Πανεπιστήμιο Αιγαίου

Τμήμα Επιστημών της Θάλασσας-Σχολή Περιβάλλοντος

Ανοικτό ακαδημαϊκό μάθημα

Διαχείριση Παρακτίων Περιοχών

Διδάσκοντες:
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Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

Άδειες Χρήσης

Χρηματοδότηση

- Το παρόν εκπαιδευτικό υλικό έχει αναπτυχθεί στα πλαίσια του εκπαιδευτικού έργου του διδάσκοντα.
- Το έργο «**Ανοικτά Ακαδημαϊκά Μαθήματα στο Πανεπιστήμιο Αιγαίου**» έχει χρηματοδοτήσει μόνο τη αναδιαμόρφωση του εκπαιδευτικού υλικού.
- Το έργο υλοποιείται στο πλαίσιο του Επιχειρησιακού Προγράμματος «Εκπαίδευση και Δια Βίου Μάθηση» και συγχρηματοδοτείται από την Ευρωπαϊκή Ένωση (Ευρωπαϊκό Κοινωνικό Ταμείο) και από εθνικούς πόρους.

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Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Karlsruhe Institute of Technology

Universität Augsburg University

Water in a Warmer World:

Too Much or Not Enough?

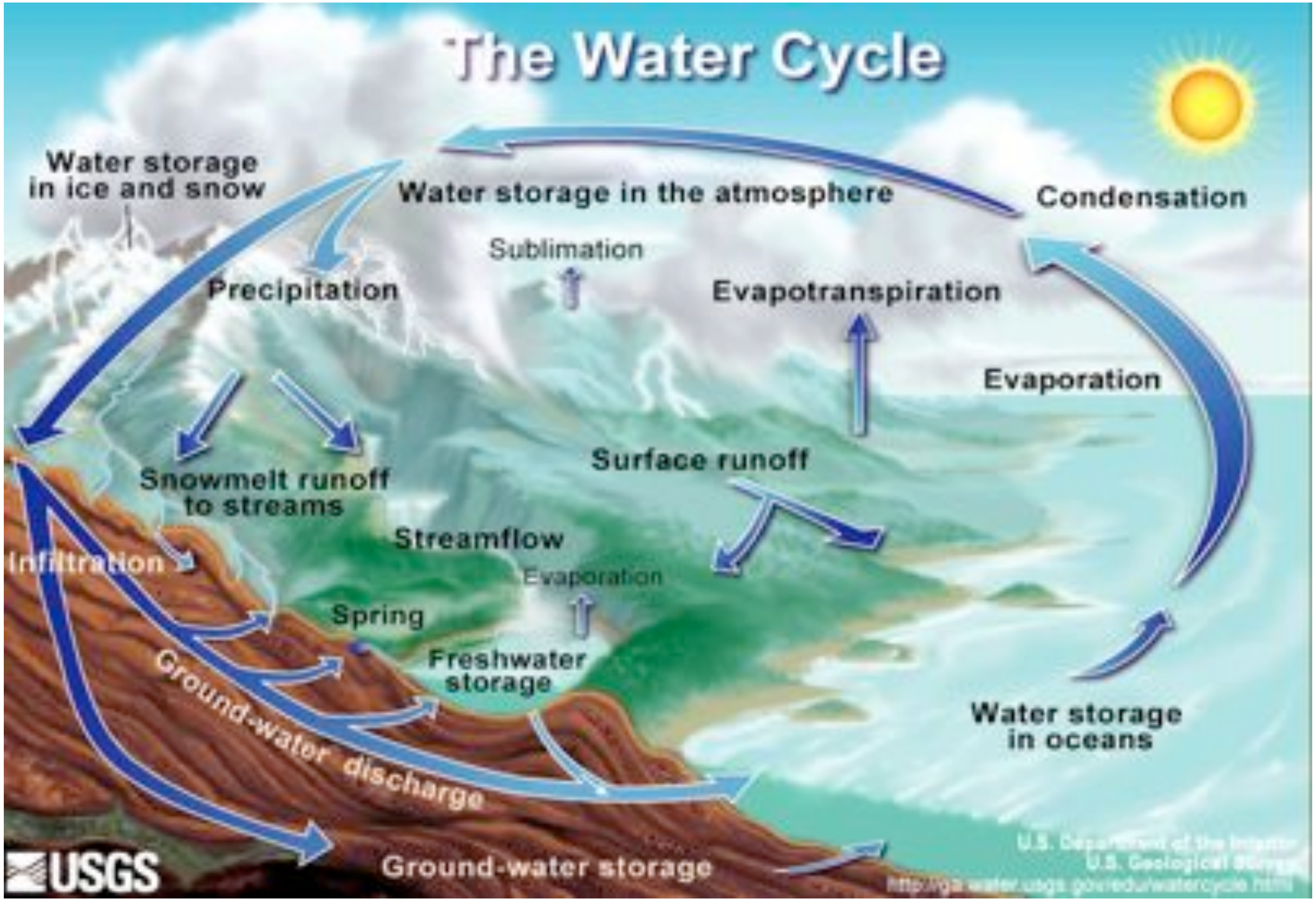
Harald Kunstmann

KIT Campus Alpine, Institute for Meteorology and Climate Research IMK-IFU, Garmisch Partenkirchen, Germany

Far Too Much Water: Donau & Elbe, June 2013 …

… and the Opposite: Droughts

Figures Like this Often Introduce Hydrology Talks …



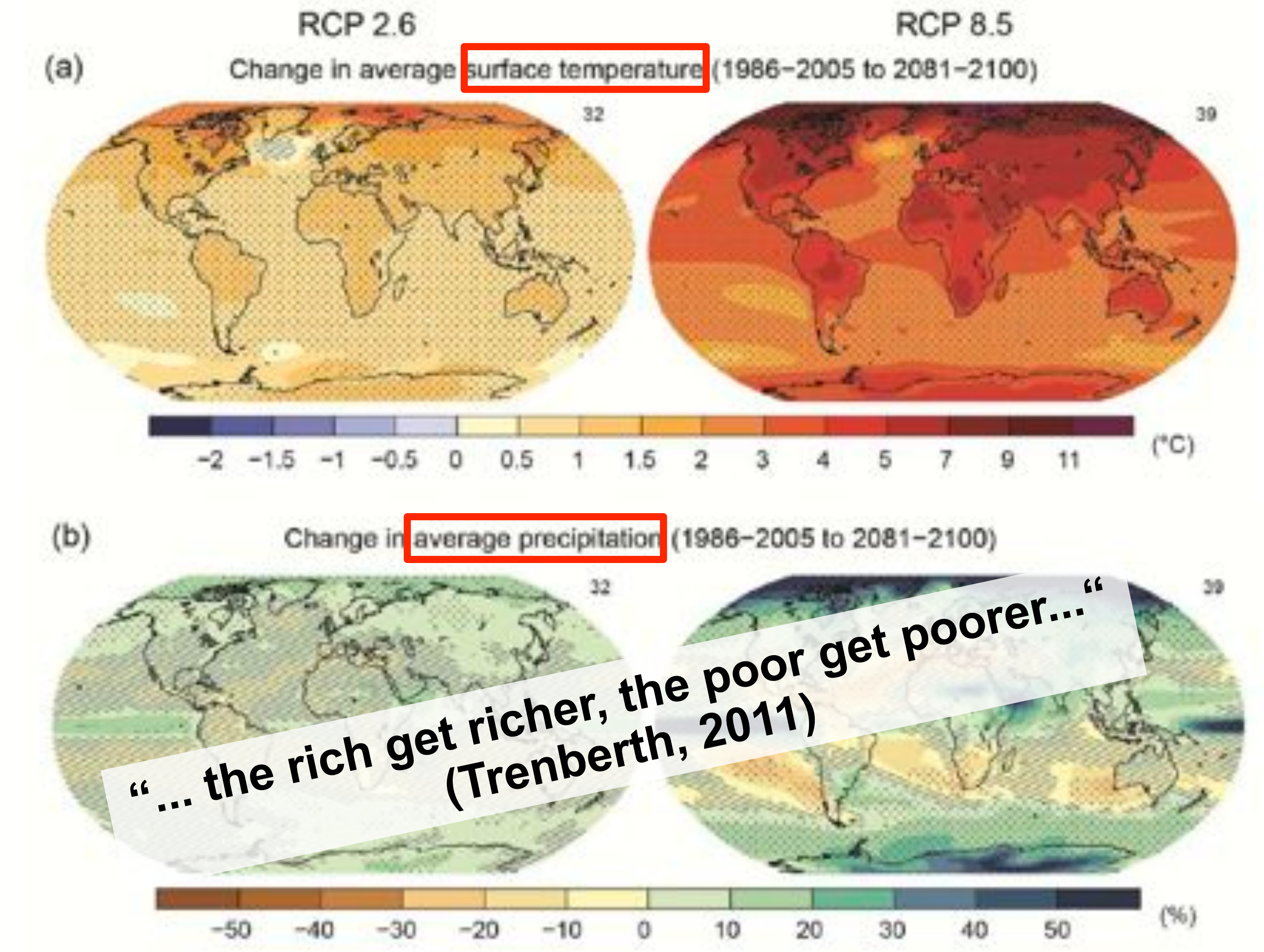
BUT:

How well do we really know the global hydrological cycle?

Global warming: change & intensification of the water cycle?

Regionalization of expected changes: more and/or less water?

