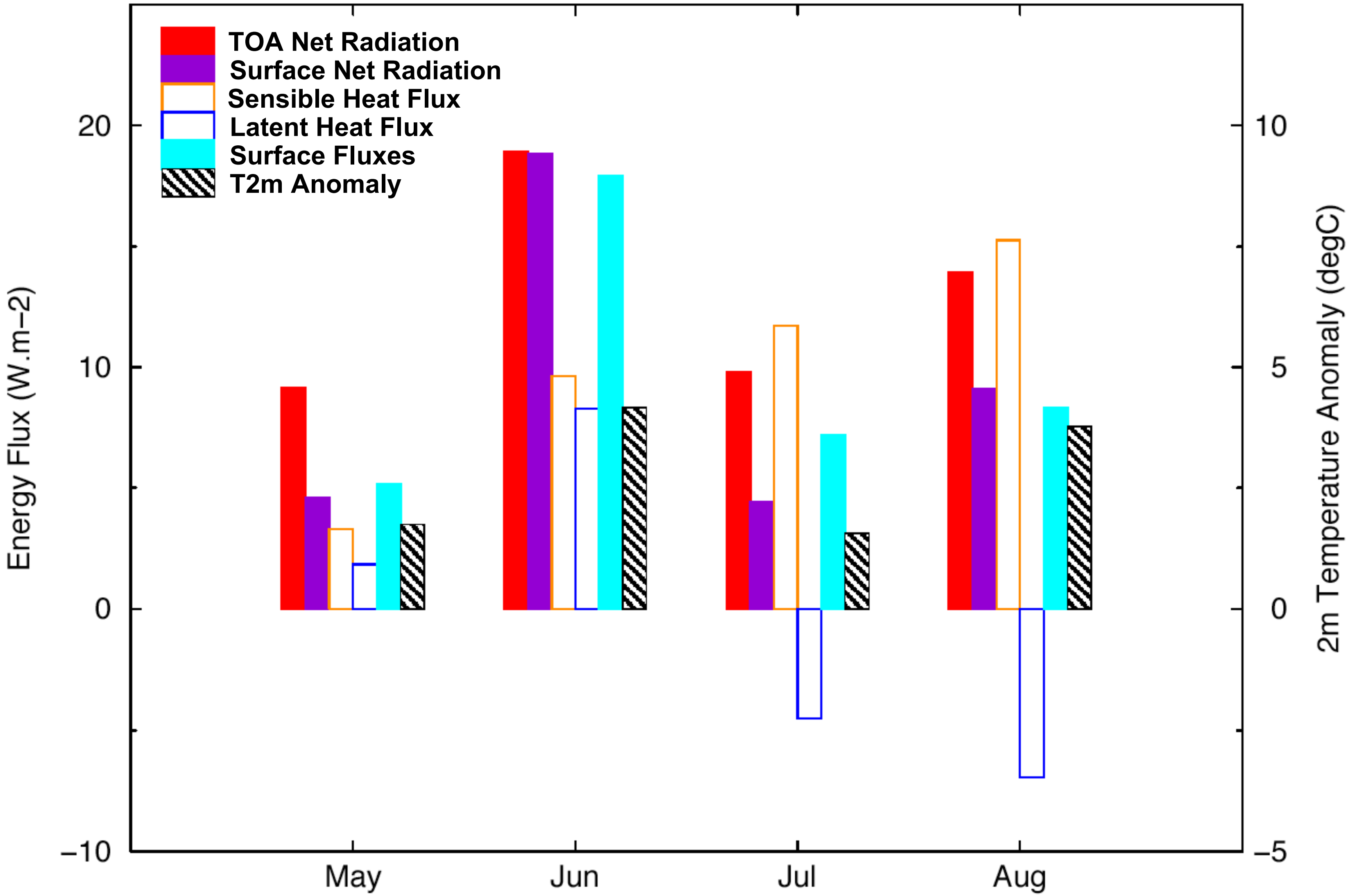


Aster Satellite (NASA/Japan)

5x5 km view in Central France

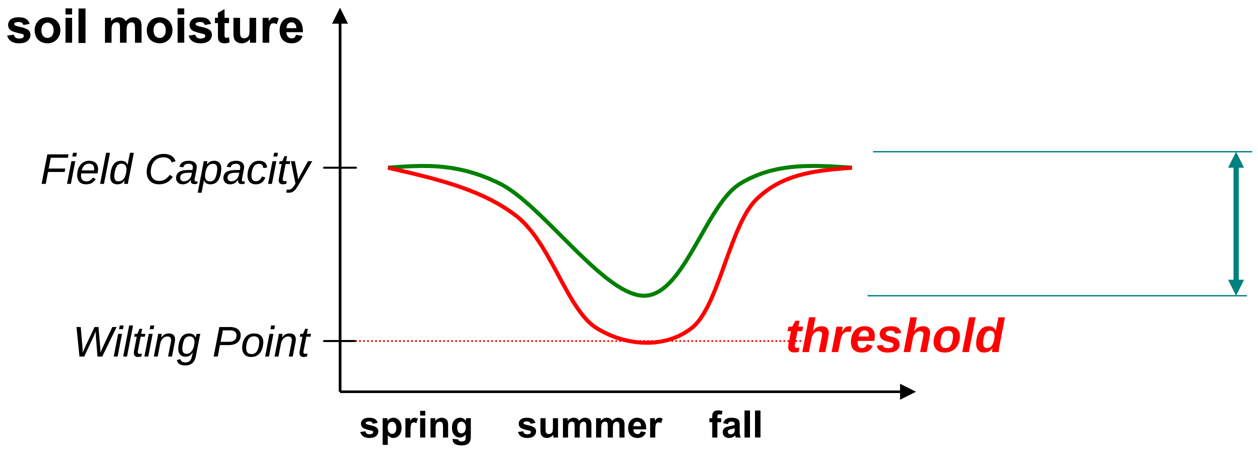
(Zaitchik et al. 2006)

Energy Flux Anomalies, Summer 2003, Europe



(Black et al. , 2004; based on ECMWF data)

Soil-moisture threshold effect



Δ ~ 150 mm

latent cooling corresponds to ~45 W/m^2 (3 months)

Key issues

What is the role of continental-scale soil-moisture variations for
- **interannual climate variability?**
- **extreme summers such as the European summer 2003?**

Is there any evidence of the soil-moisture threshold effect?

What is the amplitude of TWS (terrestrial water storage) in terms of
- **seasonal cycle?**
- **interannual variations?**

How can we exploit reanalysis data such as ERA-40 for surface hydrology? Are the data homogeneous?

Outline

Introduction and motivation

Large-scale observations of terrestrial water storage variations
- Water-Balance Approach
- GRACE Satellite
- Land-surface data assimilation

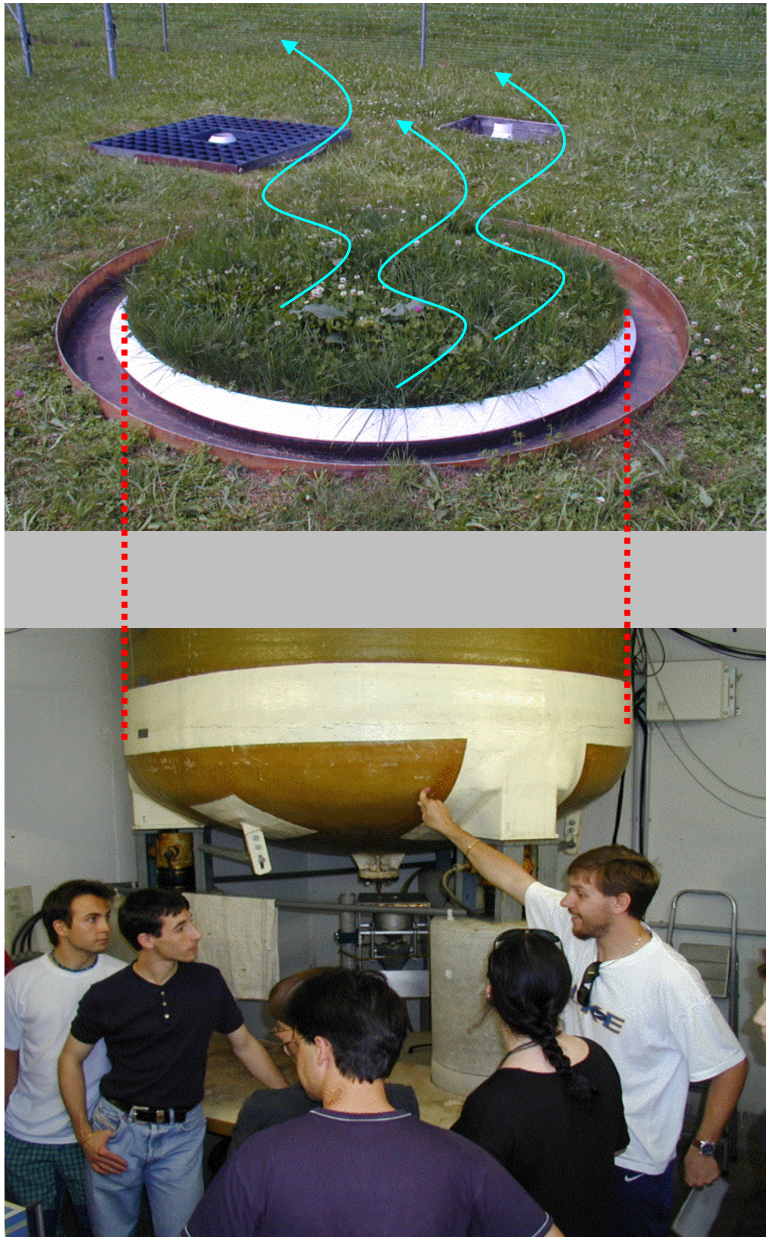
Sensitivity experiments of the European summer 2003

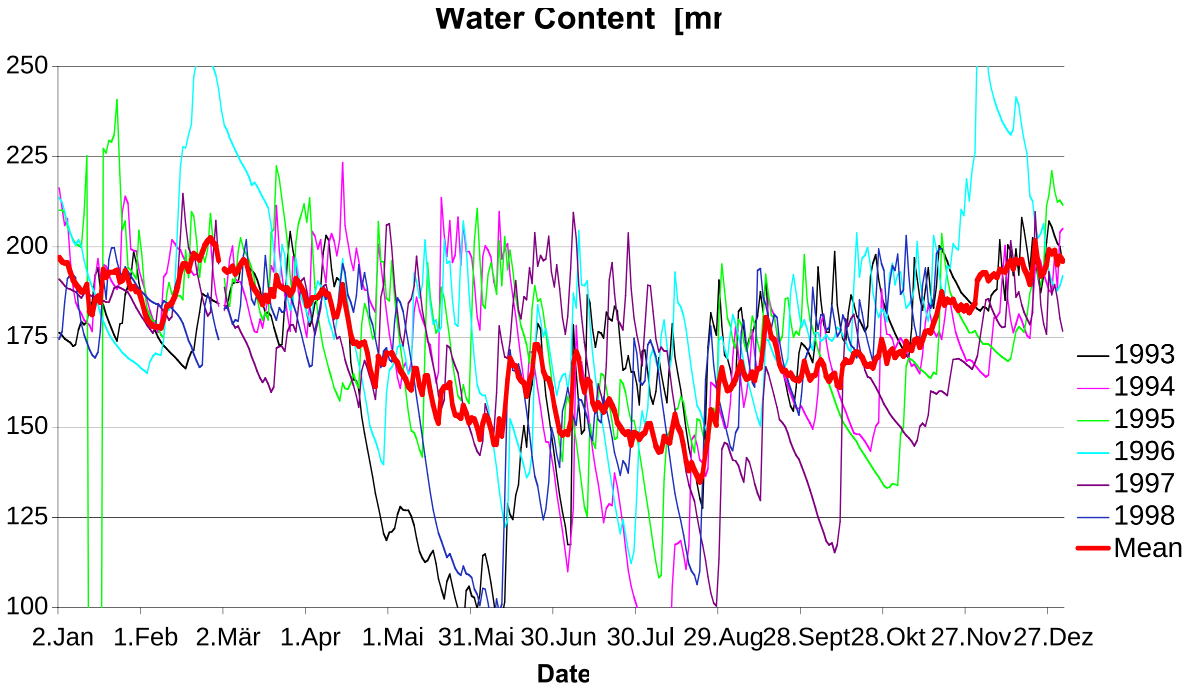
Role of terrestrial water storage for interannual variability

Homogeneity of assimilation products

Outlook

Lysimeter (Rietholzbach, CH)





- **patch-scale soil-moisture data is useful for process studies**
- **but of limited value in terms of the large-scale water balance**

(Ueli Moser, Achim Gurtz)

Water-Balance Approach

Terrestrial water balance:

$$\frac{\partial S}{\partial t} = (P - E) - R_s - R_g$$

S **= terrestrial water storage**

Atmospheric water balance:

$$\frac{\partial W}{\partial t} = -\nabla_H \vec{Q} - (P - E)$$

W **= atmospheric water storage**

Combined water balance:

$$\frac{\partial S}{\partial t} = -\nabla_H \vec{Q} - \frac{\partial W}{\partial t} - R$$

Convergence of the vertically integrated atmospheric water vapour flux

Change in column storage of water vapour

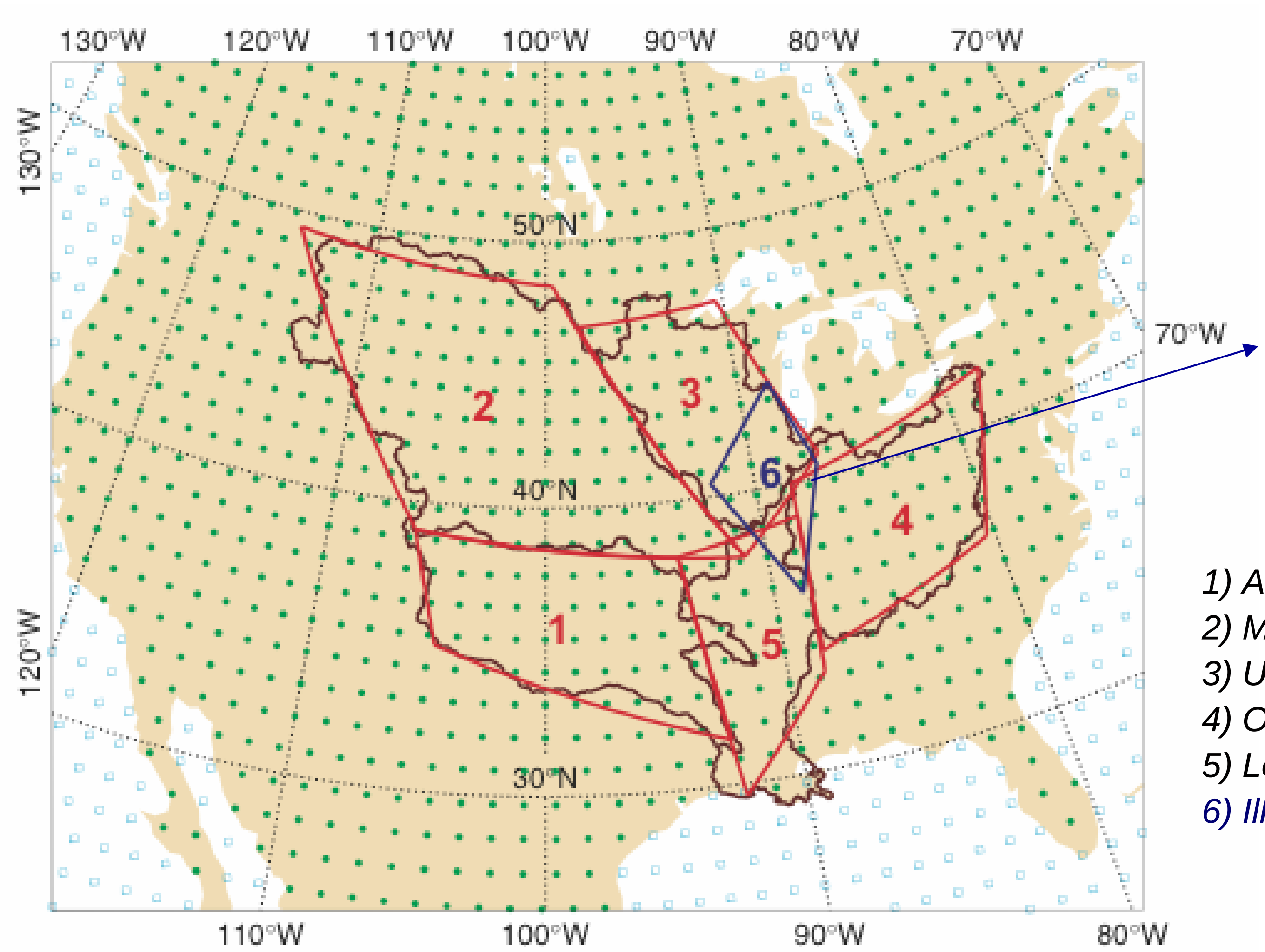
Runoff

From atmospheric reanalysis data (ERA-40)