Patterns of Expected Changes in "Warmer World"



IPCC, AR5 (2013)

Links Between Water and Energy Cycle

Physical Background

- Increased evaporation E at higher temperatures T
  e.g. empirical *Hargreaves* equation:

$$E = 0.0023 \cdot S_0 \cdot \delta_T \cdot (T + 17.8) \quad mm / day$$

- All phase transitions of water accompanied
  by energy fluxes:

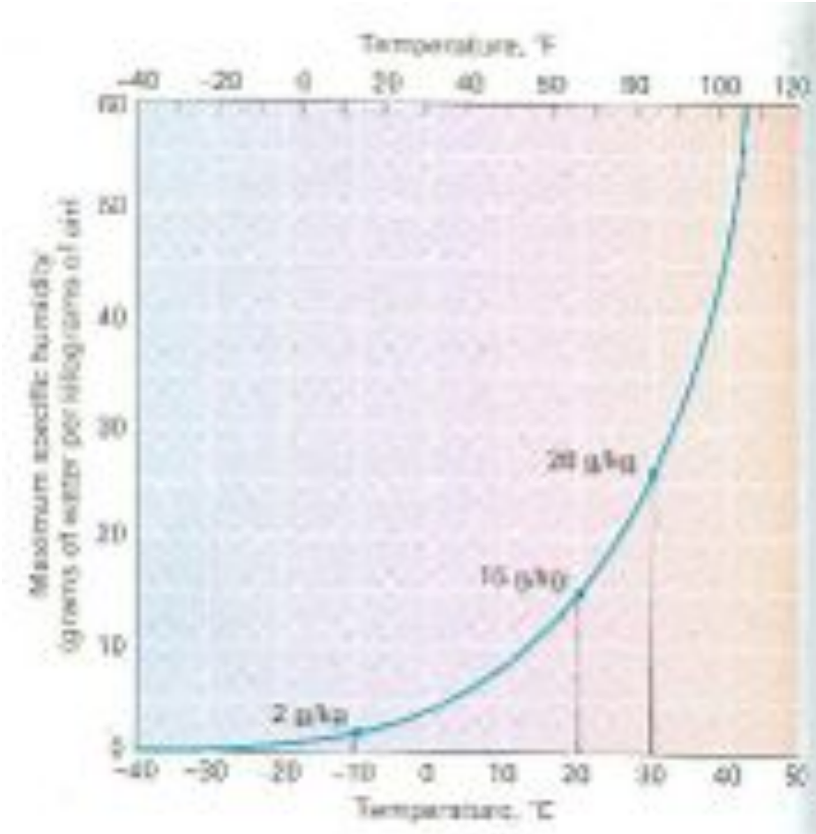
e.g. 2260 KJ/kg
to evaporate
liquid water
with T=100°C

Links Between Water and Energy Cycle

Physical Background

- Increased water vapor carrying capacity at higher temperatures: *Clausius-Clapeyron* equation & parameterizations

$$e_{sat} = 6.11 \cdot e^{\frac{17.3 \cdot T}{T+237.3}} \quad mbar$$



Change of Water Cycle in “Warmer World”?

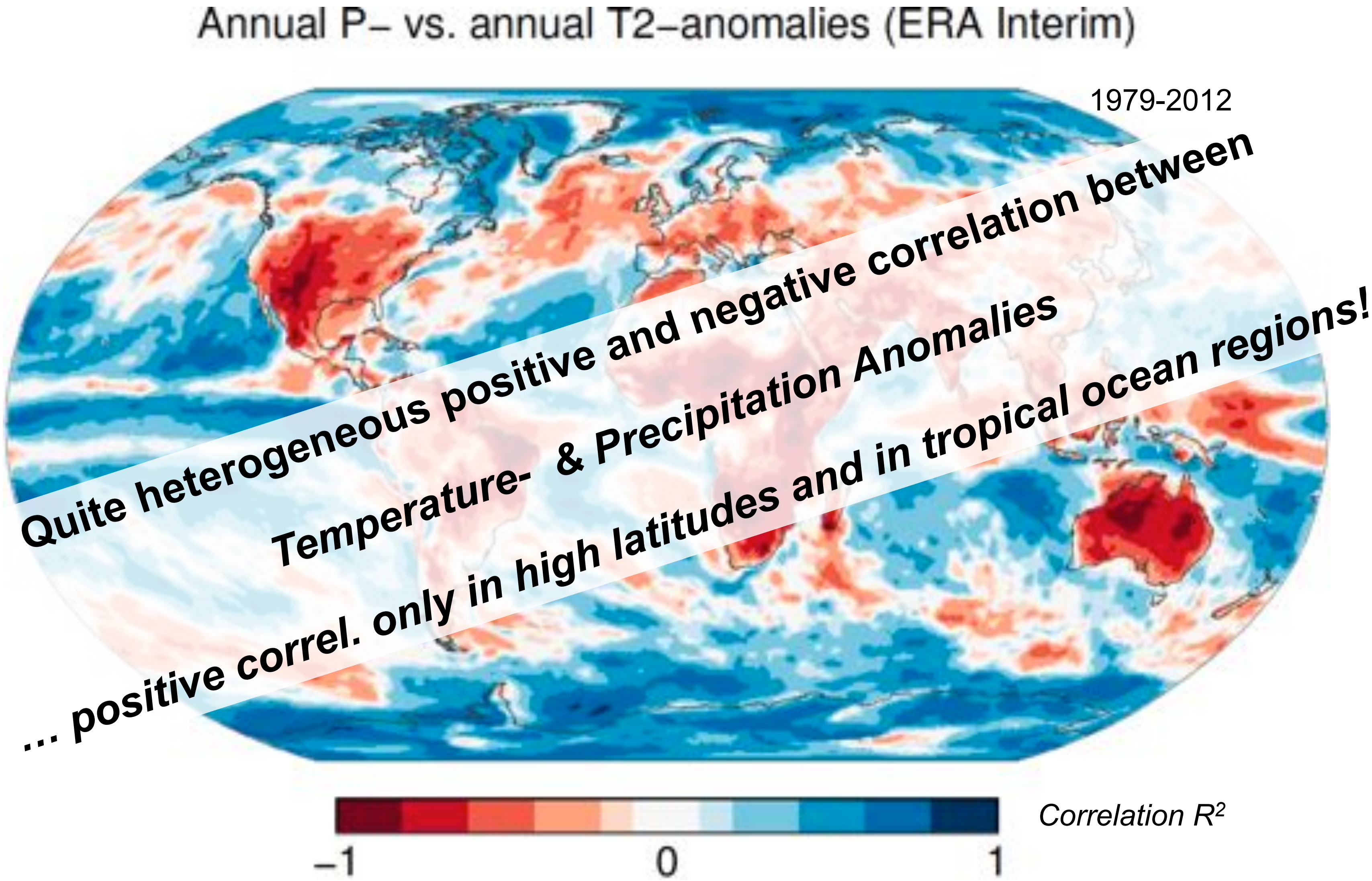
Temperature-precipitation feedback mechanisms

- **Increased temperature** in regions close to saturation
  -> at nearly constant relative humidity **increased absolute humidity**
  -> **increased precipitation** per event possible

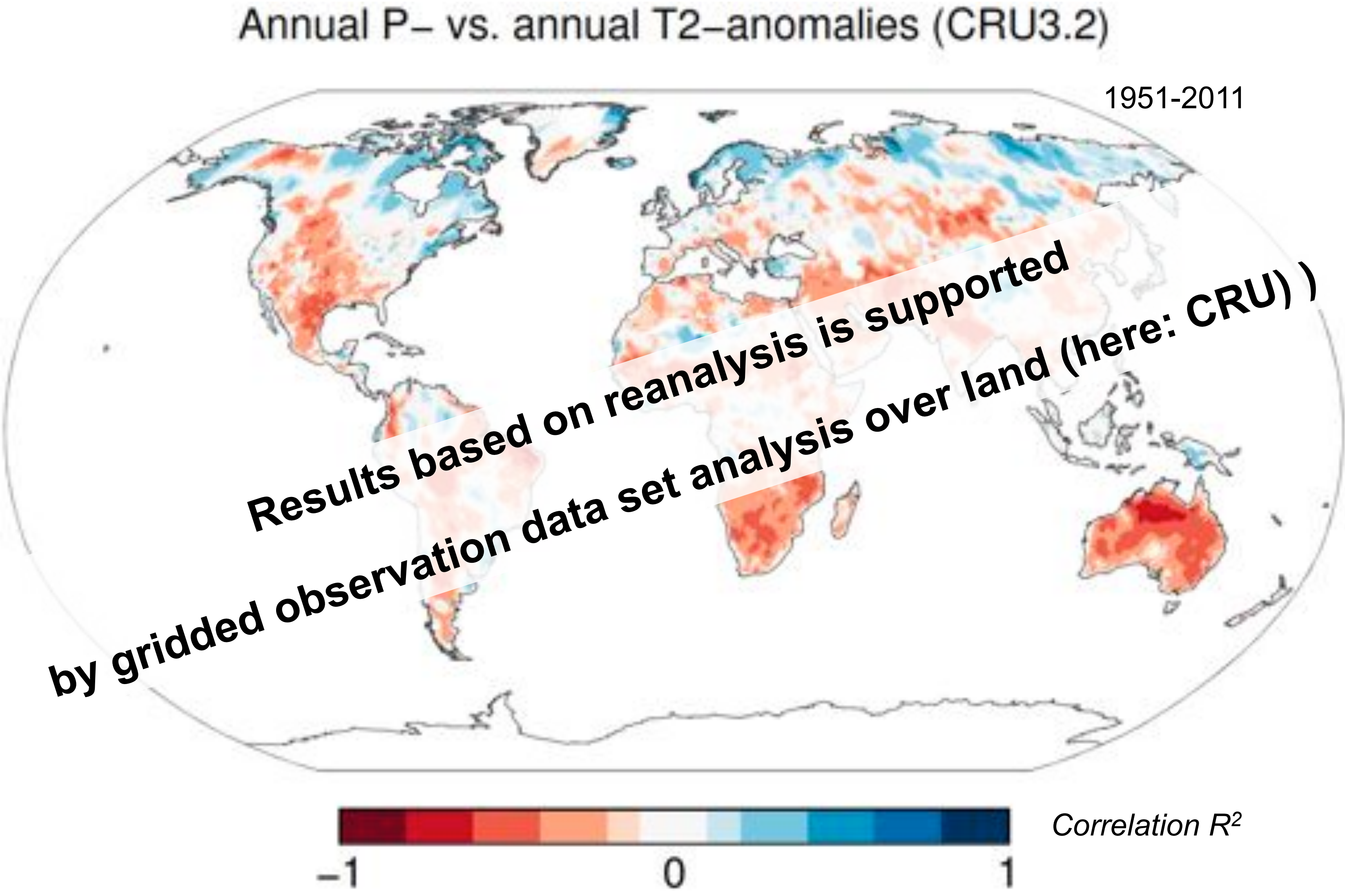
- Every precipitation event accompanied by **energy release** into atmosphere (*condensation*)
  -> decreased temperature lapse rate, stabilization of atmosphere
  -> … suppressing further convection
  -> … **decrease of *subsequent* precipitation** possible

- Large scale spatial distribution of “more” and “less” precipitation:
  interplay between **moisture processes** in atmosphere
  vs.
  atmospheric dynamics, topography, land surface properties, land-sea contrasts, …

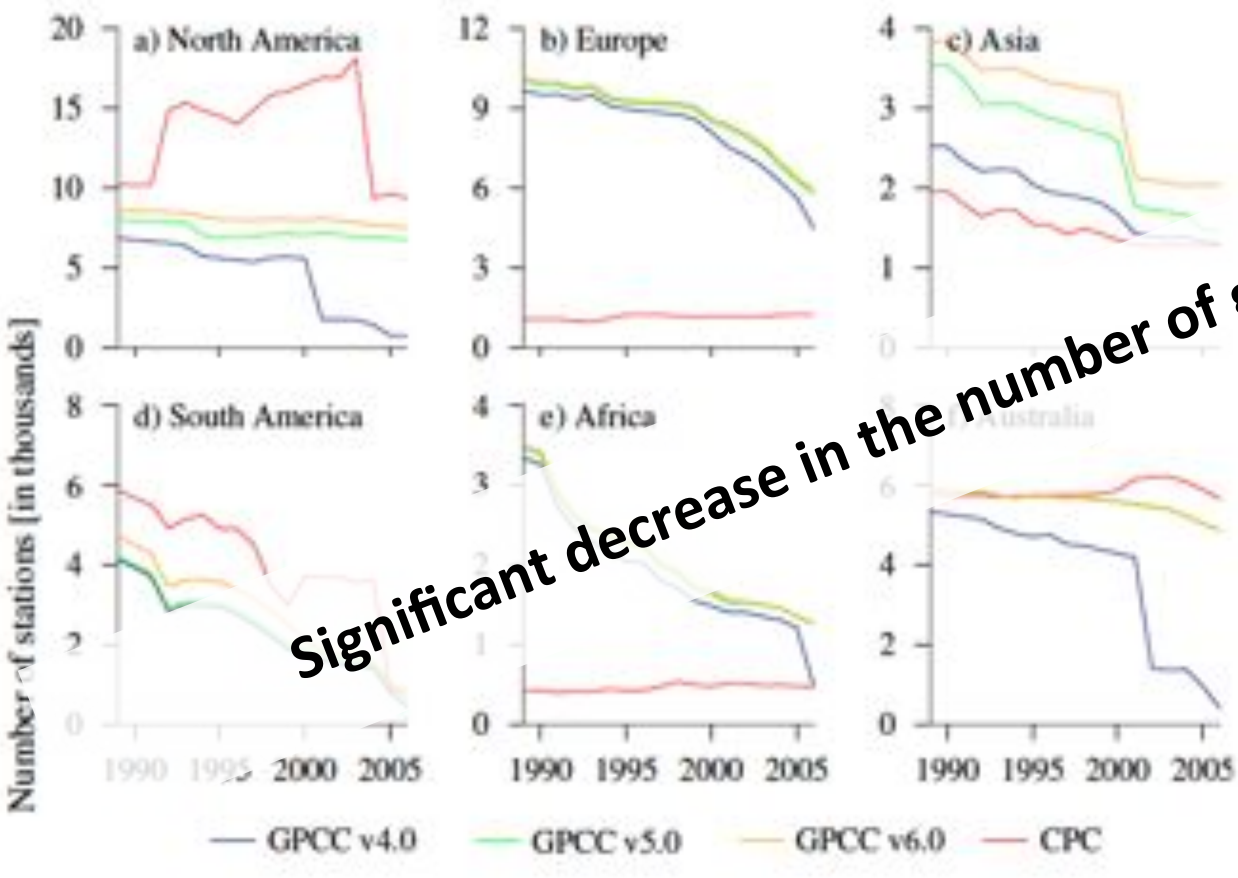
Change of Water Cycle in “Warmer World”?



Change of Water Cycle in "Warmer World"?

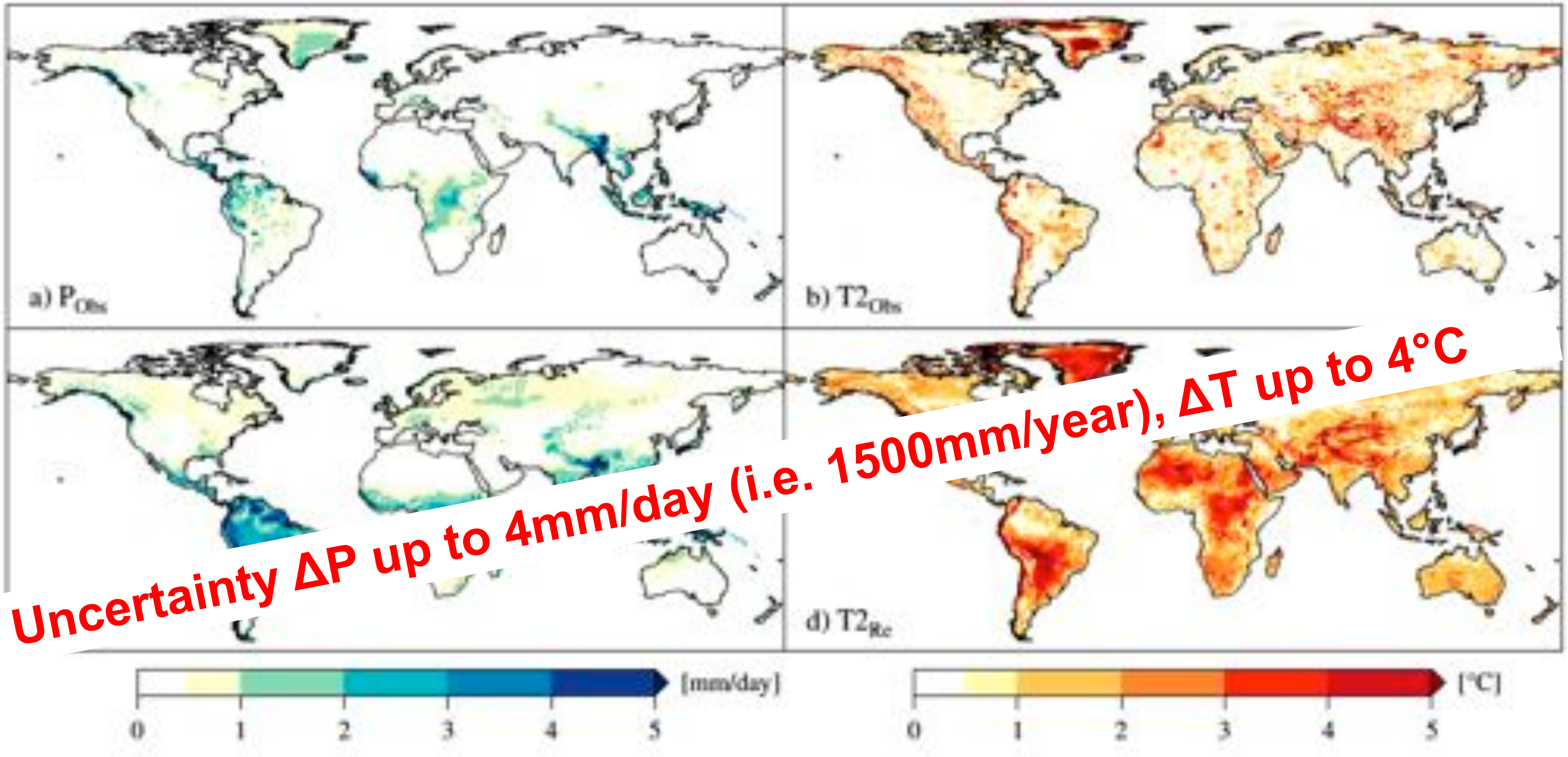


Caution: Significantly Varying Number of Original Data



Continent	Area [10^6 km^2]
North America	19.3
Europe	5.7
Asia	37.4
South America	17.8
Africa	30.0
Australia	7.7

How Well Do We Really Know the Water Cycle?