From conventional runoff observations

(Seneviratne et al. 2004)

Case Study: Mississippi River Basin



•Study Period: 1987-1996

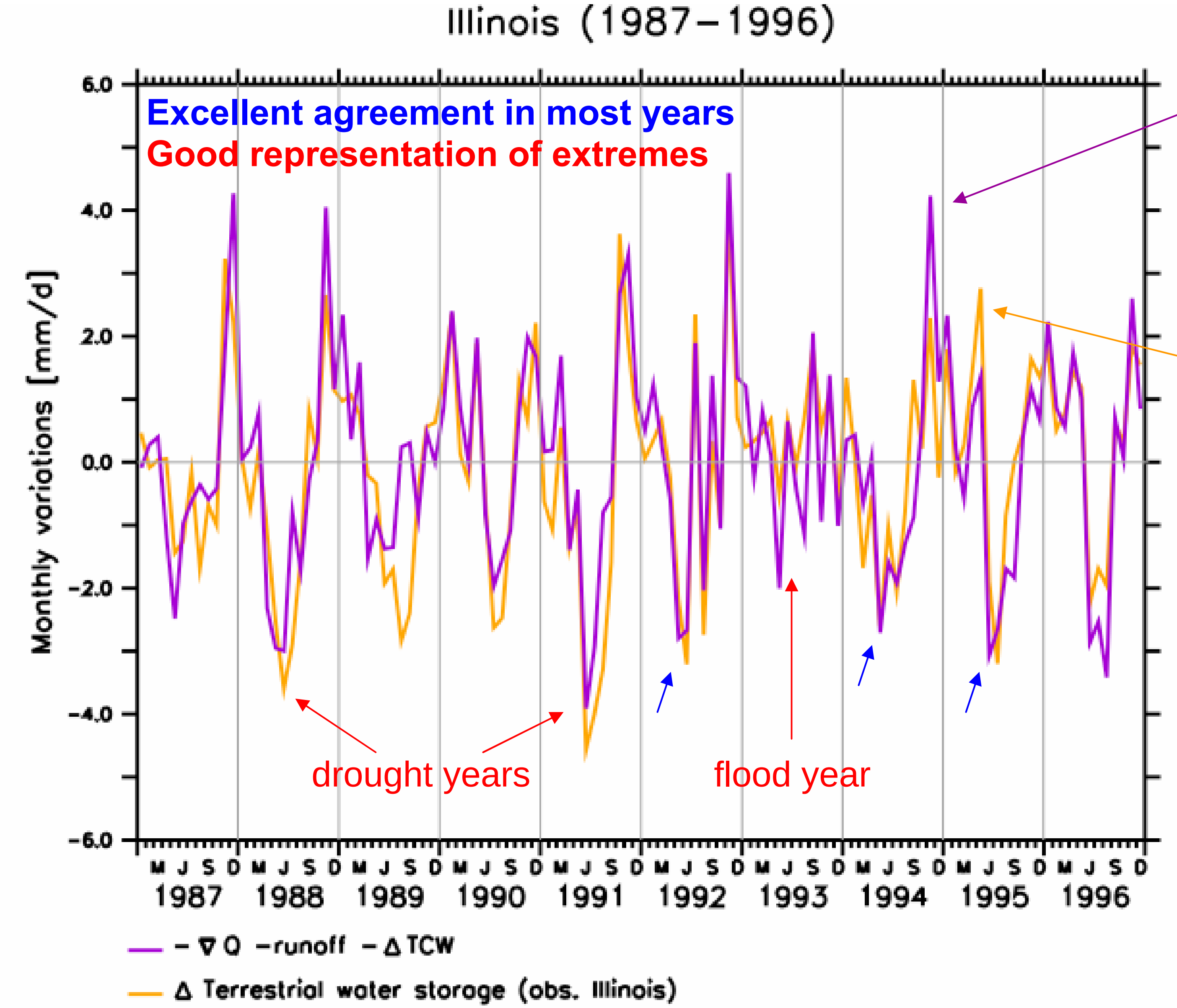
•Runoff data: USGS

•Validation against observations in Illinois (soil moisture, groundwater and snow)

1) Arkansas-Red (~6·10^5 km^2)
2) Missouri (~13·10^5 km^2)
3) Upper Mississippi (~5·10^5 km^2)
4) Ohio-Tennessee (~5·10^5 km^2)
5) Lower Mississippi (~4·10^5 km^2)
6) Illinois (~2·10^5 km^2)

(Seneviratne et al. 2004, J.Climate, 17, 2039-2057)

Validation (1): Monthly Variations



Water-balance Estimates

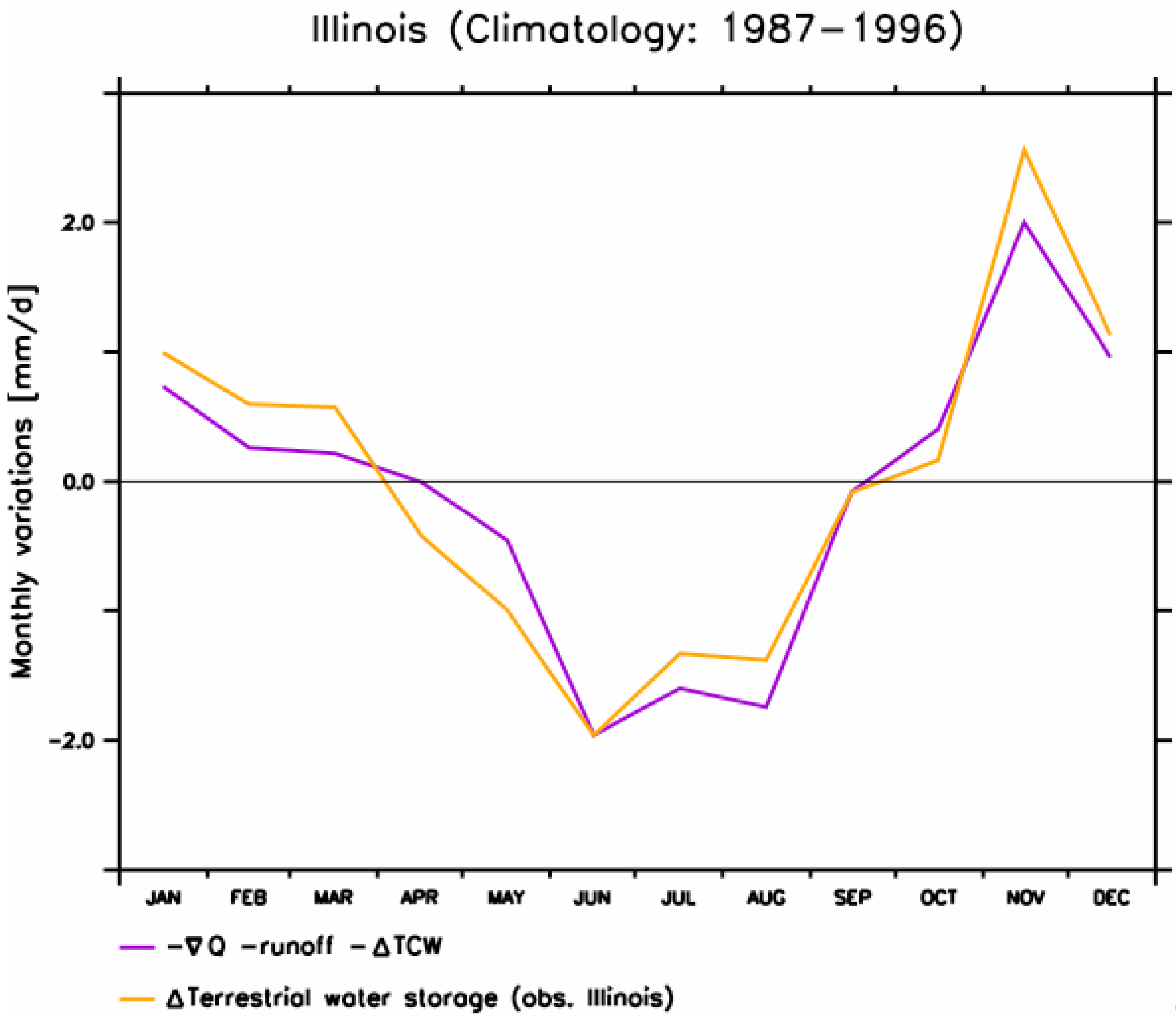
$$\frac{\partial S}{\partial t} = -\nabla_H \vec{Q} - \frac{\partial W}{\partial t} - R$$

Observations

(soil moisture+groundwater+snow)

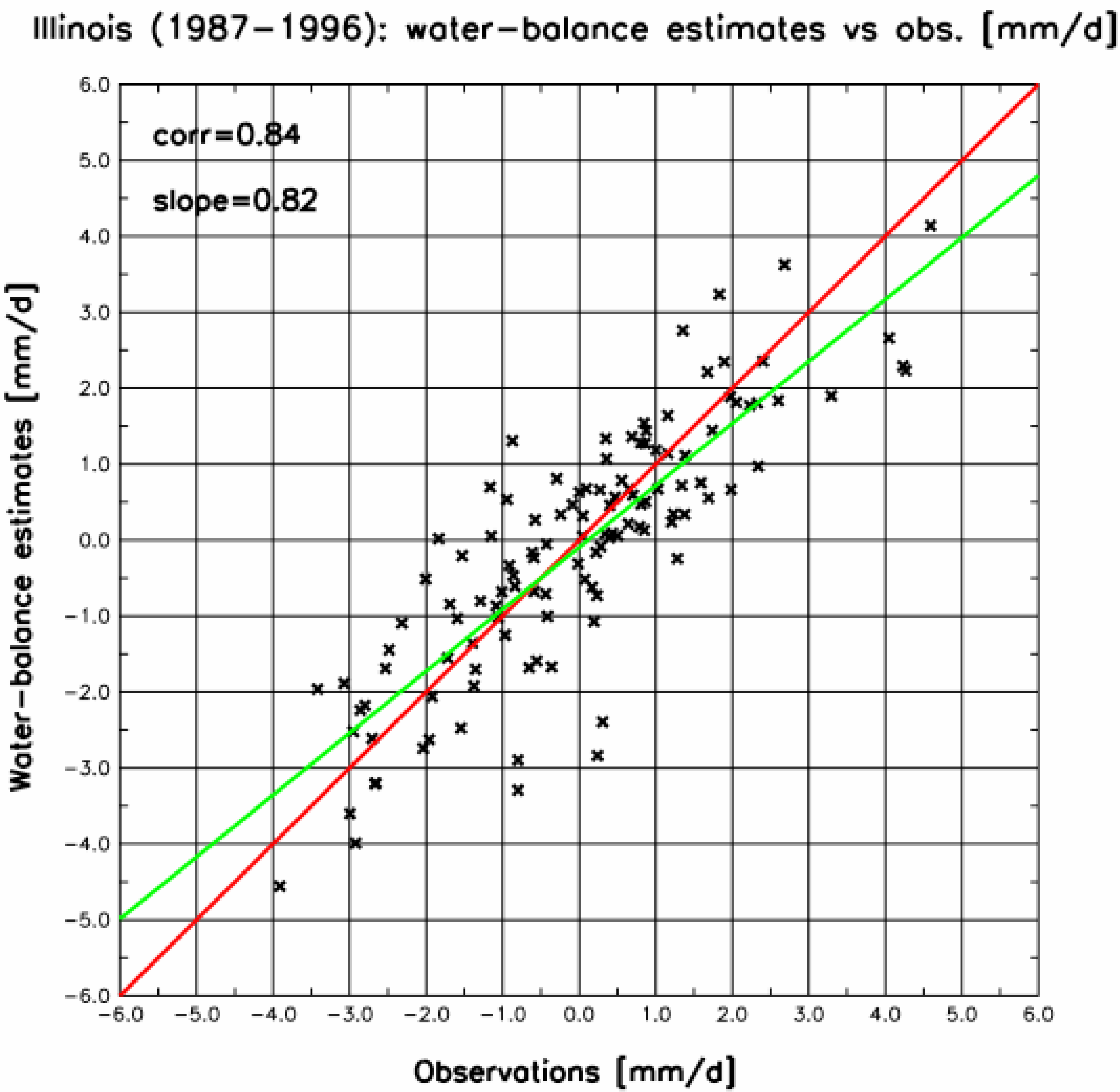
(Seneviratne et al. 2004)

Validation (2): Seasonal Cycle



(Seneviratne et al. 2004)