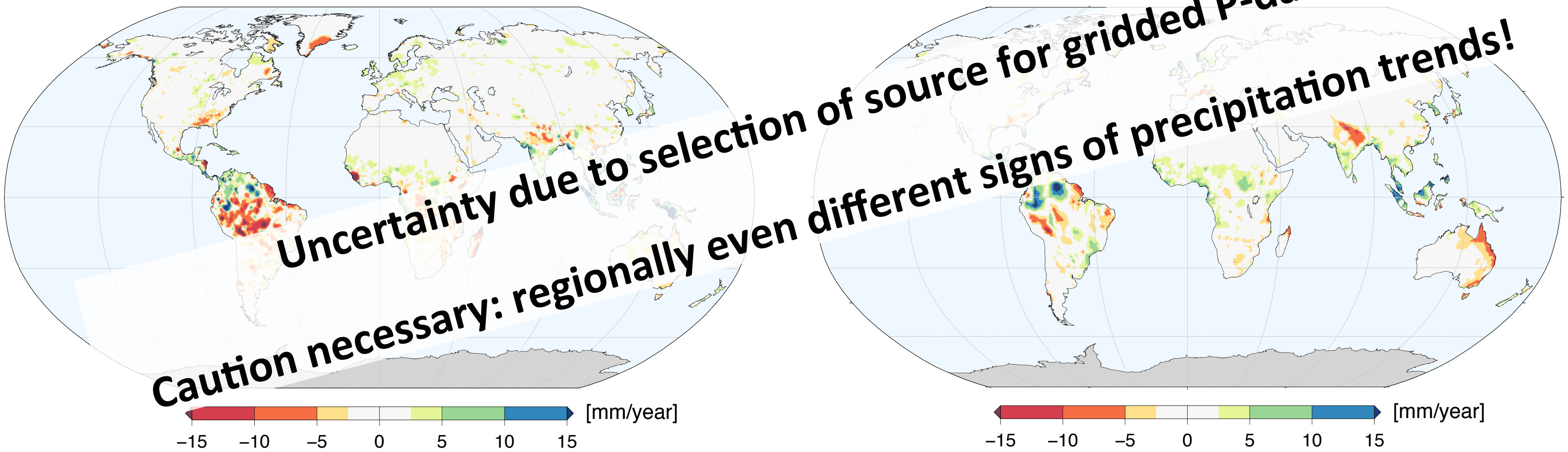


Precipitation observation ensemble: GPCC, GPCP, CPC, CRU, DEL
Temperature observation ensemble: CRU, DEL
Reanalysis ensemble: ERA-Interim, MERRA, CFSR

Trends from Gridded Observation Data Sets?

Trend des Jahresniederschlags zwischen 1979 und 2010
Datengrundlage: GPCC Version 6.0

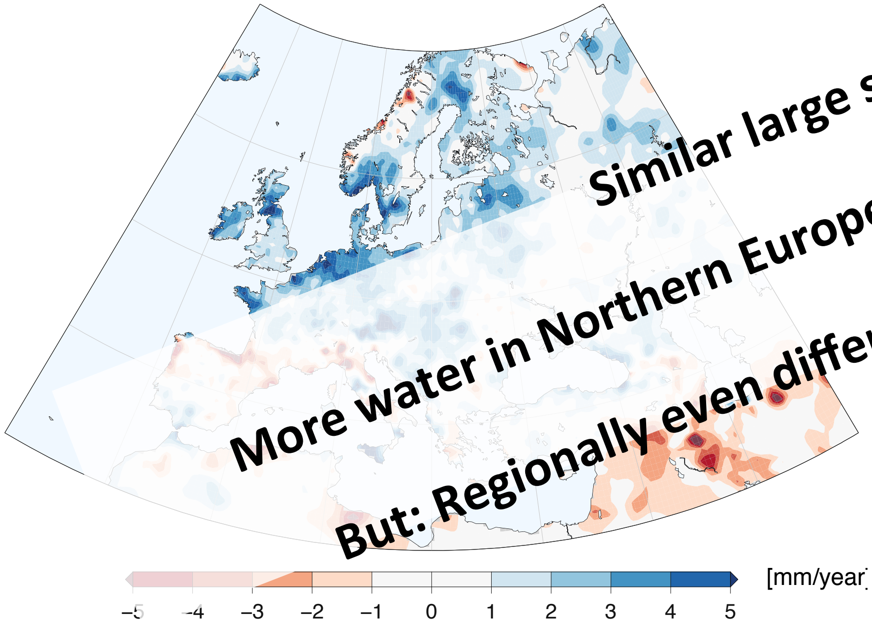
Trend des Jahresniederschlags zwischen 1979 und 2009
Datengrundlage: CRU Version 3



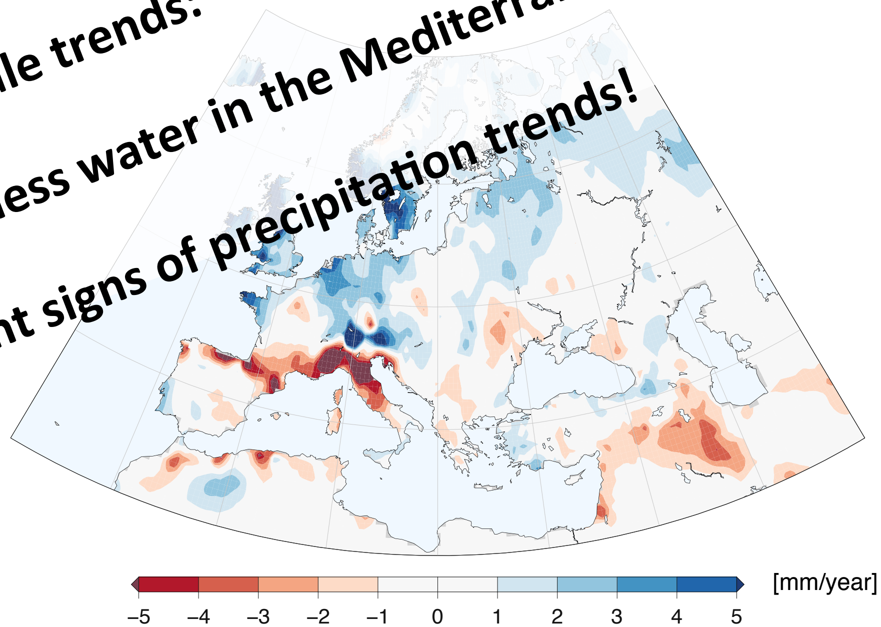
Trends from Gridded Observation Data Sets?

Europe

Mittlerer Jahresniederschlag zwischen 1979 and 2010
Datengrundlage: GPCC Version 6.0



Trend des Jahresniederschlags zwischen 1979 and 2009
Datengrundlage: CRU Version 3



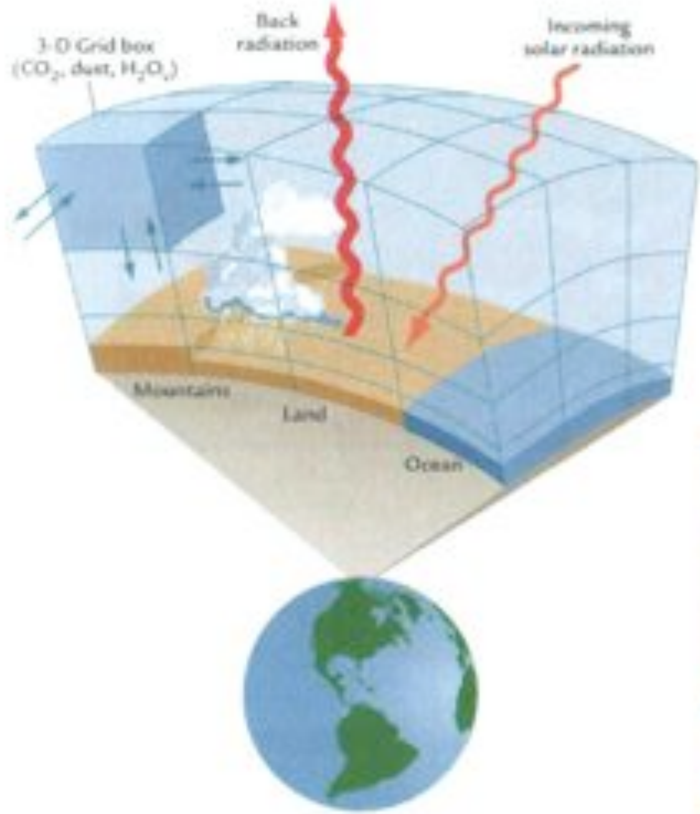
Similar large scale trends:

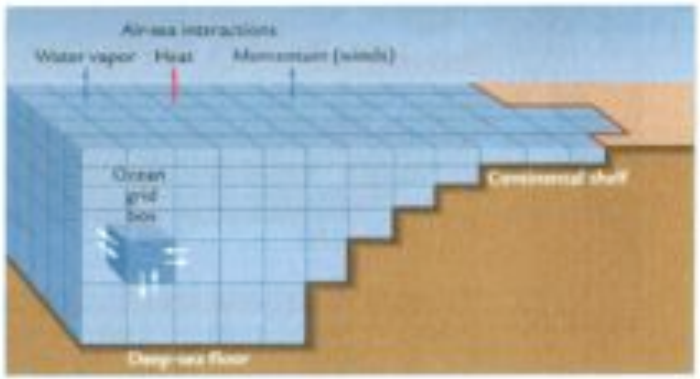
More water in Northern Europe, less water in the Mediterranean

But: Regionally even different signs of precipitation trends!

Methods: Climate Modeling

Global & regional climate models for the understanding of historic climate and projections of future climate





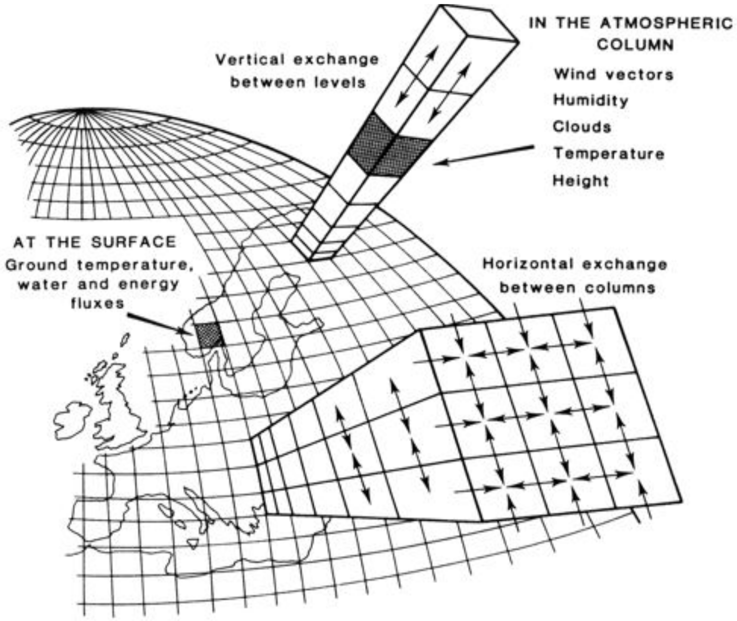
Source: Stocker (2011)

Methods: Climate Modeling

Atmosphere
Continents
Ocean
Ice shelves

For every grid cell explicit calculation of grid-scale state

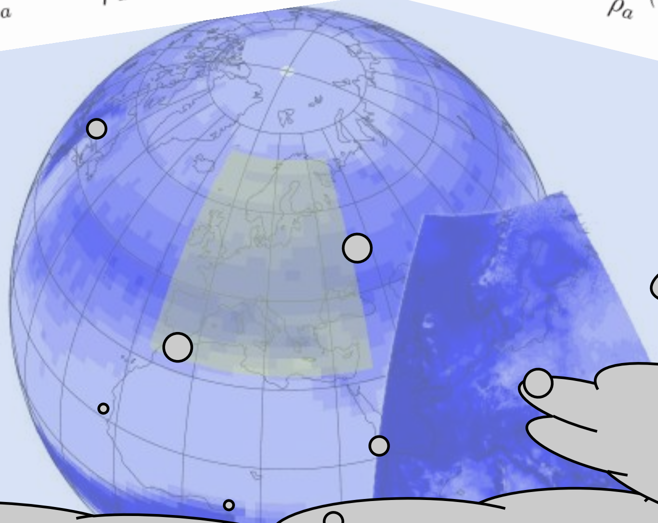
- **Atmosphere:** T, q, p, v, etc.
- **Soil:** T_{soil}, θ



Model equations:
changes of state variables due to

- **Grid-scale processes:**
  physical function of grid-scale variables
- **Sub-grid scale processes**
  empirically derived function of
  grid-scale state variables → parameterizations

Regional Atmospheric Modeling



Momentum Conservation

$$\frac{\partial \vec{v}}{\partial t} + (\vec{v}\cdot\nabla)\,\vec{v} = -f\vec{k}\times\vec{v} - \nabla\Phi - \frac{1}{\rho_a}\nabla p_a + \frac{\eta_a}{\rho_a}\nabla^2\vec{v} + \frac{1}{\rho_a}\left(\nabla\cdot\rho_a \mathbf{K_m}\nabla\right)\vec{v}$$

Energy Conservation

$$\frac{\partial \theta_v}{\partial t} + (\vec{v}\cdot\nabla)\,\theta_v = \frac{1}{\rho_a}\left(\nabla\cdot\rho_a\mathbf{K_h}\nabla\right)\theta_v + \frac{\theta_v}{c_{p,d}T_v}\sum_{n=1}^{N}\frac{dQ_n}{dt}$$

Gas Law

$$p = \frac{nR^*T}{V}$$

Air Mass Conservation

$$\frac{\partial \rho_a}{\partial t} + \nabla\cdot(\vec{v}\rho_a) = 0$$

Water Mass Conservation

$$\frac{\partial q_v}{\partial t} + (\vec{v}\cdot\nabla)\,q_v = \frac{1}{\rho_a}(\nabla\rho_a\mathbf{K_h}\nabla)\,q_v + R_{evap} - R_{cond} - R_{iini} - R_{idep/sub}$$

$$\frac{\partial q_c}{\partial t} + (\vec{v}\cdot\nabla)\,q_c = \frac{1}{\rho_a}(\nabla\rho_a\mathbf{K_h}\nabla)\,q_c + R_{cond} + R_{iini} + R_{idep/sub} - R_{aconv} - R_{accr}$$

$$\frac{\partial q_r}{\partial t} + (\vec{v}\cdot\nabla)\,q_r = \frac{1}{\rho_a}(\nabla\rho_a\mathbf{K_h}\nabla)\,q_r - R_{evap} + R_{aconv} + R_{accr} - \frac{\partial V_f\rho_a g q_r}{\ldots} \quad (2.22)$$

Energy Conservation Land Surface

$$L_vE + H + G = SW_{net} + LW_{net} = (1-\alpha)SW\downarrow + LW\downarrow - \epsilon\,\sigma_B\,T^4_{surf}$$

Soil Temperature Diffusion

$$C_v(\Theta)\frac{\partial T_s}{\partial t} = \frac{\partial}{\partial z}\left[K_t(\Theta)\frac{\partial T_s}{\partial z}\right]$$

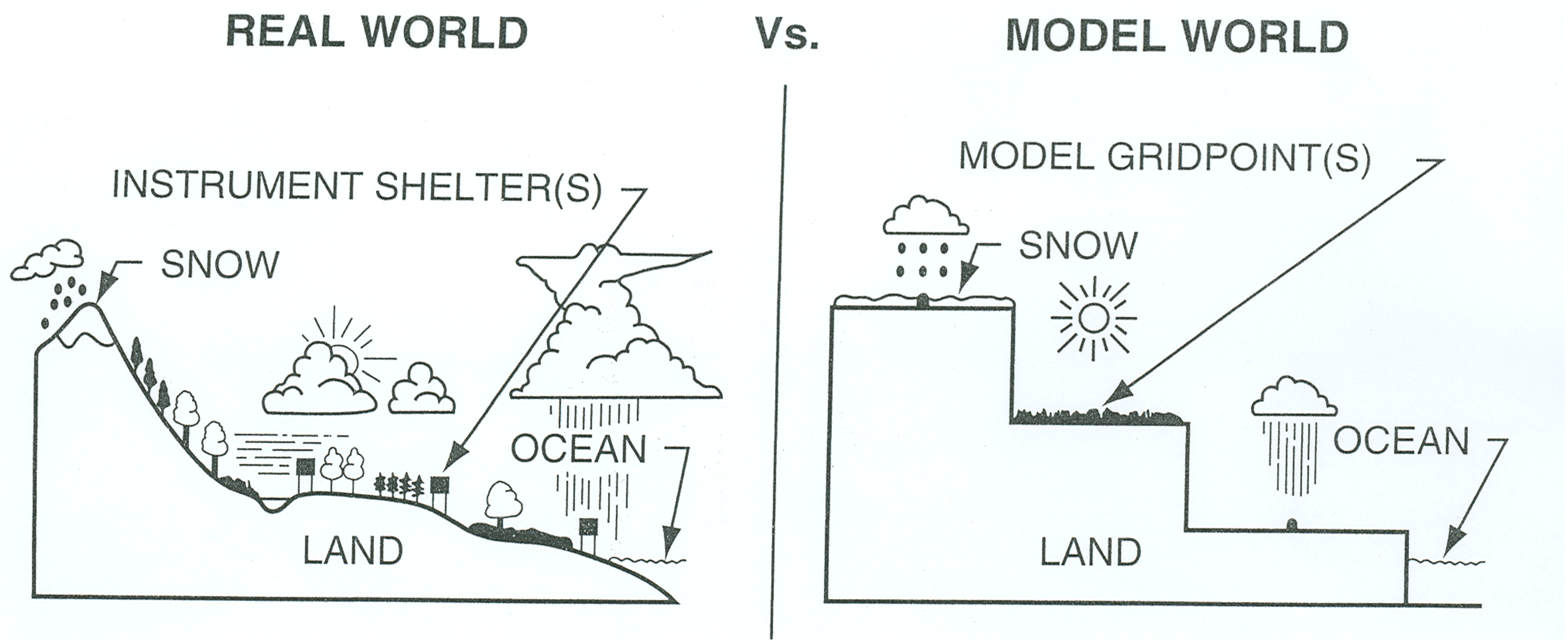
Precipitation Micro Physics

$$R_{evap\ (rain)} = \frac{2\pi N_{0r}(S_w-1)}{A_r+B_r}\left[\frac{0.78}{\Lambda_r^2} + 0.32\left(\frac{a_r\rho}{\eta_a}\right)^{1/2} S_c^{1/3}\frac{\Gamma(5/2+b_r/2)}{\Lambda_r^{5/2+b_r/2}}\right]$$