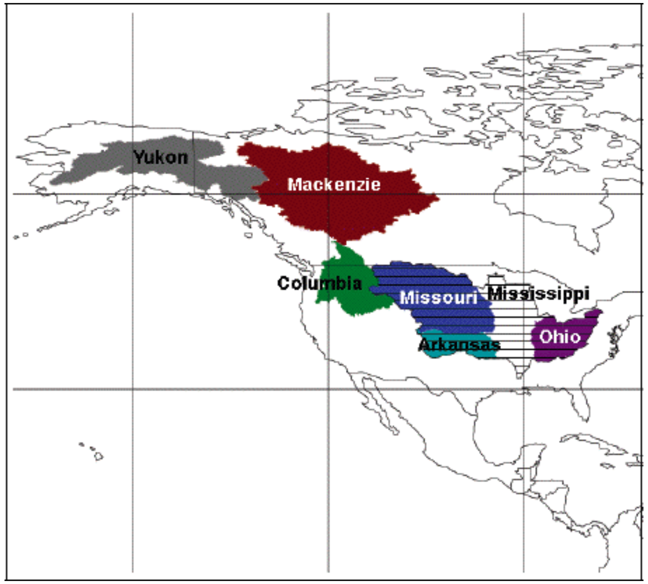
Validation (3): Correlation

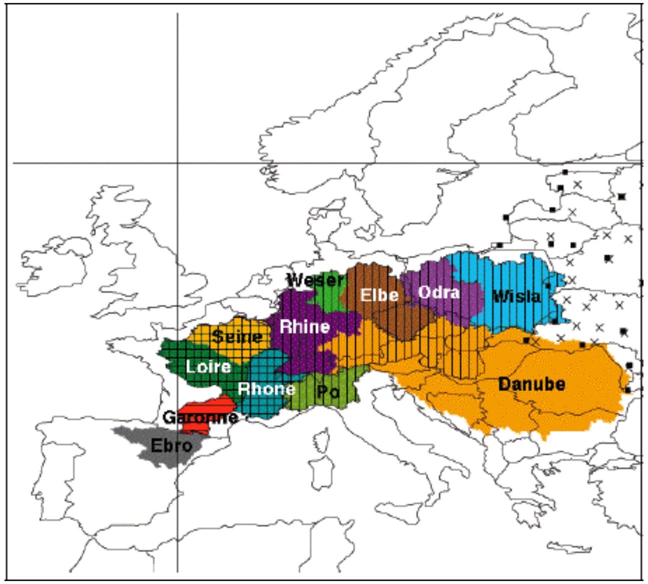


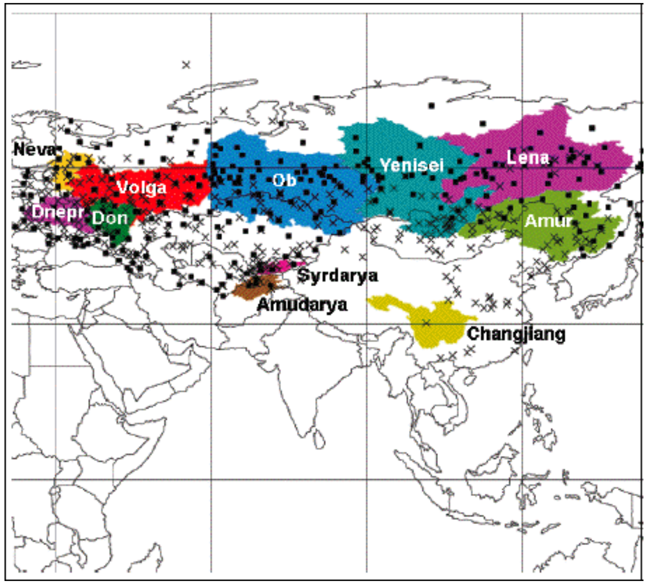
corr = 0.84
slope = 0.82

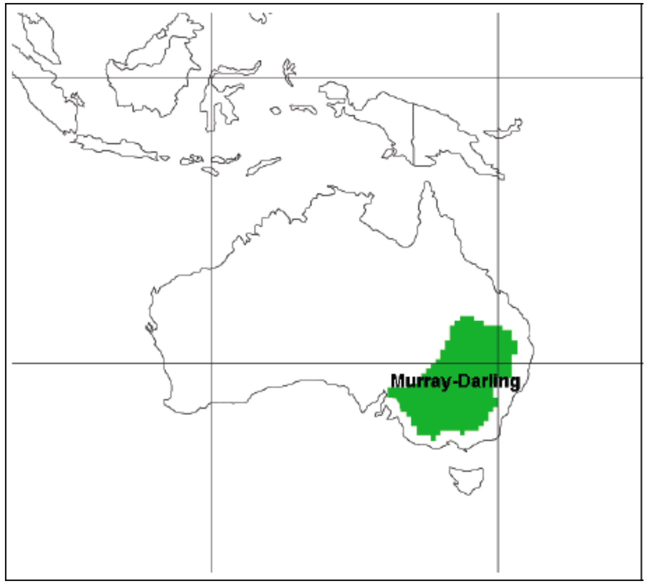
(Seneviratne et al. 2004)

Application to catchments









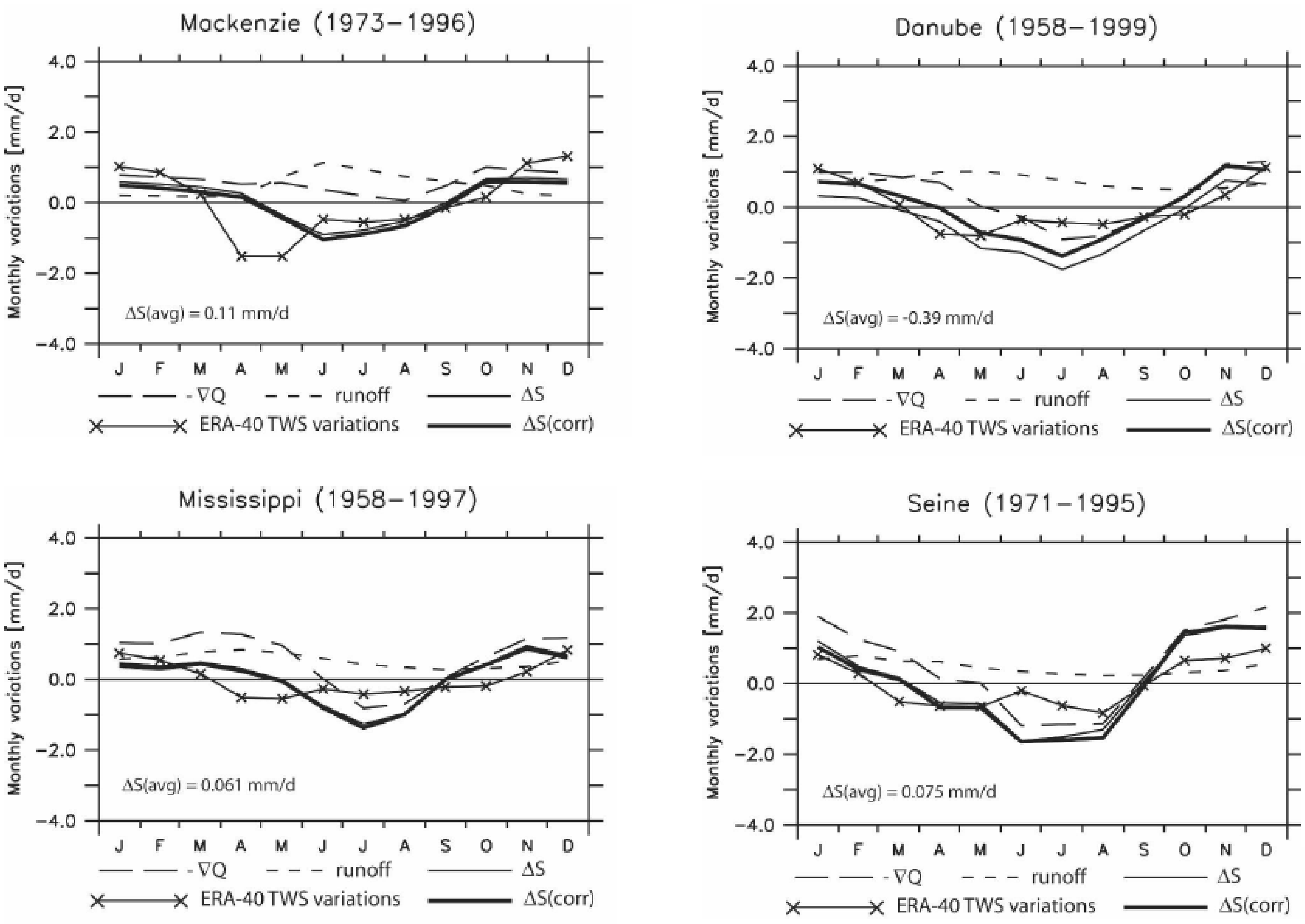
Systematic application to 37 mid-latitude river basins, with areas between 36,000 and 2,868,000 km^2.

Validation using soil moisture data (Robock et al. 2000)

Data available at http://www.iac.ethz.ch/data/water_balance/

Hirschi, M., S. I. Seneviratne and C. Schär (2006): Journal of Hydrometeorology, 7, 39–60

ERA-40 validation with basin-scale water-balance estimates



(Hirschi et al. 2006)

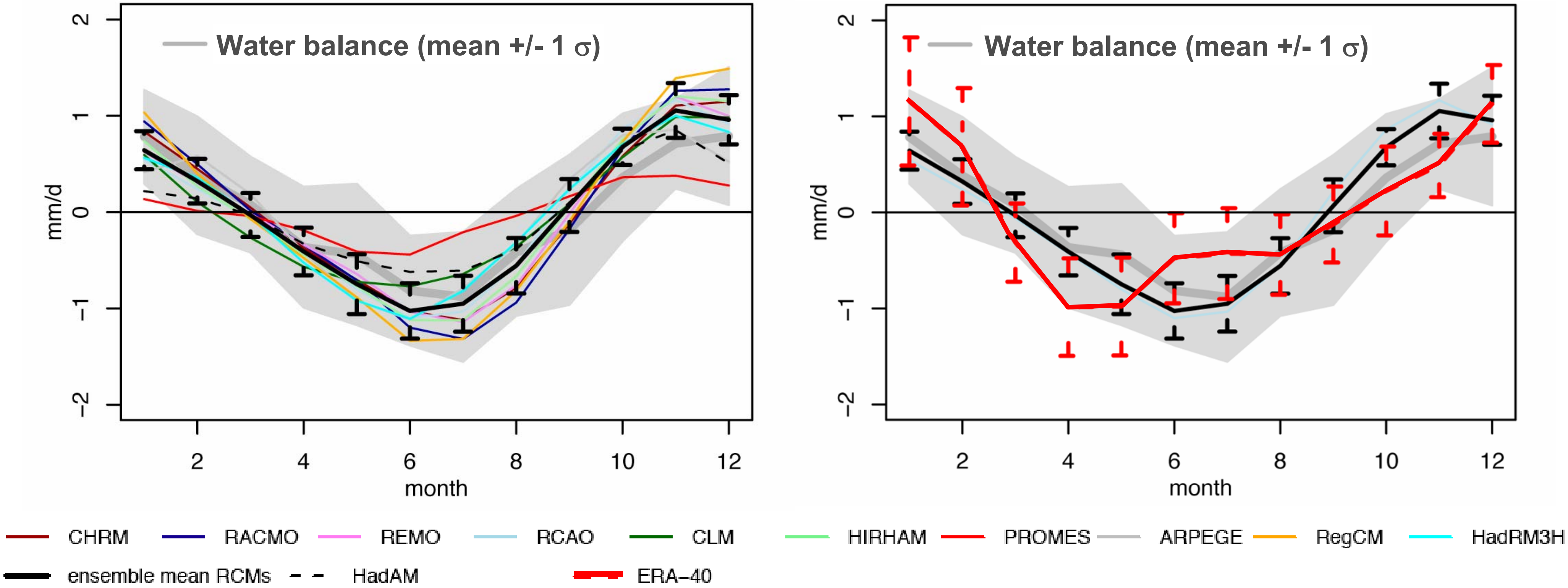
Climate model validation

Detailed validation in Central European Domain (1972-1990):

- **10 regional climate models**
- **1 global driving model (HadAM3)**
- **ERA-40**

PRUDENCE (EU FP5)

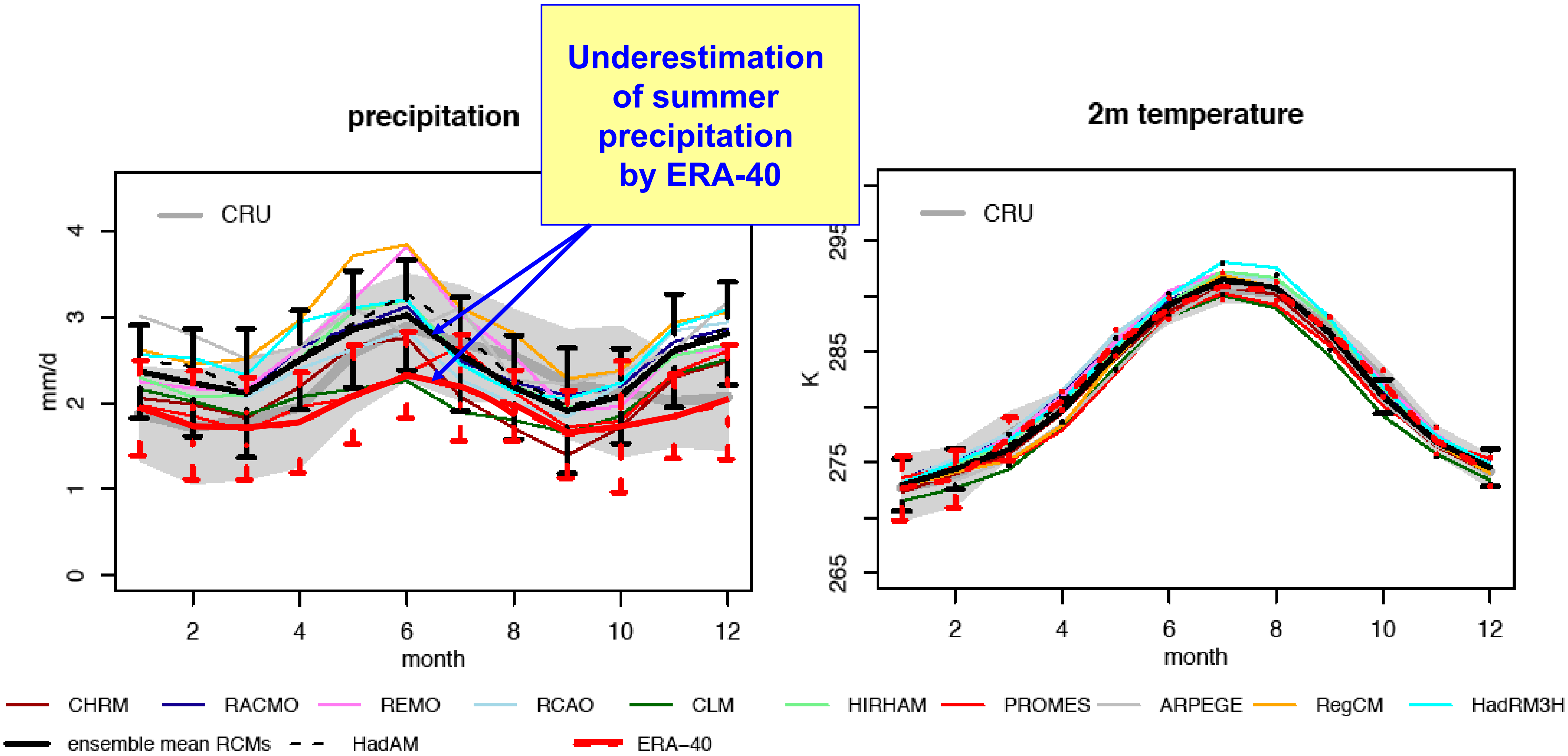
Terrestrial water storage variations [mm/d]



(Martin Hirschi, ETH Zurich, work in progress)