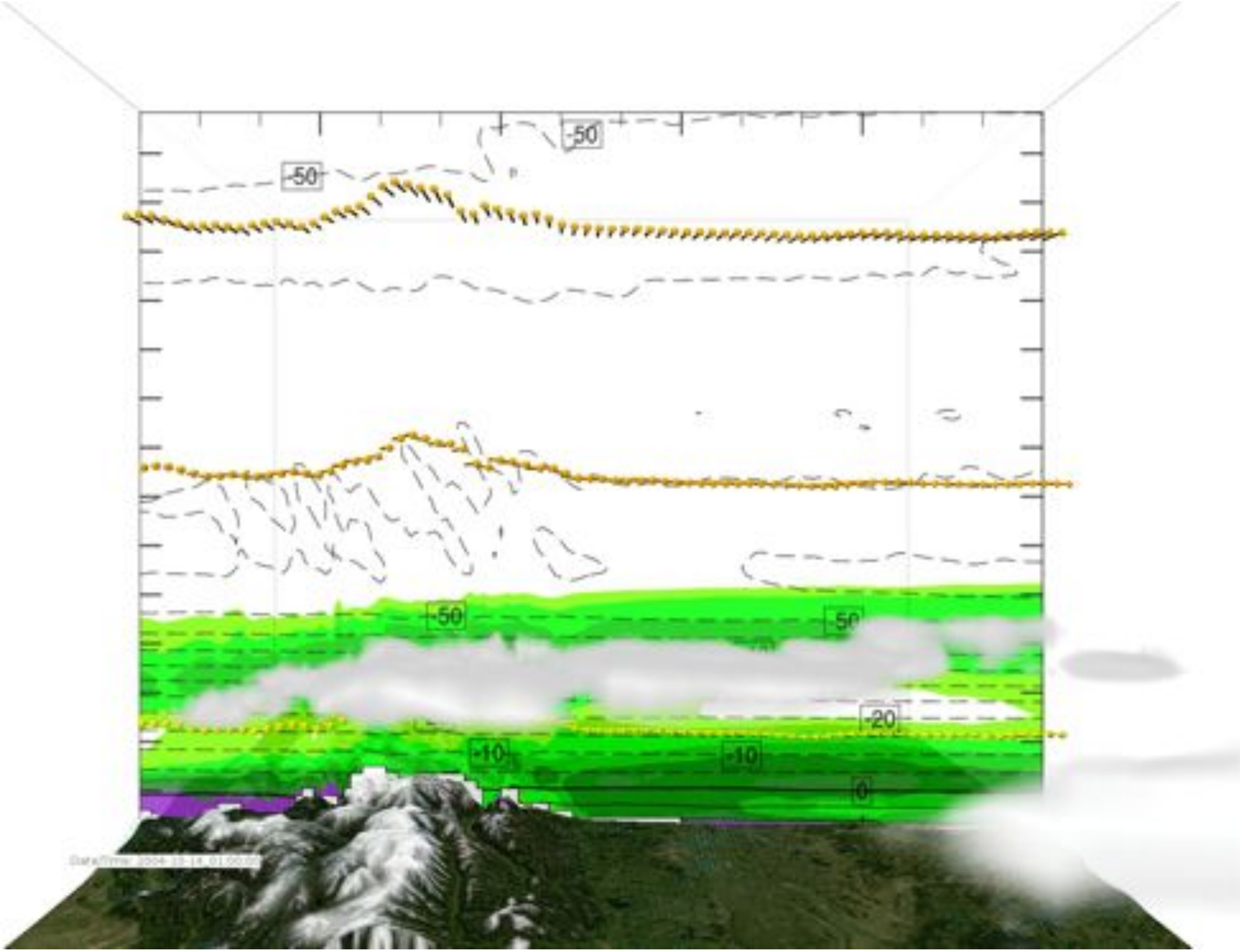
Soil Water Infiltration

$$\frac{\partial\Theta}{\partial t} = \frac{\partial}{\partial z}\left[D(\Theta)\frac{\partial\Theta}{\partial z}\right] + \frac{\partial k(\Theta)}{\partial z}$$

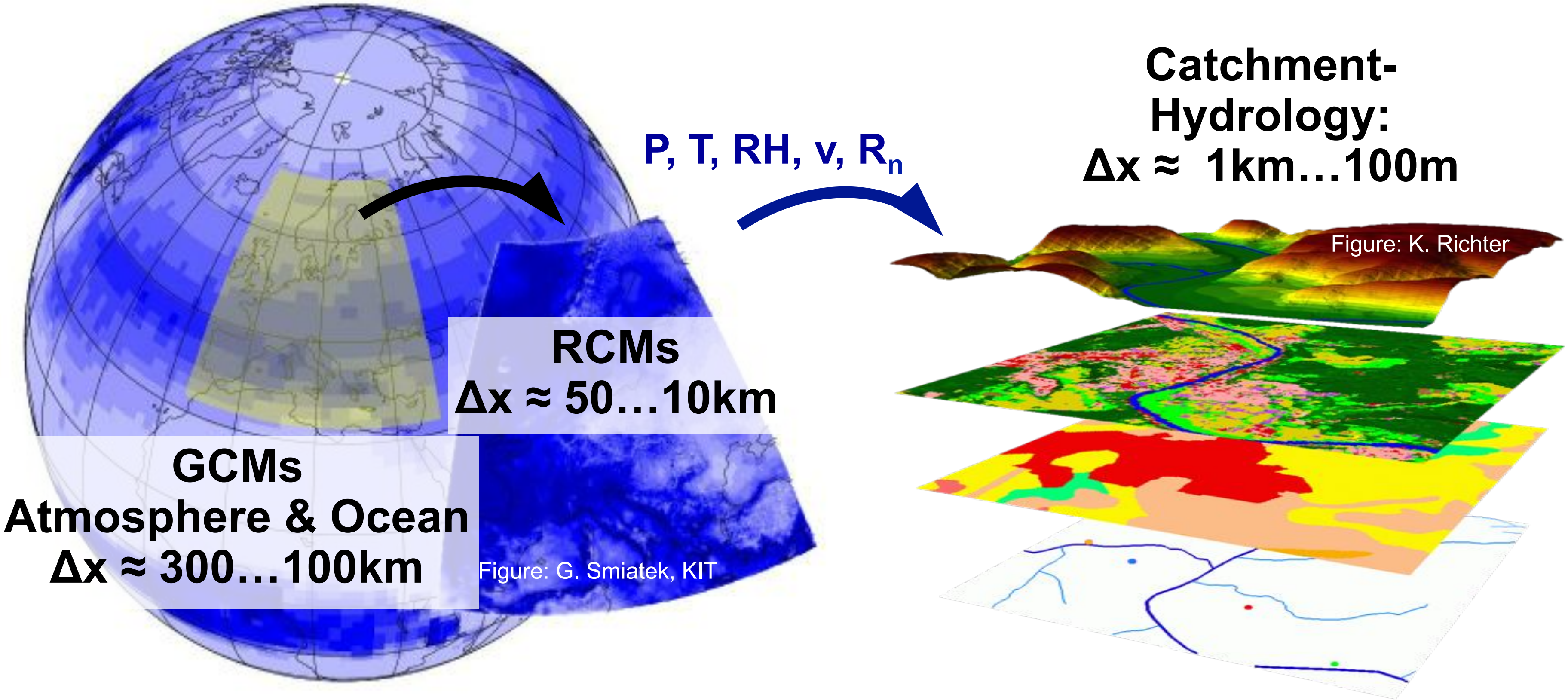
Methods: Climate Modeling - Role of Model Resolution



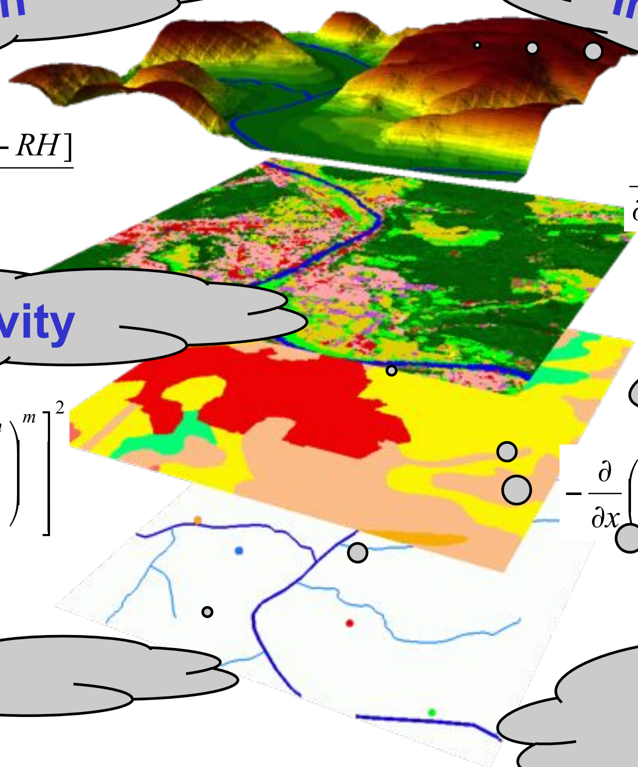
Methods: Climate Modeling



Methods: 1-Way Coupled Model Systems



Hydrological Modeling



Evapotranspiration

$$E = \frac{s(T_a)[K+L] + \gamma K_E \rho_w \lambda_v v_a e_{sat}(T_a)[1-RH]}{\rho_w \lambda_v [s(T_a)+\gamma]}$$

Infiltration

$$\frac{\partial}{\partial z'}\left(K_h(\theta)\frac{\partial \Psi(\theta)}{\partial z'}\right) - \frac{\partial K_h(\theta)}{\partial z'} = \frac{\partial \theta}{\partial t}$$

Hydraulic Conductivity

$$K_h(\theta) = K_{h,sat}\sqrt{\frac{\theta-\theta_{res}}{\phi-\theta_{res}}}\left[1-\left(1-\left(\frac{\theta-\theta_{res}}{\phi-\theta_{res}}\right)^{1/m}\right)^m\right]^2$$

Groundwater Flow

$$-\frac{\partial}{\partial x}\left(K_{hx}\frac{\partial h}{\partial x}\right) - \frac{\partial}{\partial y}\left(K_{hy}\frac{\partial h}{\partial y}\right) - \frac{\partial}{\partial z}\left(K_{hz}\frac{\partial h}{\partial z}\right) + R = -S_s\frac{\partial h}{\partial t}$$

Routing

$$v_h = M\left(\frac{Q_h / v_h}{B_h + \frac{2Q_h}{v_h\, B_h}}\right)^{2/3}\sqrt{I}$$