Model validation with basin-scale estimates

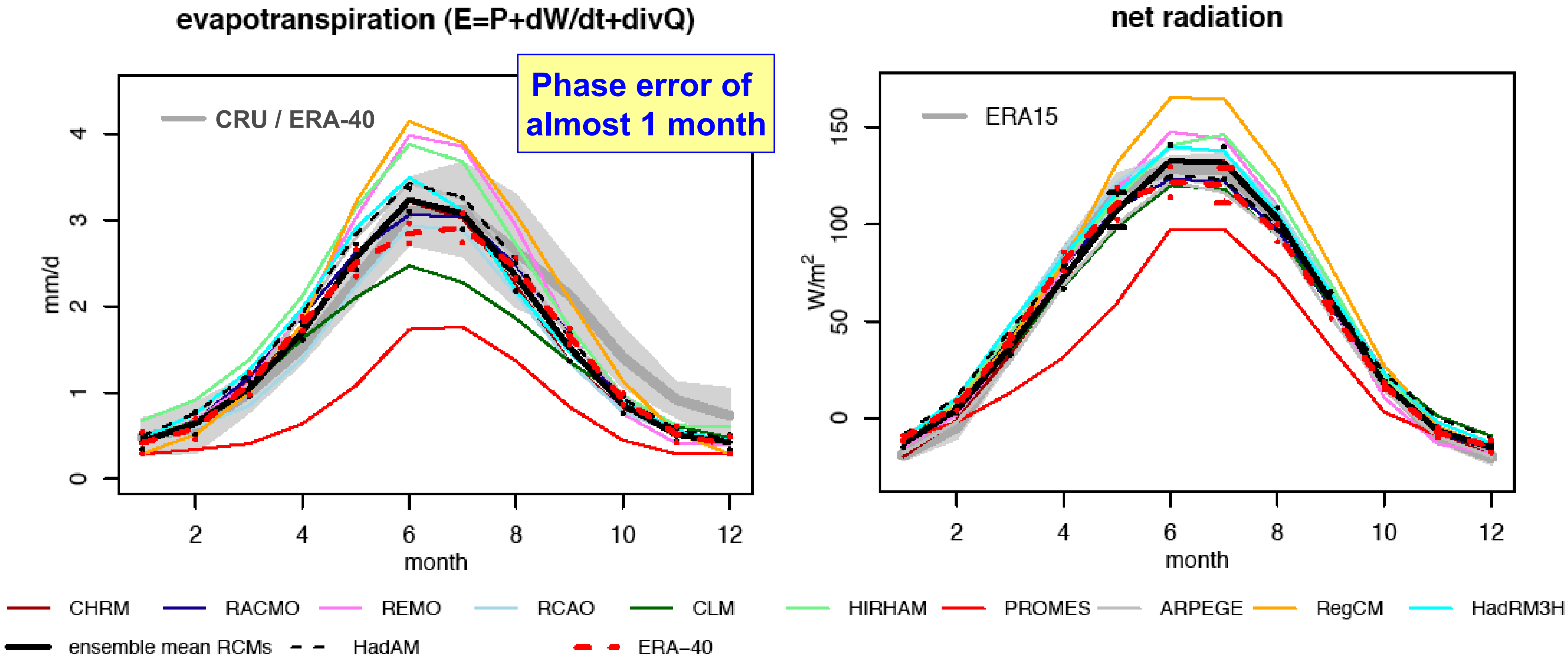
Central European Domain (1972-1990)



(Martin Hirschi, ETH Zurich, work in progress)

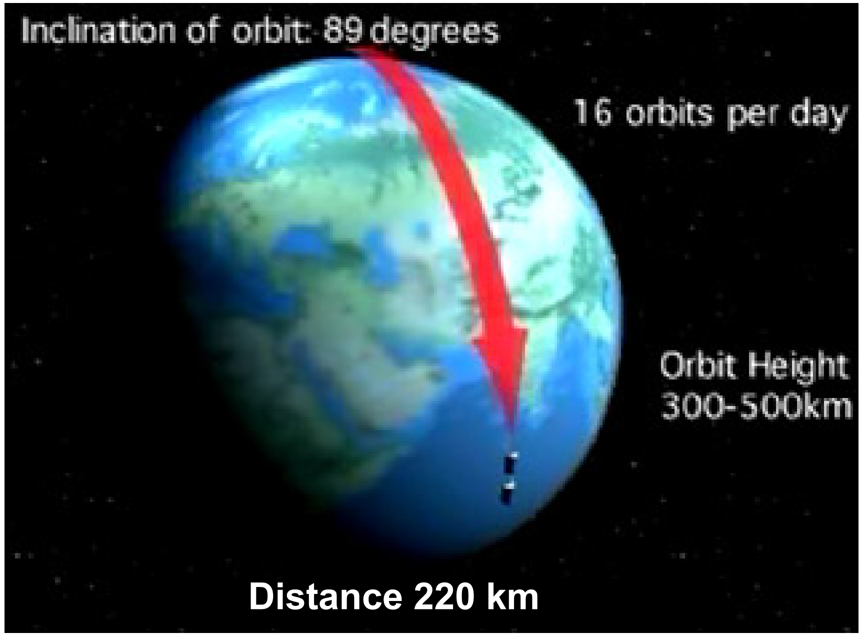
Model validation with basin-scale water-balance estimates

Central European Domain (1972-1990)



(Martin Hirschi, ETH Zurich, work in progress)

GRACE Mission



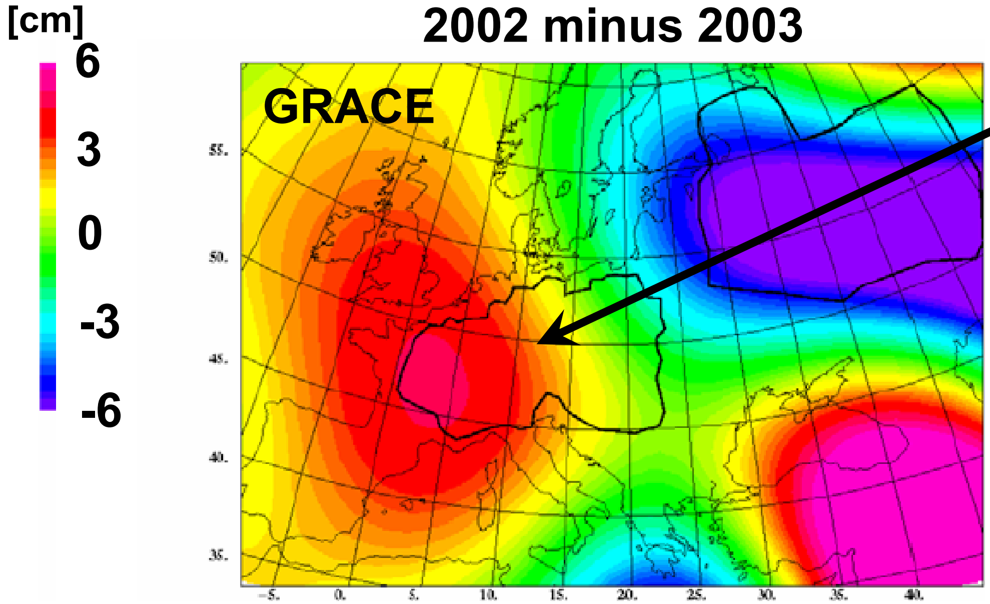
Twin satellite

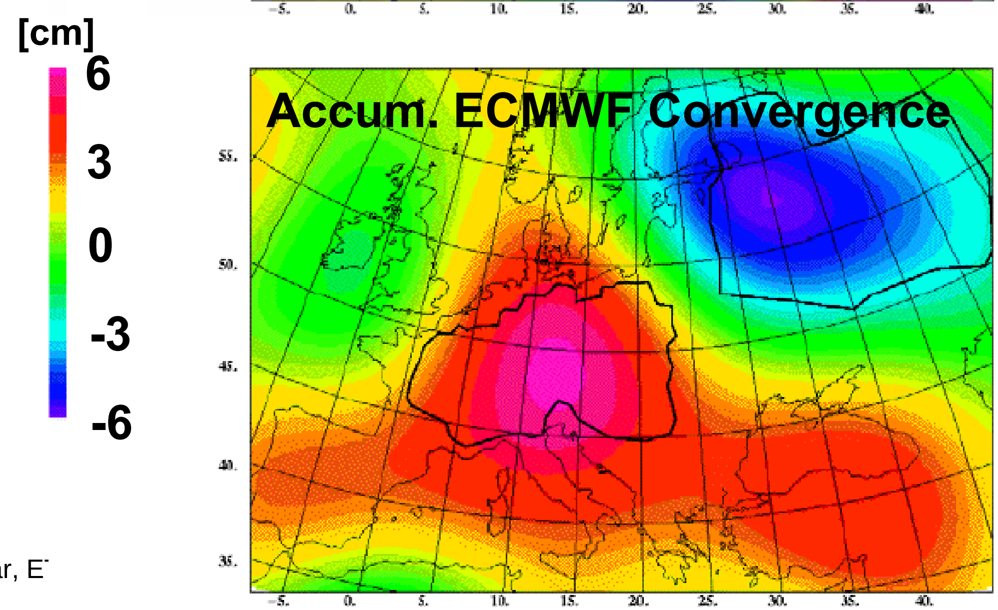
Infers low-resolution terrestrial water anomaly from gravity anomaly

Quasi-operational since 2002

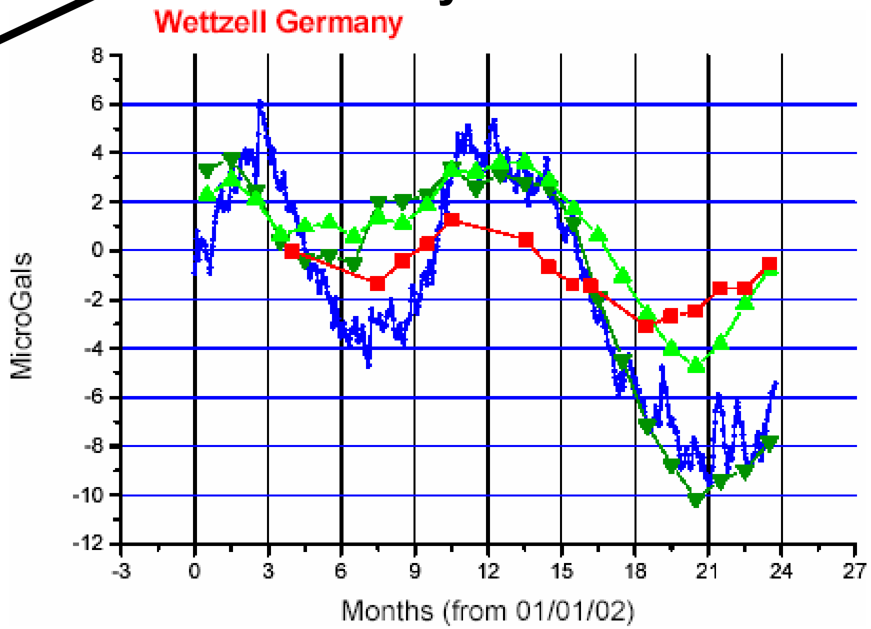
GRACE Observations 2002-2003

Summer Drying 2002 minus 2003





Water Storage Gravity / Model



GRACE
Superconducting Gravimeters
GLDAS
GLDAS spatially smoothed

(Andersen et al. 2004)

Comparison

	Ground measurements	Atmospheric water-balance	GRACE	LSM data assimilation
Resolution	Point measurements	300-1000 km (10^5-10^6 km^2)	1000-2000 km	typically 50km
Main advantage	Ground truth	Retrospective dataset (1958-present); large coverage	Global coverage	Good results in regions with good forcing; higher resolution
Main limitation	Point-scale measurements; limited temporal and geographical coverage	Depend on quality of convergence data (radiosonde, satellite data, drifts)	Only recent data (since 2002); low resolution	Results depend on quality of forcing data; models optimized for regions with validation data

Outline

Introduction and motivation

Large-scale observations of terrestrial water storage variations

Sensitivity experiments of the European summer 2003
- **Global models: ECMWF seasonal forecasting system (Ferranti and Viterbo 2006)**
- **Regional models: RCM driven by ECMWF analysis (Fischer et al. 2006)**

Role of terrestrial water storage for interannual variability

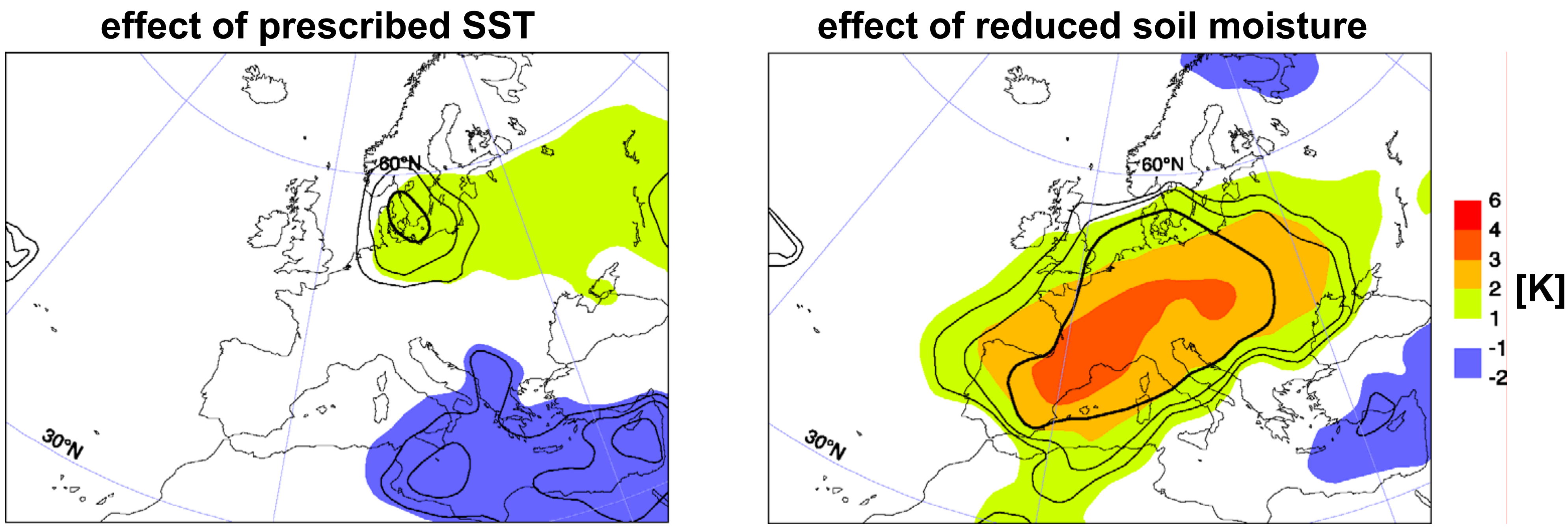
Homogeneity of assimilation products

Outlook

SST versus SM

Experiments with ECMWF seasonal forecasting system

JJA 2003 surface temperature anomaly



(Ferranti and Viterbo 2006)

Sensitivity experiments using an RCM

Regional Climate Model (RCM) simulations with prescribed large-scale forcing.
Model: CHRM = Climate High-Resolution Model (DWD origin)
Lateral boundary conditions: ERA-40 and operational ECMWF analysis

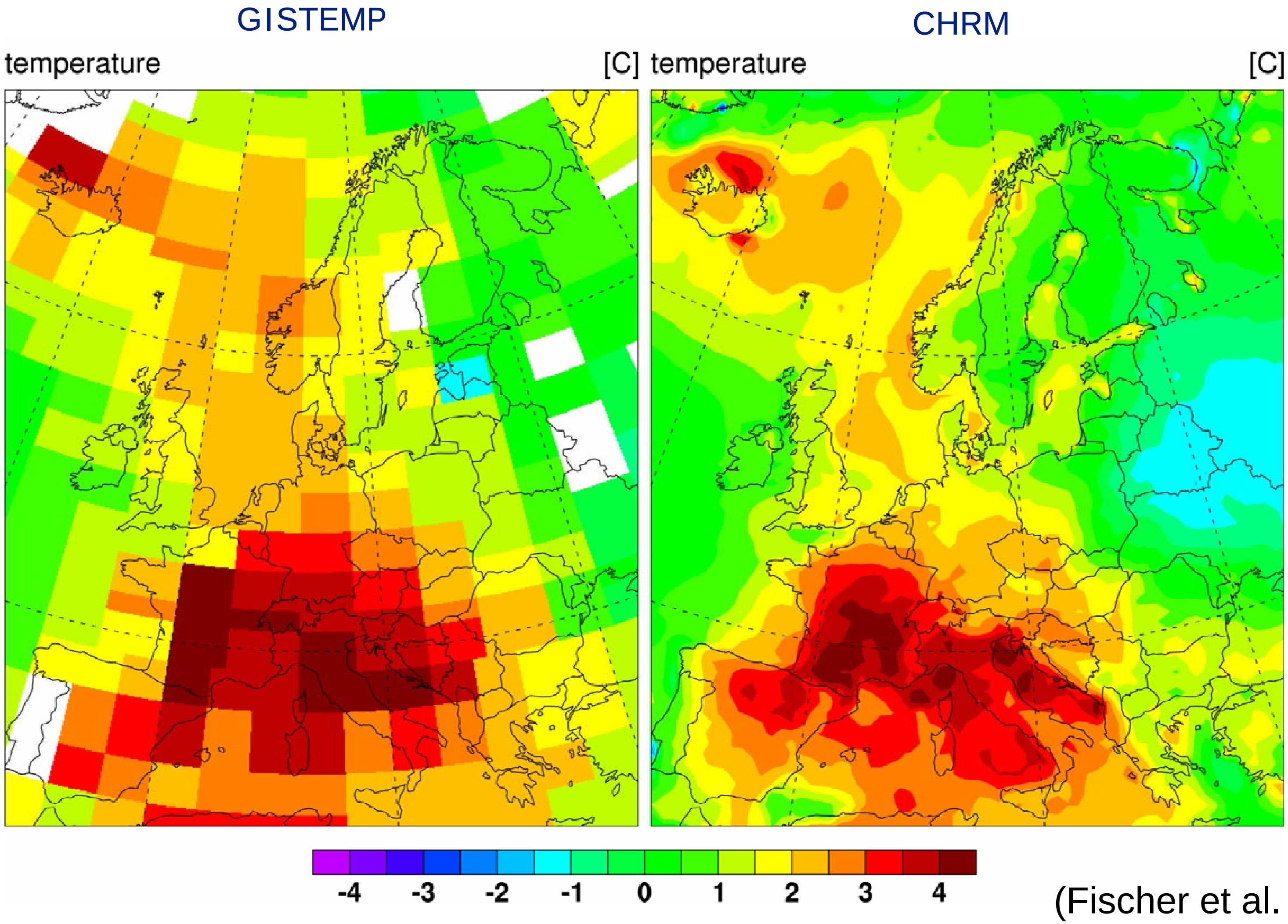
Simulations:

- **CLIM: Control climate, 1958-2001 simulation, driven by ERA-40**
- **CTL 2003: Control 2003, driven by ECMWF op, continuation of CLIM**
- **Dry and Wet simulations:**
  As CTL 2003, but with modified spring soil moisture on April 1, 2003

(Fischer et al. 2006)

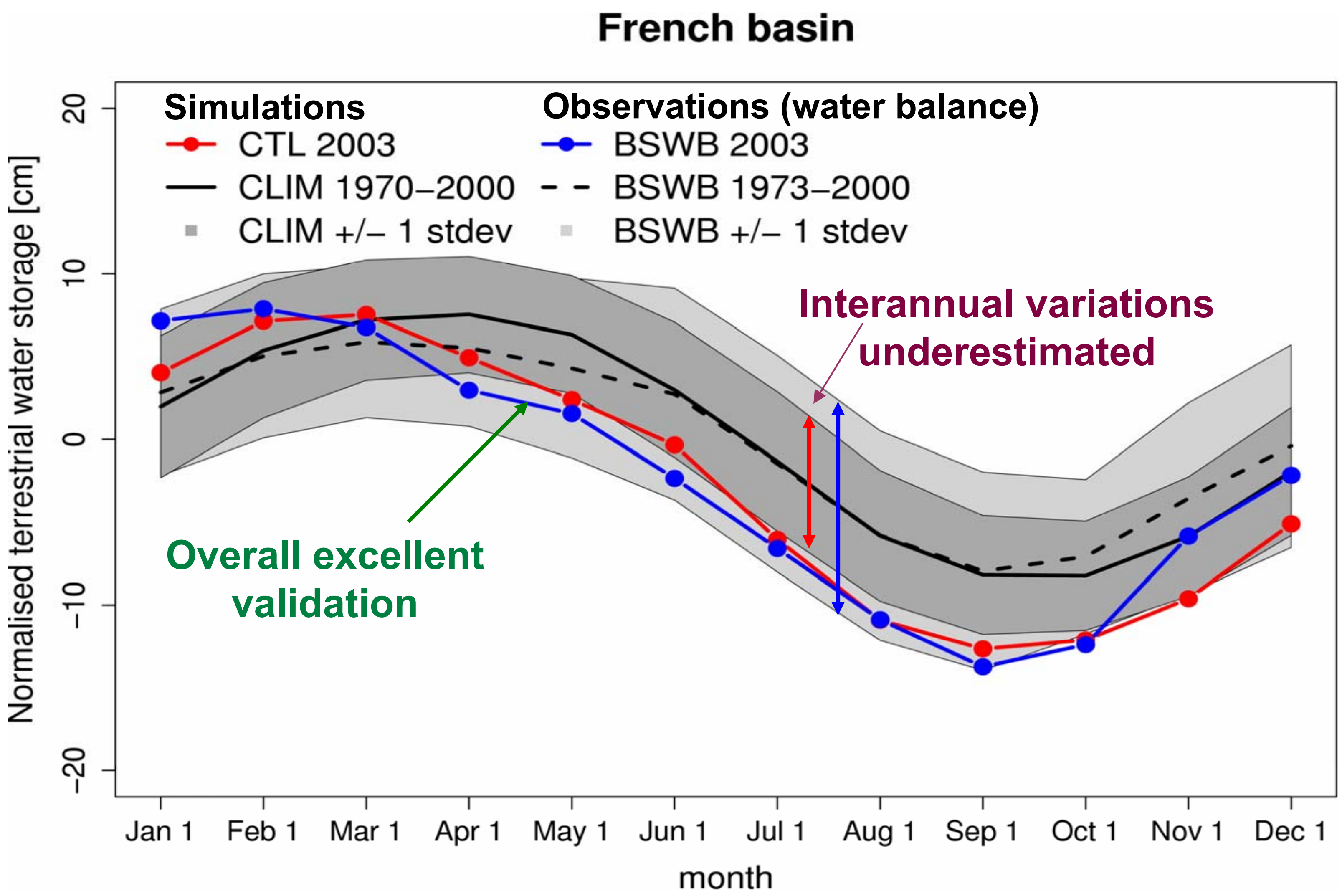
Validation of surface temperature anomaly

JJA 2003 wrt 1970-2000



(Fischer et al. 2006)

Terrestrial water storage

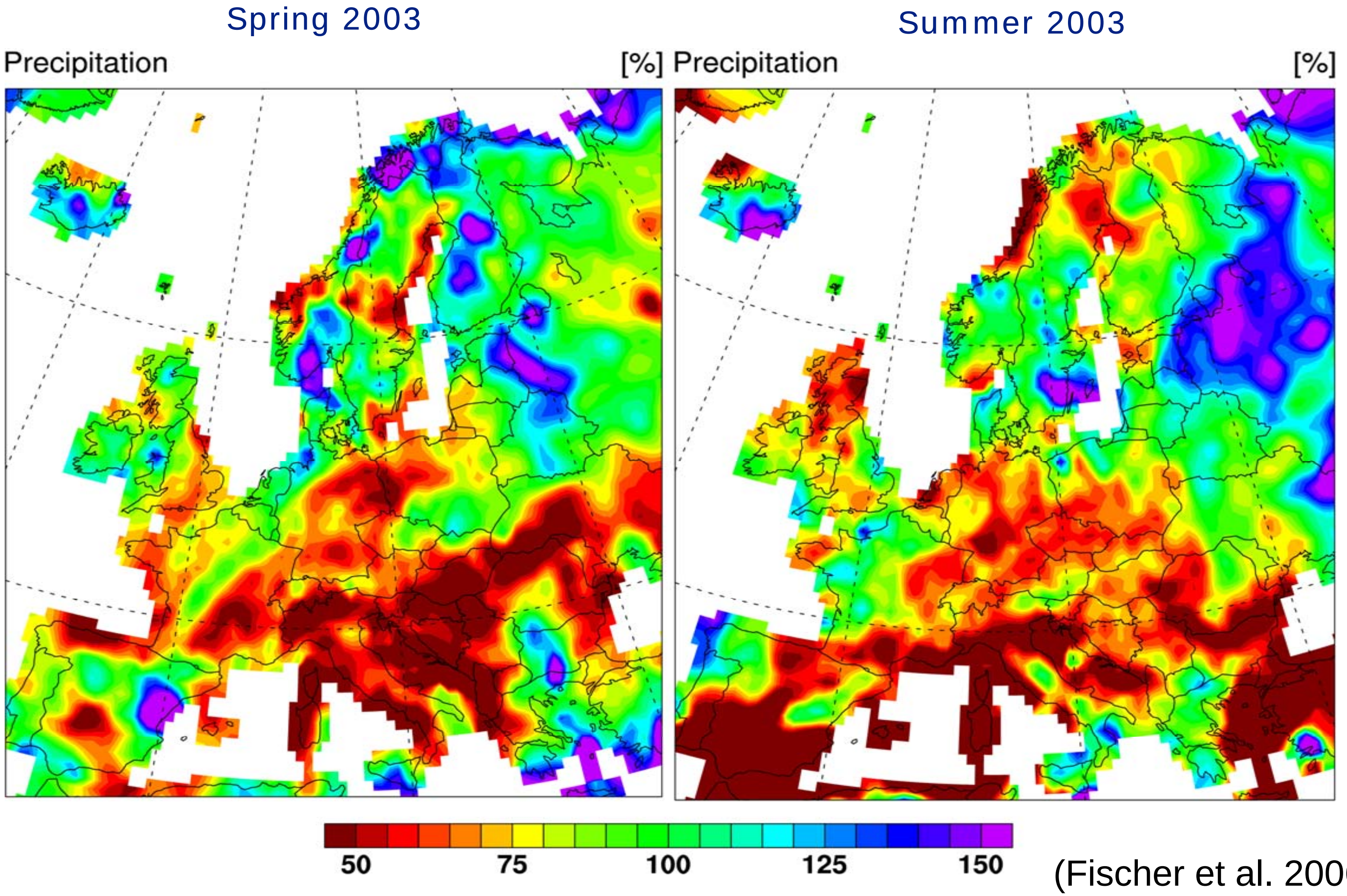


(Fischer et al. 2006)

Precipitation anomaly

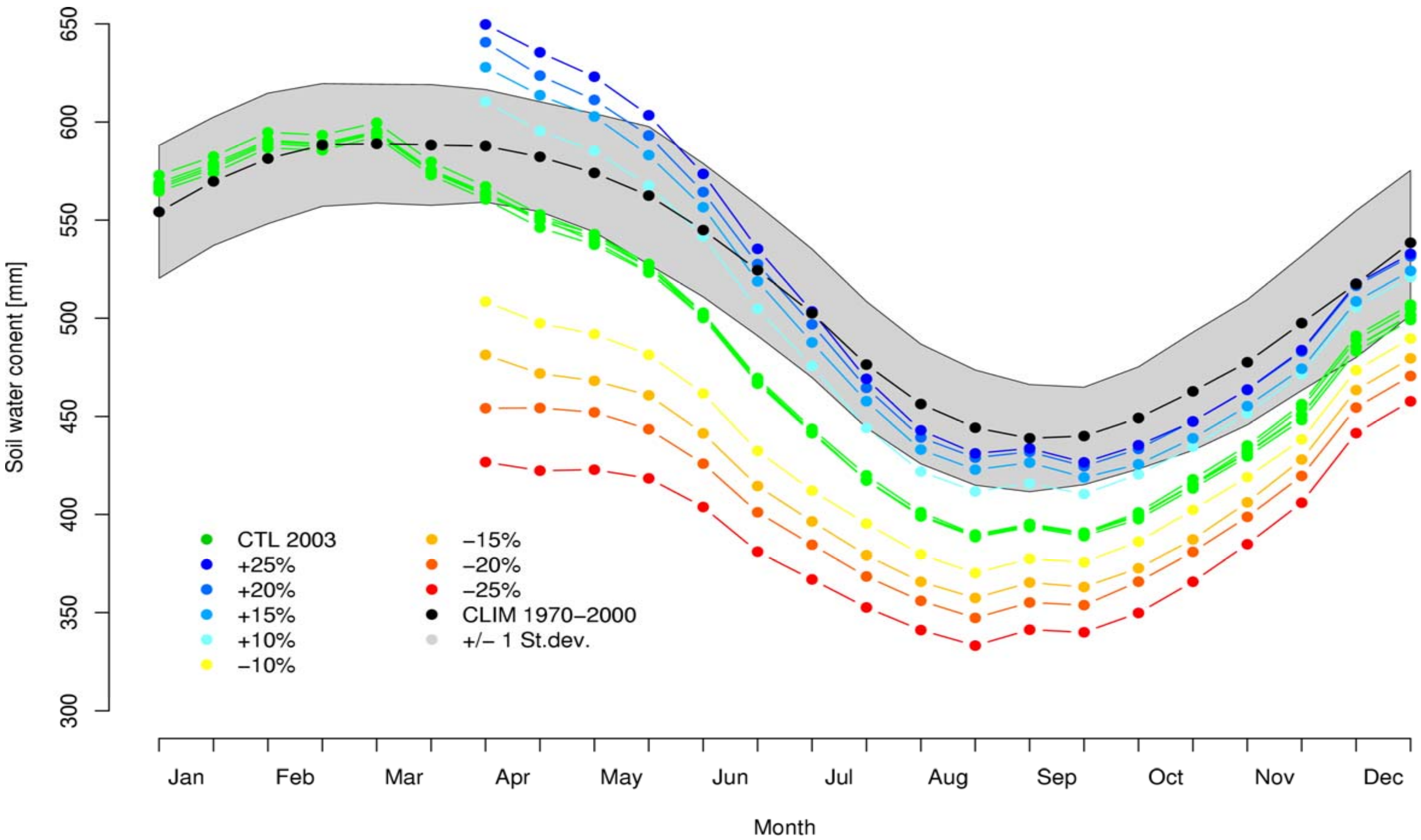
Low TWS is strongly affected by low preceding precipitation.