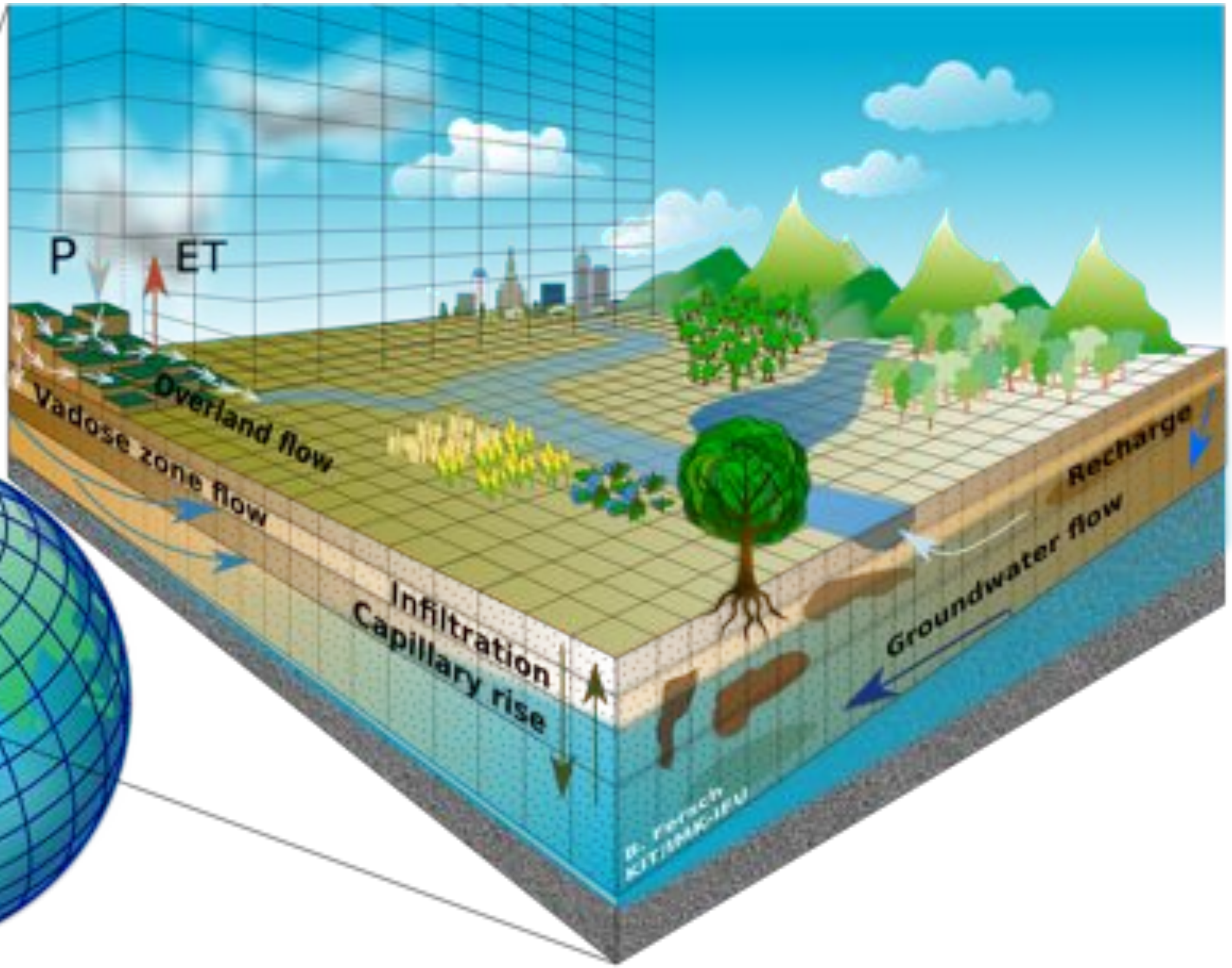
Wave retention

$$Q_{out} = \left(Q_{v,t-1}\cdot e^{-\Delta t/k_v} + Q_{v,t}\cdot(1-e^{-\Delta t/k_v})\right) + \left(Q_{h,t-1}\cdot e^{-\Delta t/k_h} + Q_{h,t}\cdot(1-e^{-\Delta t/k_h})\right)$$

Δx, Δy = 100m-1km, Δt =1h-1d

Towards Fully Coupled Regional Earth System Models

High Performance Computing



Climate Change & Water Availability: EM / Near East

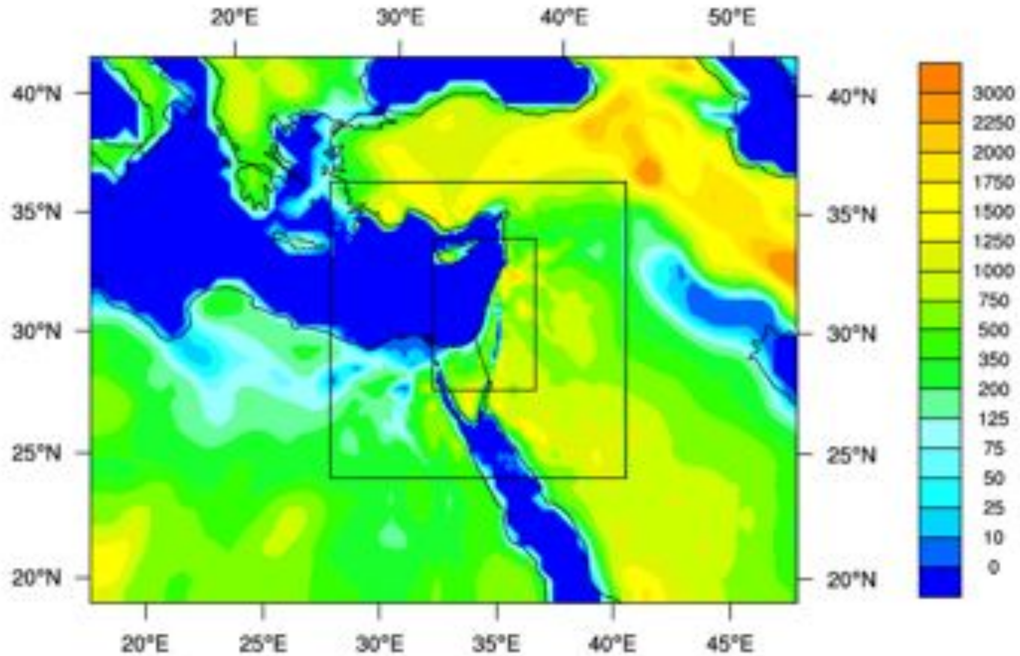
Climate & Water

- Region suffers from water scarcity already today
- Stress on water resources by population growth
- Climate change?