GPCC observed precipitation



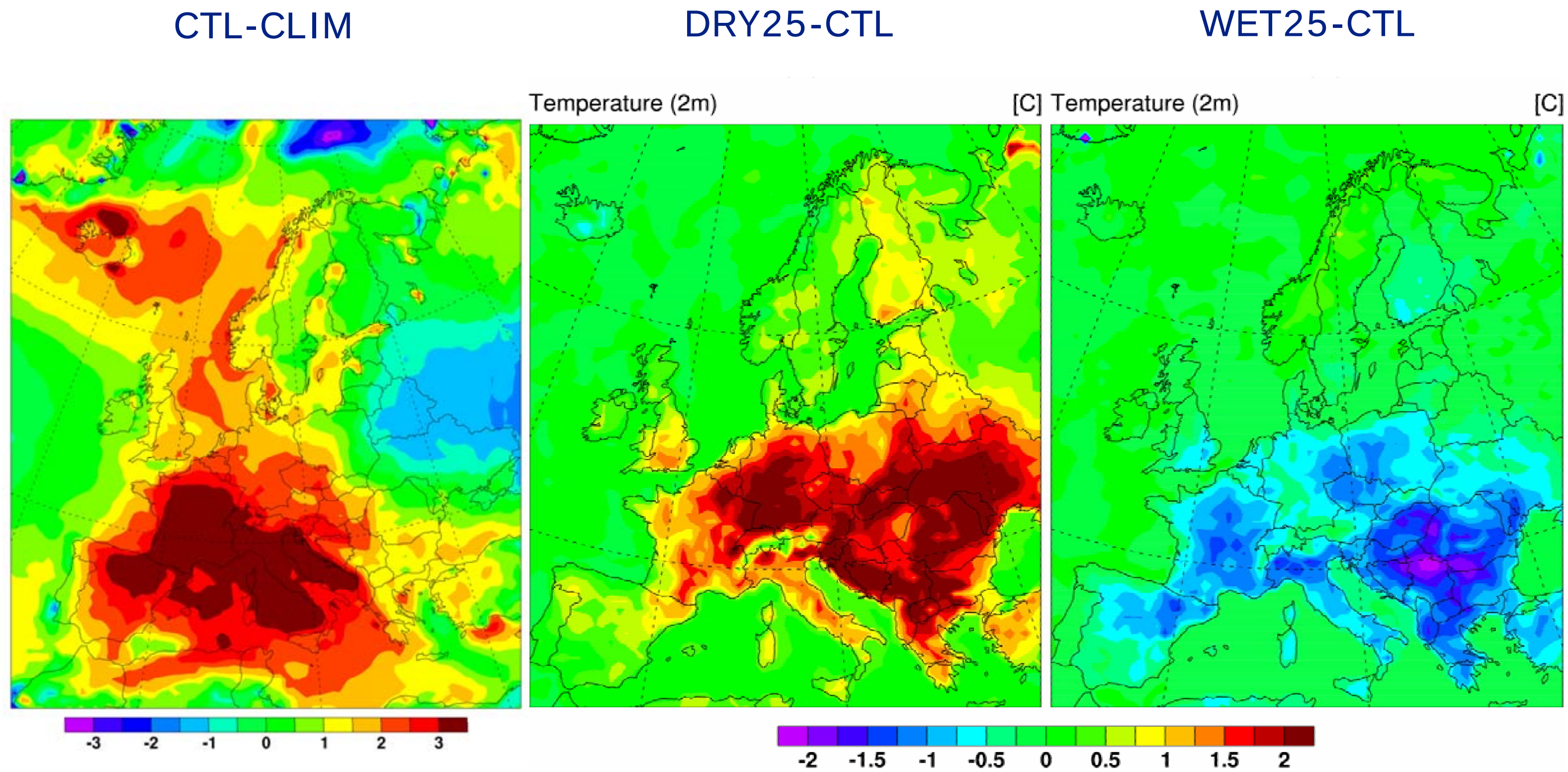
(Fischer et al. 2006)

Soil moisture experiments



(Fischer et al. 2006)

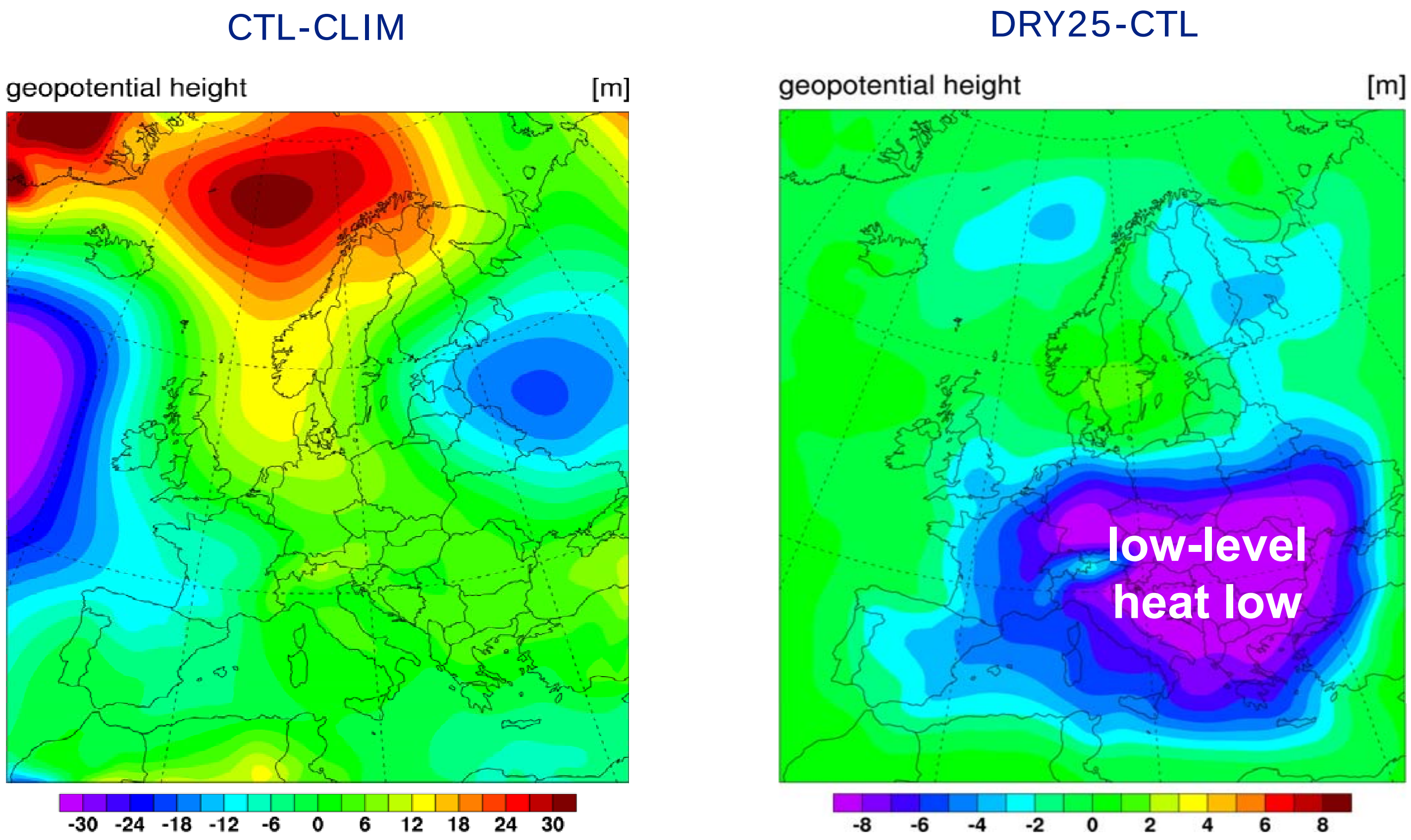
Soil-moisture induced temperature anomaly



Dry soil → larger (>2K) and spatially extended anomaly

(Fischer et al. 2006)

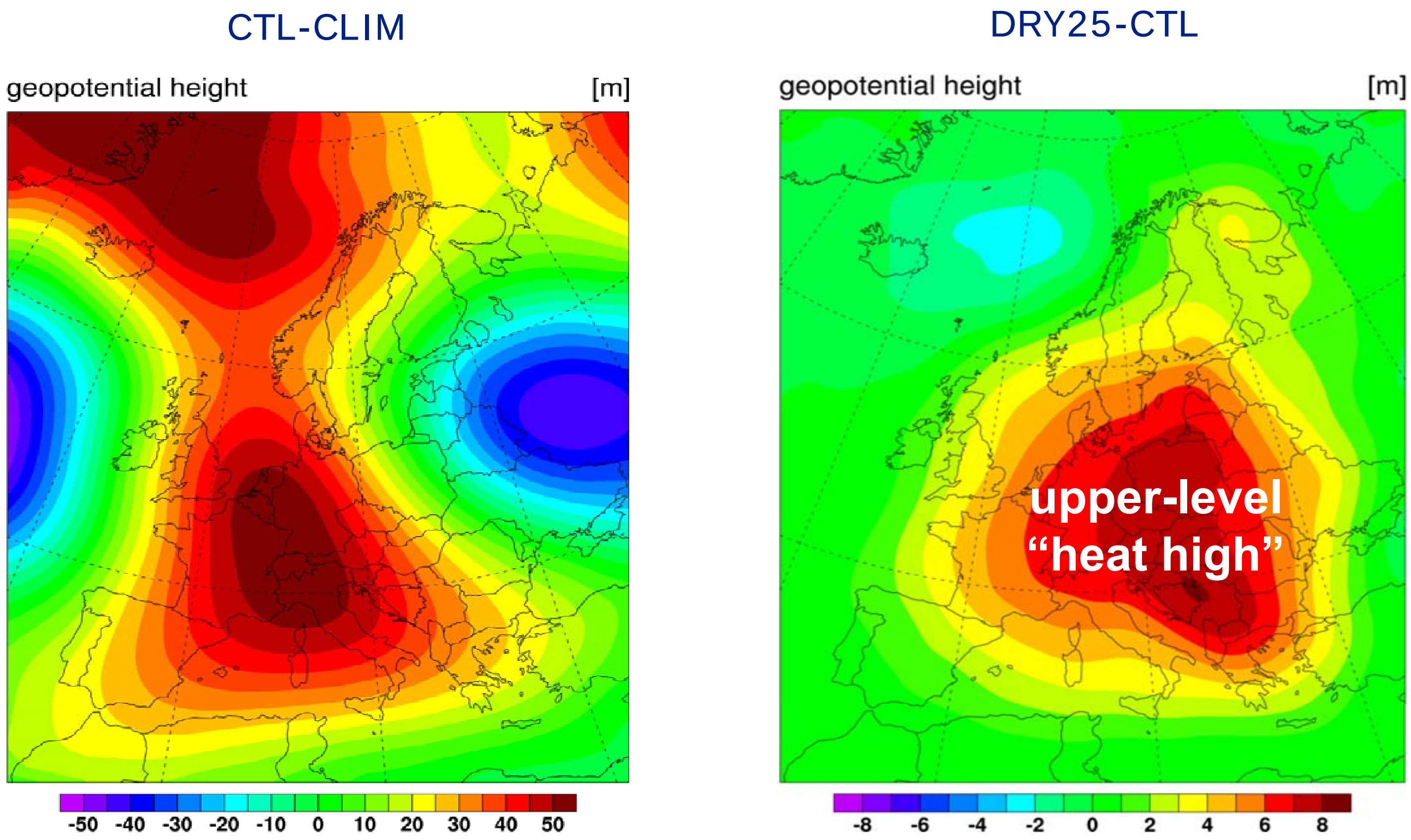
Soil-moisture induced 1000hPa height anomalies



Dry soil → surface heat low

(Fischer et al. 2006)

Soil-moisture induced 500hPa height anomalies



Dry soil → positive 500hPa height anomaly

POSITIVE FEEDBACK!

(Fischer et al. 2006)

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Introduction and motivation

Large-scale observations of terrestrial water storage variations

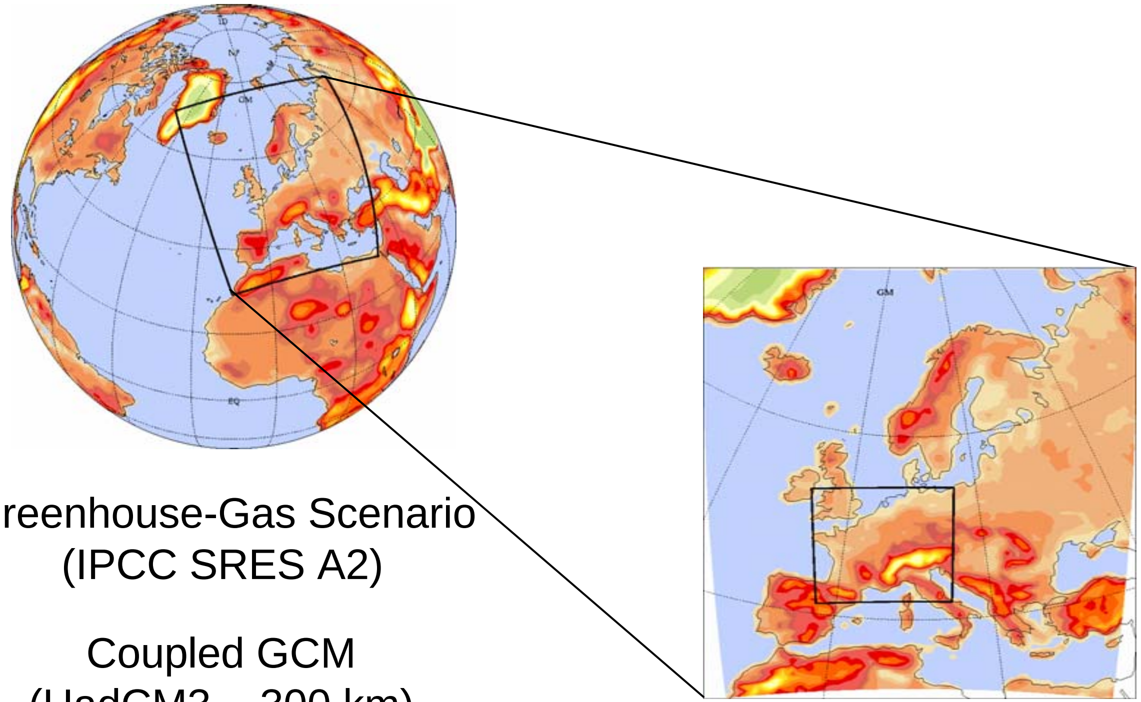
Sensitivity experiments of the European summer 2003

Role of terrestrial water storage for interannual variability
- current climate
- greenhouse gas climate

Homogeneity of assimilation products

Outlook

Climate Change Simulations



Greenhouse-Gas Scenario
(IPCC SRES A2)

Coupled GCM
(HadCM3, ~300 km)

Atmospheric GCM
(HadAM3, ~120 km)

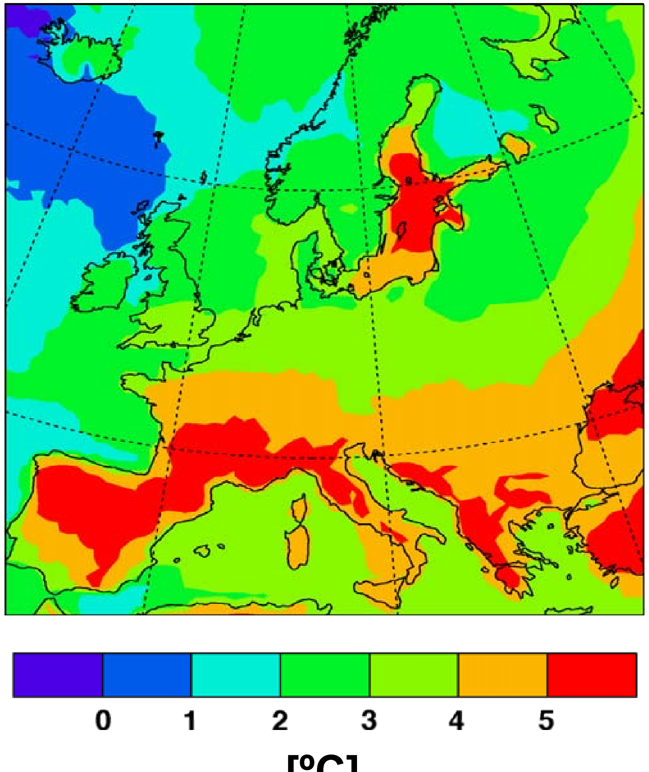
Regional Climate Model (RCM)
(CHRM / ETH, 56 km)

Time slice experiments
CTRL (1961-1990)
SCEN (2071-2100)

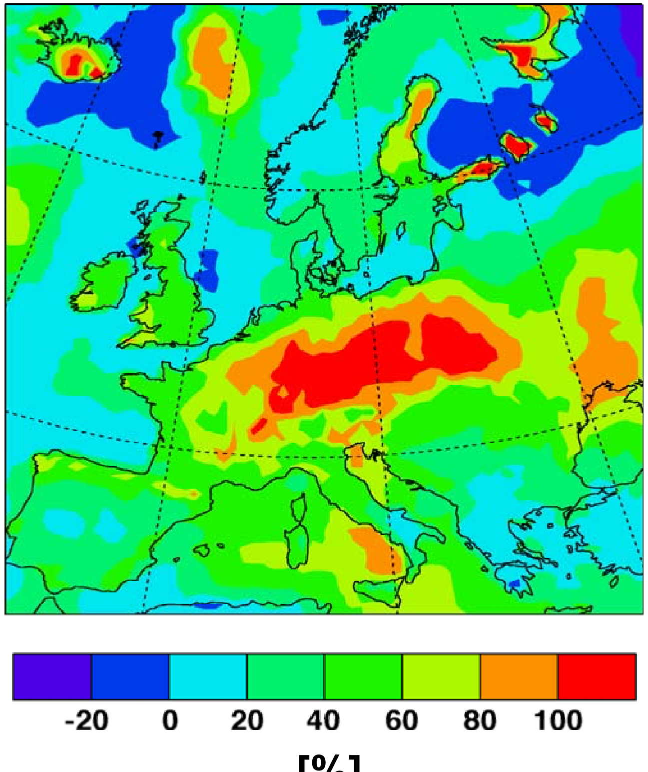
(EU-Project PRUDENCE, NCCR Climate)

Climate Change Simulations (European Summer)

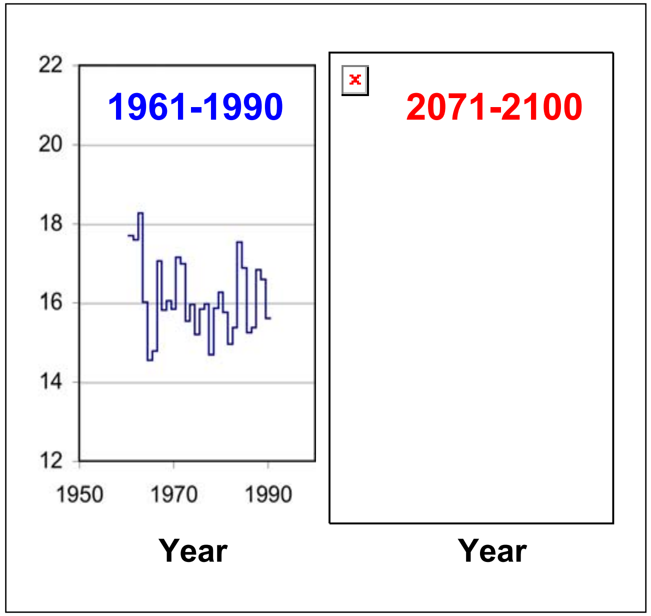
Change in Temperature ΔT



Change in Variability Δσ/σ (StdDev of seasonal T)



Zurich Temperature Series

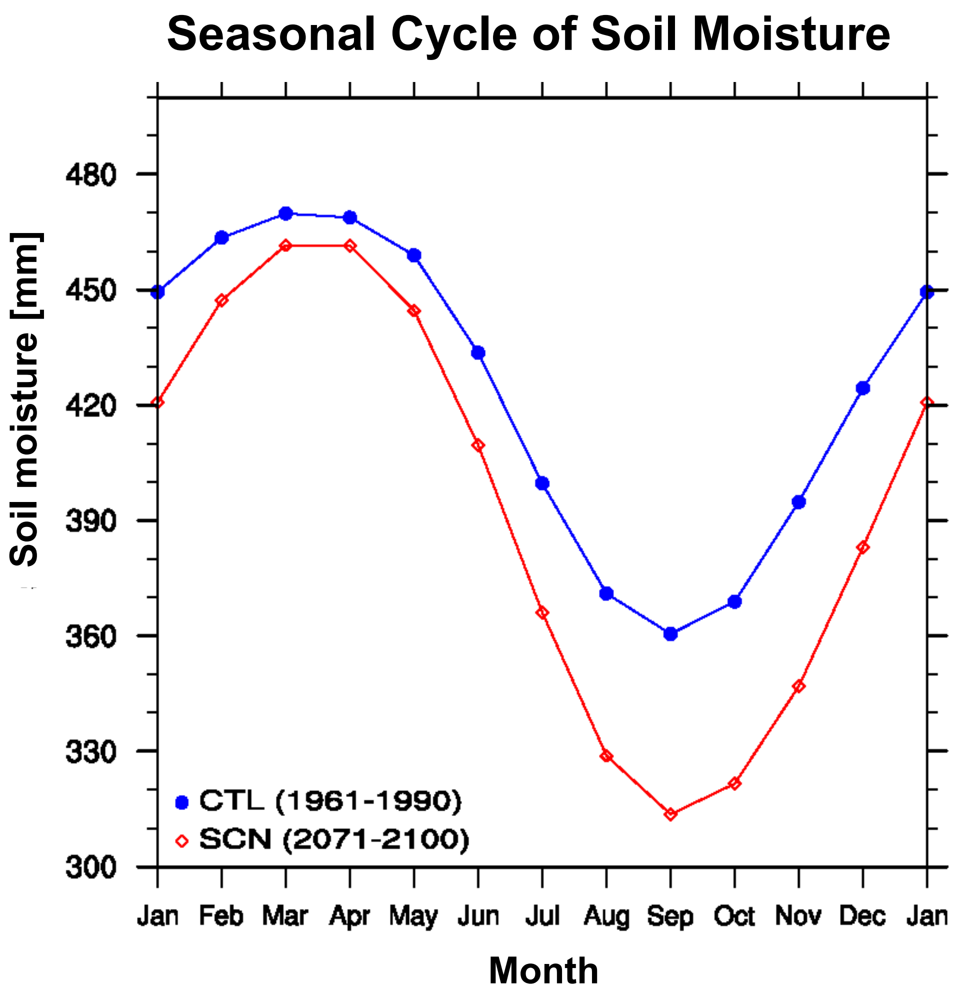


2071-2100 versus 1961-1990

Land-bound Increase in variability in Central Europe is indicative of land-surface processes

(Schär et al. 2004, *Nature*, **427**, 332-336)

Climate Change Simulations (European Summer)



Scenario simulations have increased amplitude of seasonal soil moisture cycle: Makes soil-moisture threshold effect more likely!

Schär, ETH Zürich

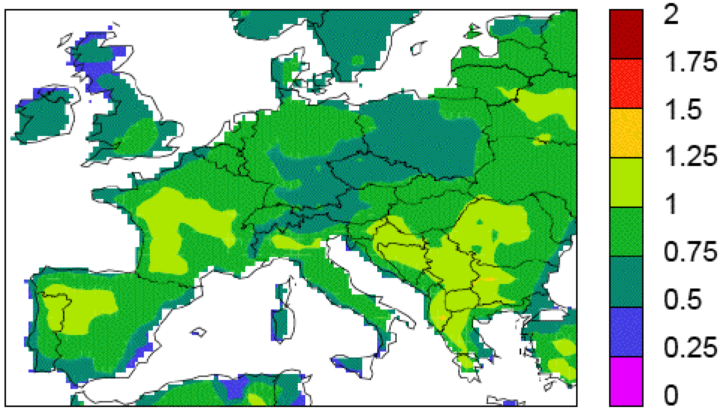
(Vidale et al. 2006, *Climatic Change*, in press)

Experiments with decoupled land-surface

Control Climate

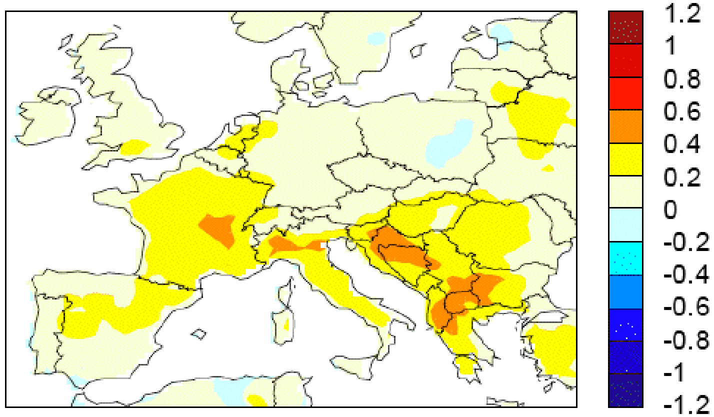
coupled soil

T_{2M} (K), stdev, CTL



Coupled simulations have interactive soil moisture

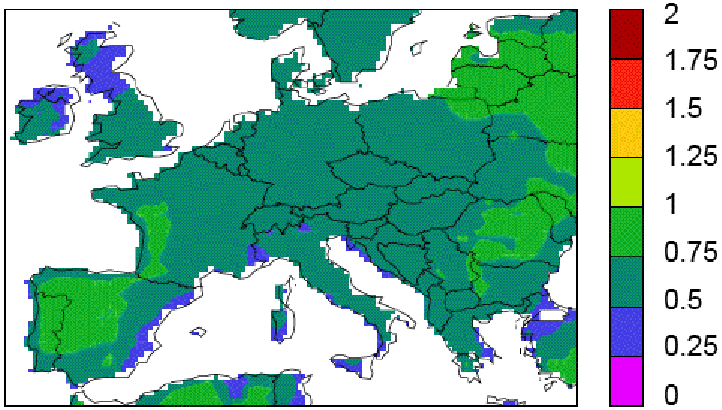
CTL-$CTL_{UNCOUPLED}$



Variability of summer T2m is strongly affected by land-atmosphere coupling (CTL and SCEN)

decoupled soil

T_{2M} (K), stdev, $CTL_{UNCOUPLED}$



Decoupled simulations have prescribed seasonal cycle of soil moisture

(Seneviratne et al., in press)

Outline

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Large-scale observations of terrestrial water storage variations

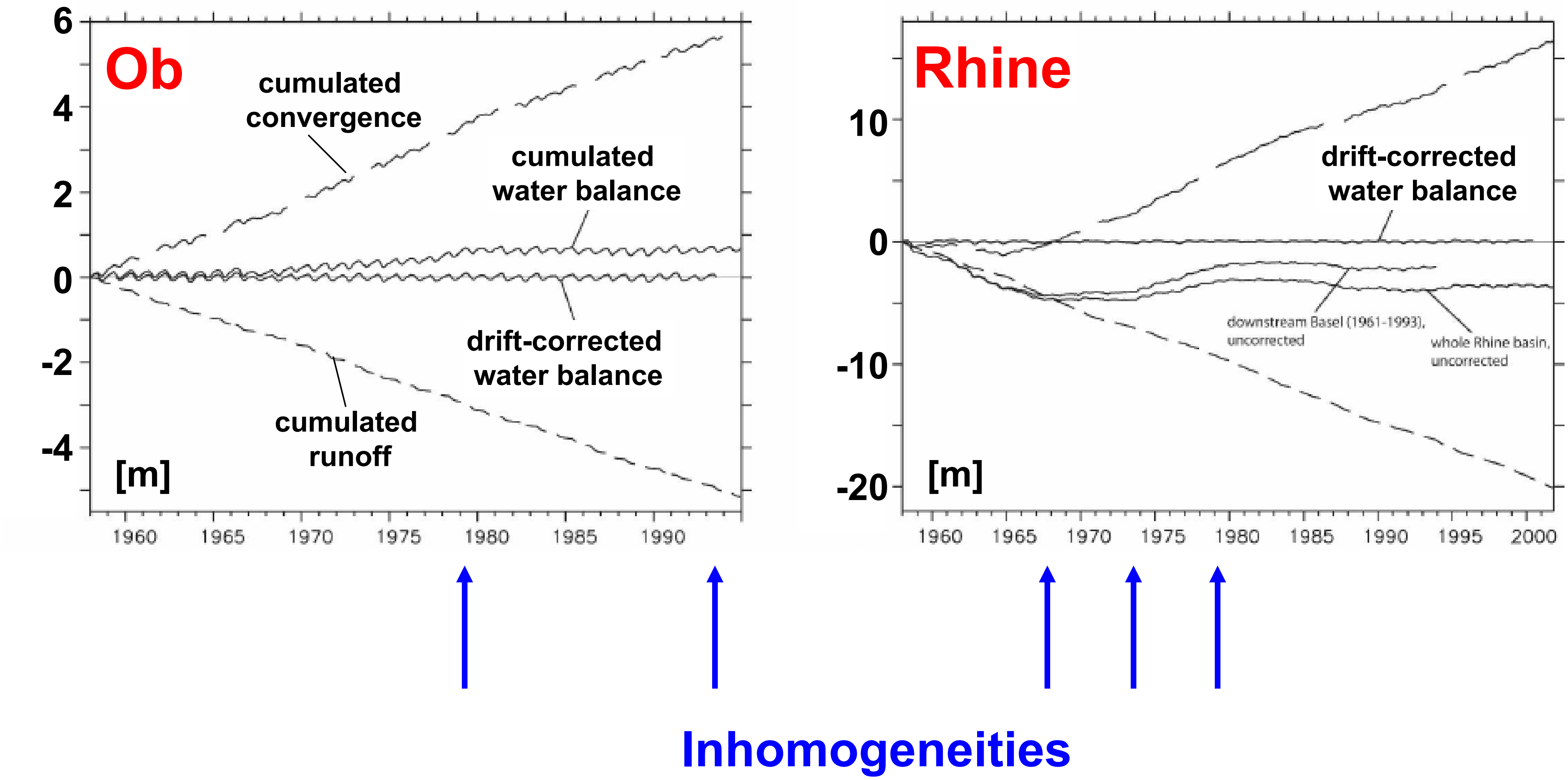
Sensitivity experiments of the European summer 2003

Role of terrestrial water storage for interannual variability

Homogeneity of assimilation products
- drift in water balance products
- inhomogeneities in precipitation

Outlook

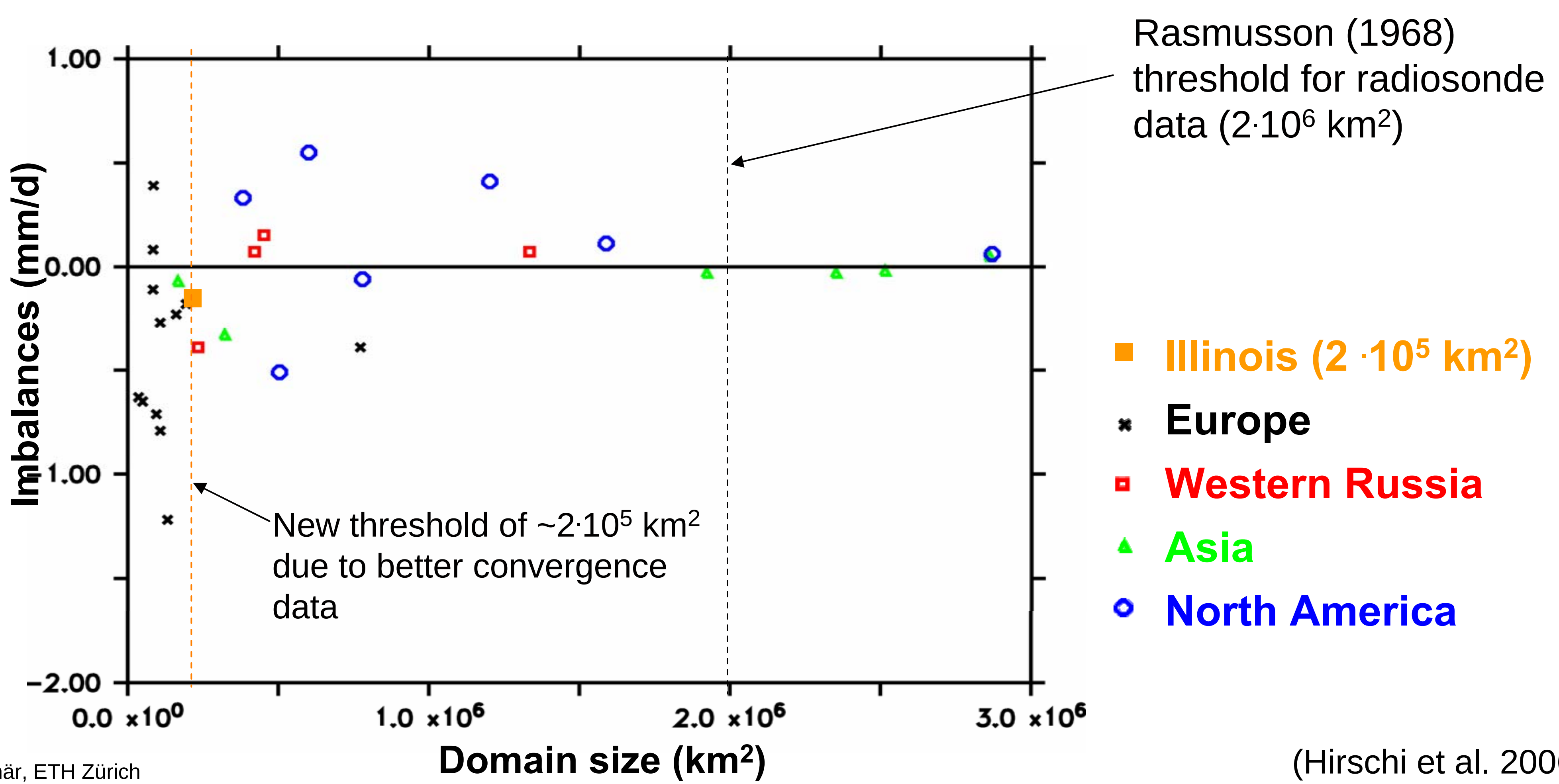
Long-term basin-scale imbalances



(Hirschi et al. 2006)

Long-term basin-scale Imbalances $\left\{ \frac{\partial \overline{S}}{\partial t} + \frac{\partial \overline{W}}{\partial t} \right\}$

The accuracy of the computed water balances depends both on *domain size* and on *regional characteristics*



(Hirschi et al. 2006)

Homogeneity of EC precipitation

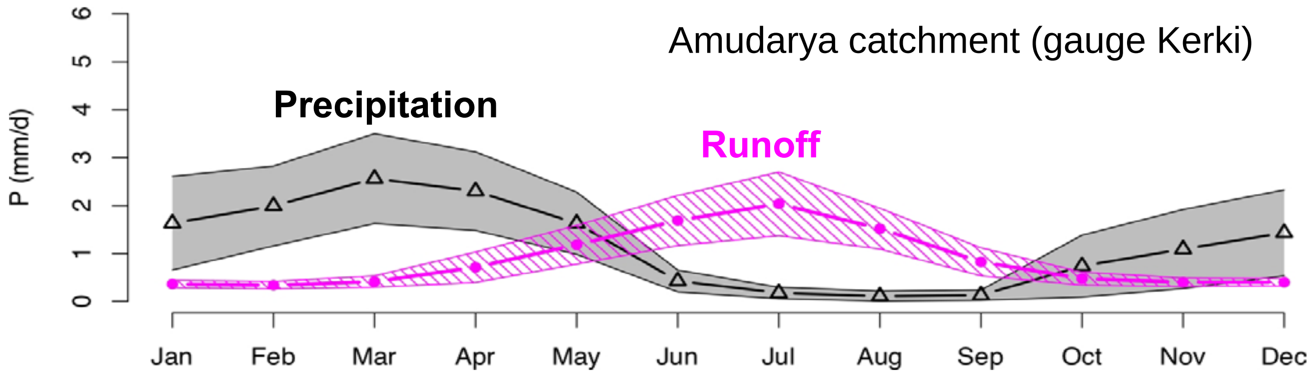
Seasonal runoff forecasting in Central Asia

Basic idea:

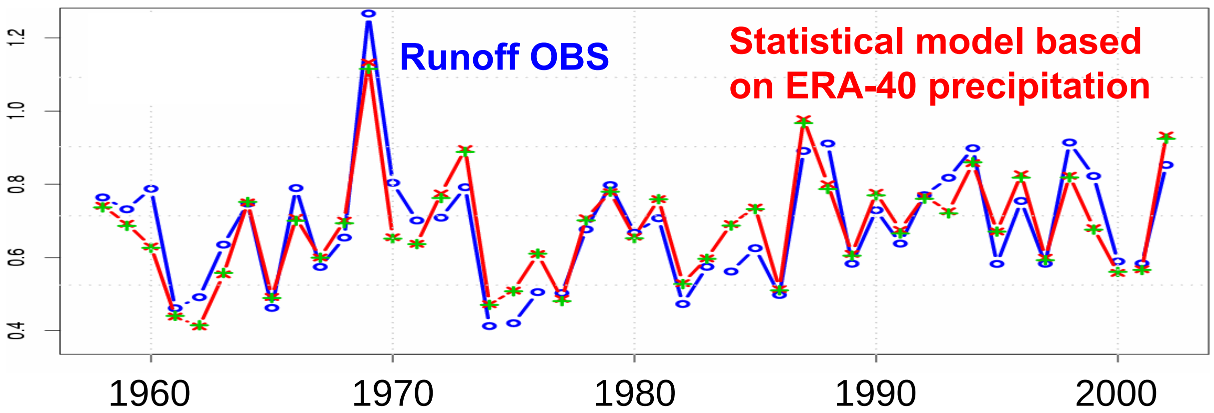
(1) Exploit lag between precipitation P and runoff R

(2) Use ERA-40 and operational ECMWF precipitation (instead of real P data)

(3) Link P and R with a statistical model (requires homogeneity of basin-scale precipitation)



Initial testing: method appears to works (better than with real real-time data available):



Schär et al. 2004, J. Hydromet, 5, 959-973

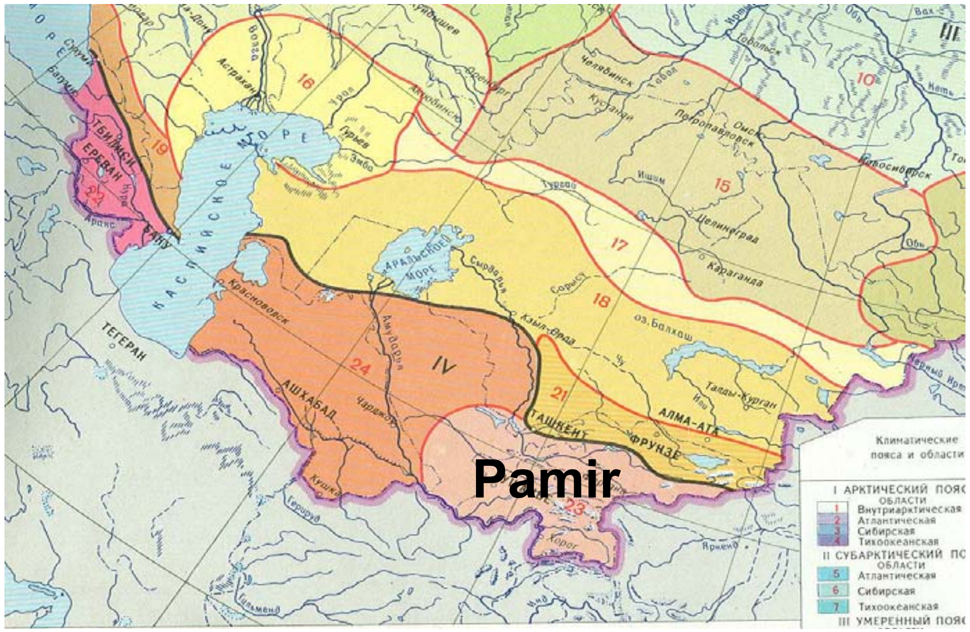
(Reinhard Schiemann, Mariya Glazirina)

Homogeneity of EC precipitation

To test homogeneity, compare following precipitation data sets:

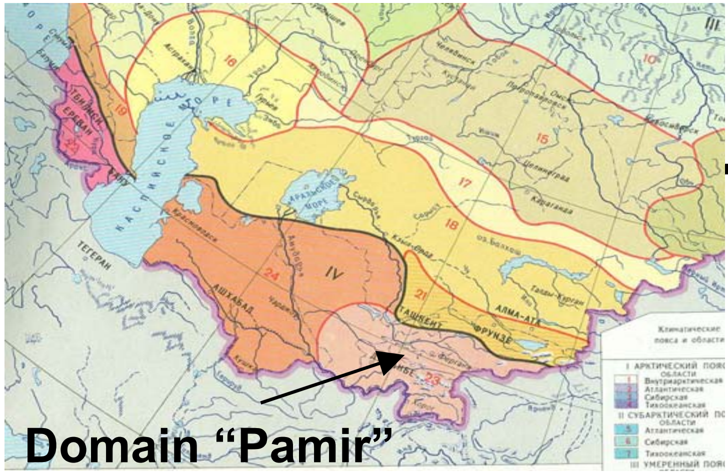
- **OBS: CRU, GPCC, UDEL, analysis based on (delayed-time) rain-gauge observations**
- **ERA40**
- **ECOP: ECMWF operational analysis**
- **CHRM(ERA40): Regional climate model driven by ERA-40**
- **CHRM(ECOP): Regional climate model driven by ECMWF operational analysis**

Averaged over Pamir-region:

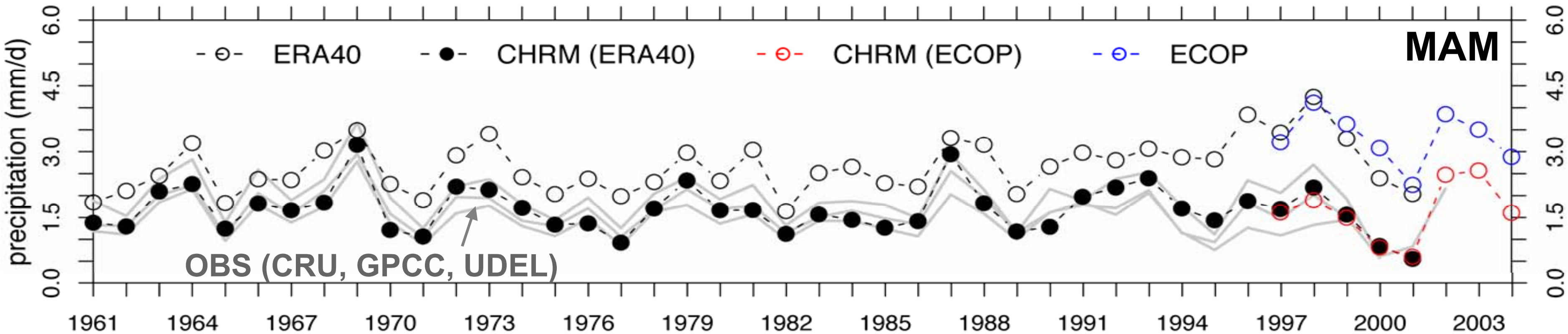


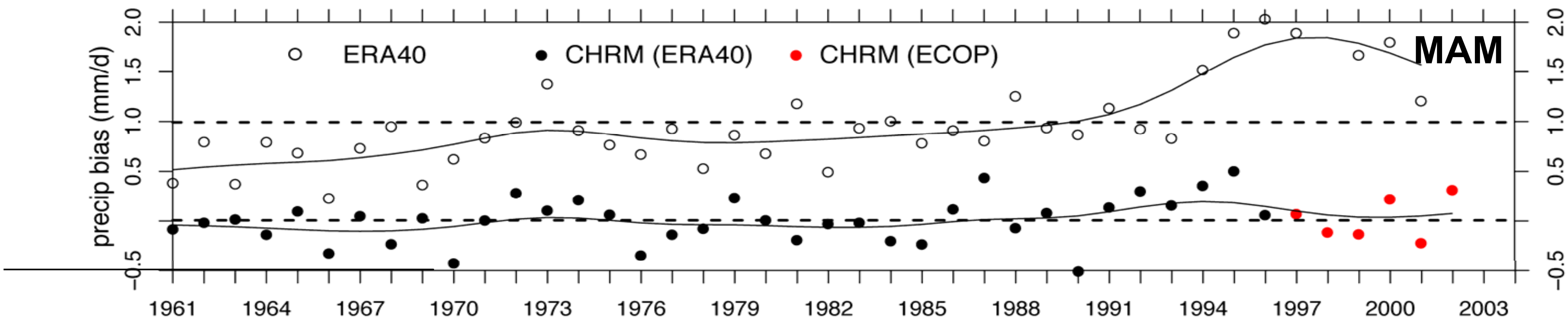
(Schiemann et al. 2006)

Homogeneity of EC precipitation



In MAM and JJA, there is a spurious P increase around 1994. It is also evident in ECMWF operational data (ECOP below). The inhomogeneity disappears when EC data is downscaled using a regional climate model (CHRM below).





(Schiemann et al. 2006)

Conclusions

Evidence from OBS and SIM that JJA 2003 was strongly affected by soil-moisture temperature feedbacks

Evidence from SIM that TWS variations are important for interannual variability of the European summer climate.

Implications for seasonal forecasting!

ERA-40 water vapor convergence data appears rather reliable,
ERA-40 soil moisture is not.

Outlook

Future reanalyses should include some land-surface data assimilation, either offline or online with the atmospheric assimilation.

Prime source of TWS variations is precipitation variability, precipitation observations should be included!

More realistic representation of land-surface is needed.

Steps towards conservation of water substance should be beneficial.

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