5 Regional Climate Models

- Resolution 54, 18, **6 km**
- Time period: 1960-2100
- Forcing: 2 GCMs

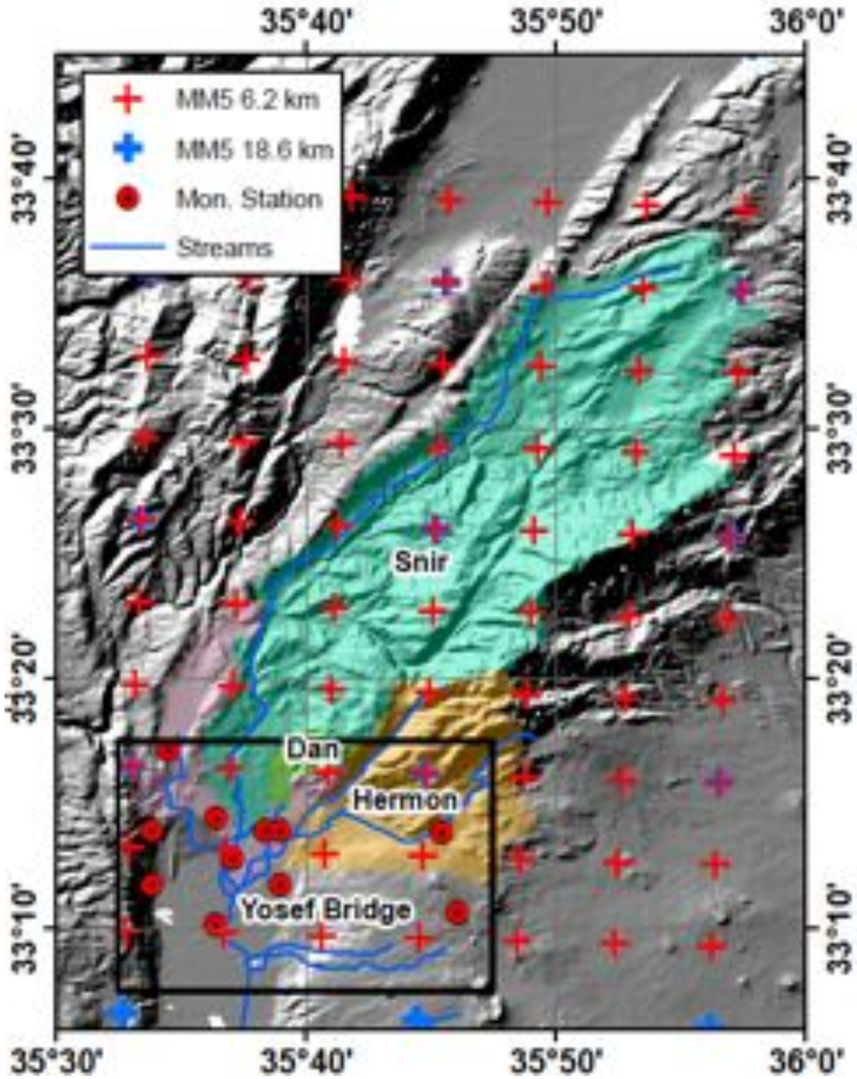
Nested approach



Climate Change & Water Availability: EM / Near East

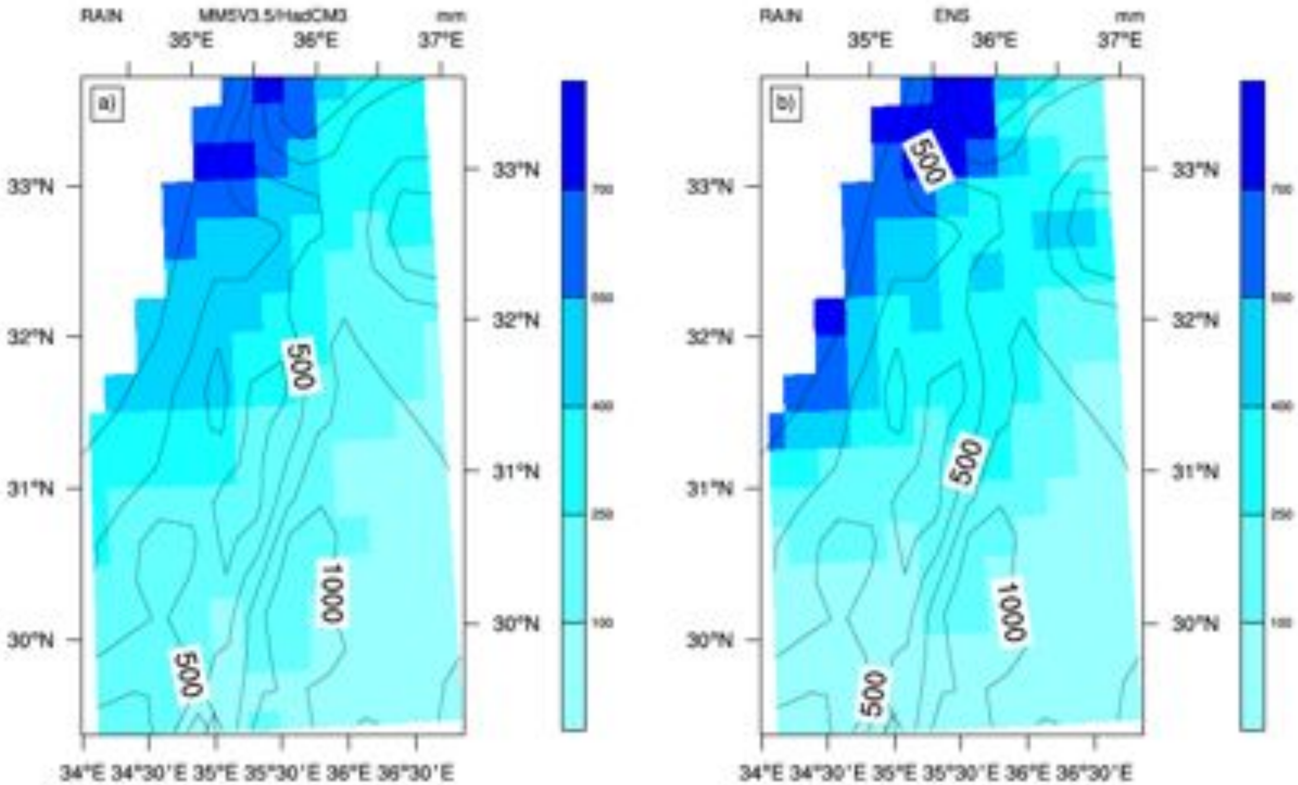
Upper Jordan River

- Major drinking water source for Israel
- 800 km^2
- Partially karstic environment
- Outflow also to springs in Lebonon & Syria
- Complex terrain
- Here: modeled with *WaSiM* with *dx,dy = 450m*



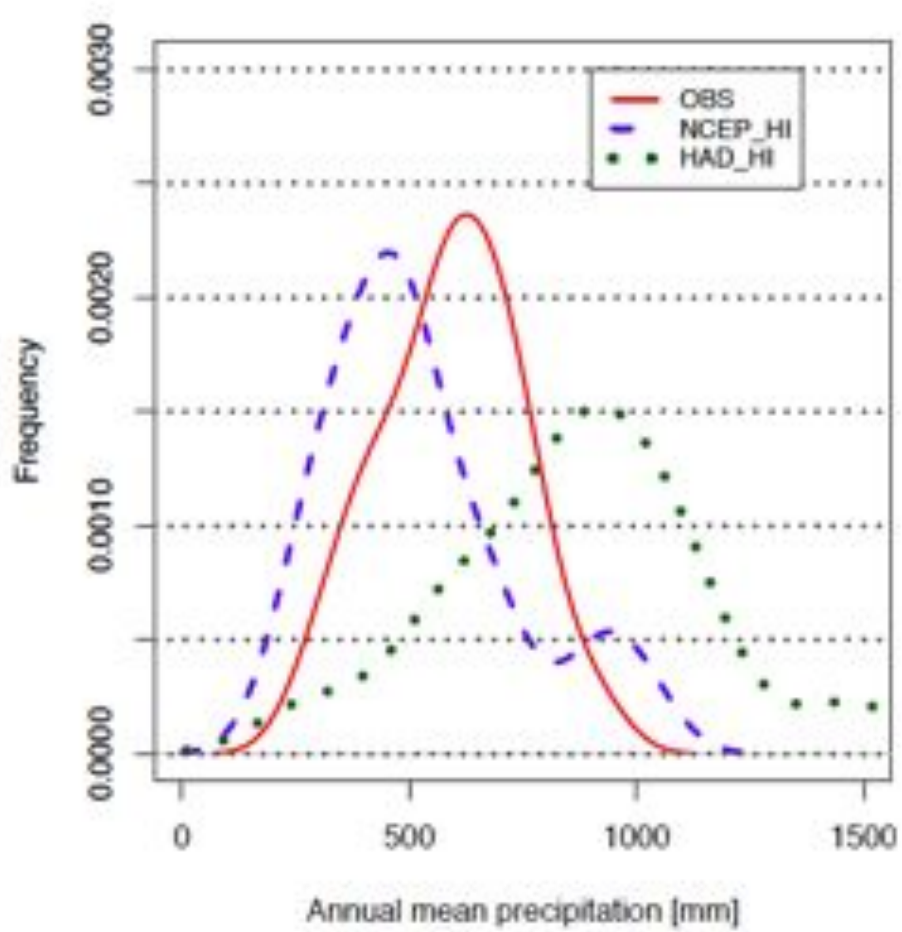
Climate Change & Water Availability: EM / Near East

Simulated vs. observed mean annual precipitation



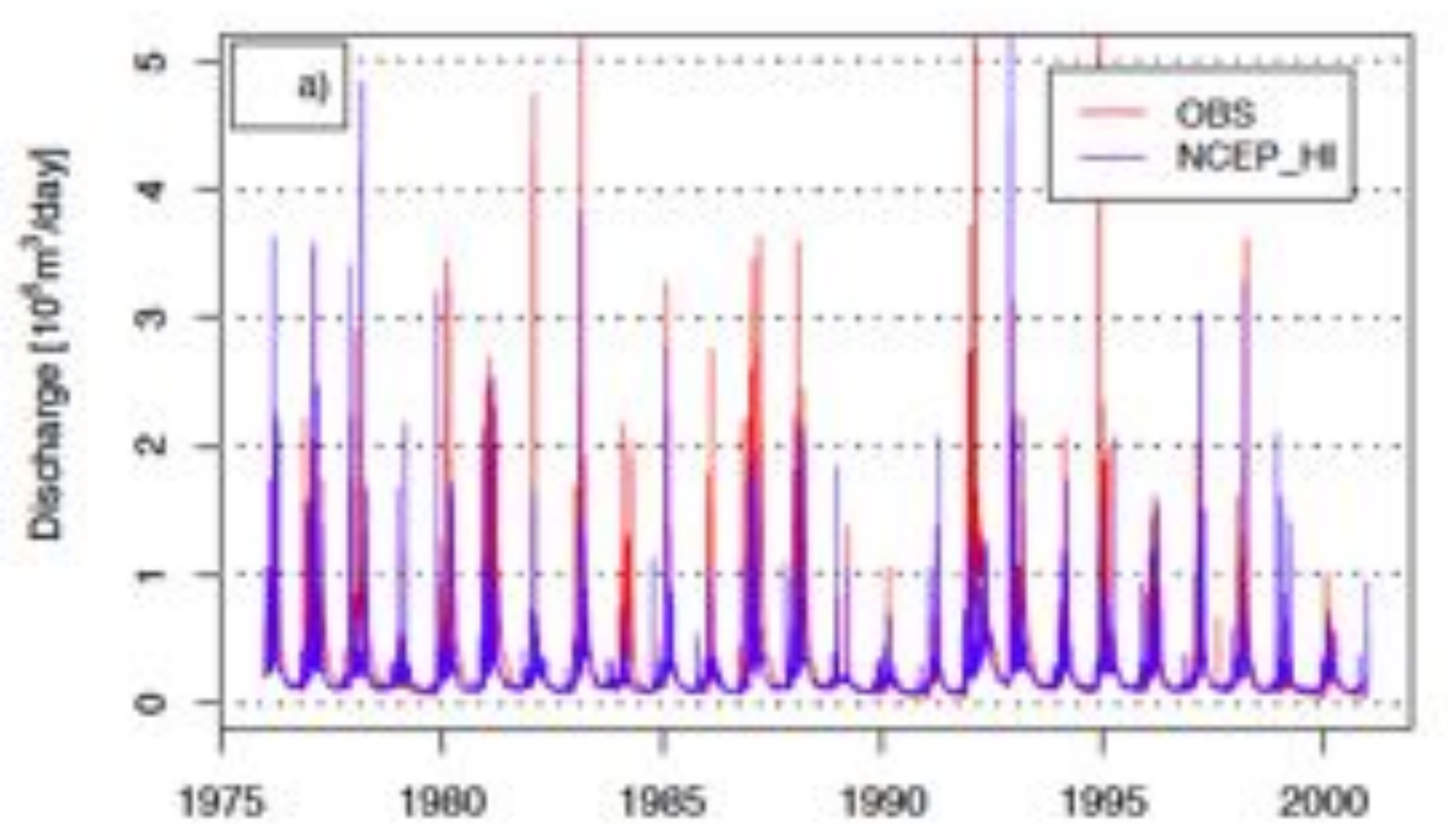
Climate Change & Water Availability: EM / Near East

Simulated vs. Observed Mean Annual Precipitation



Climate Change & Water Availability: EM / Near East

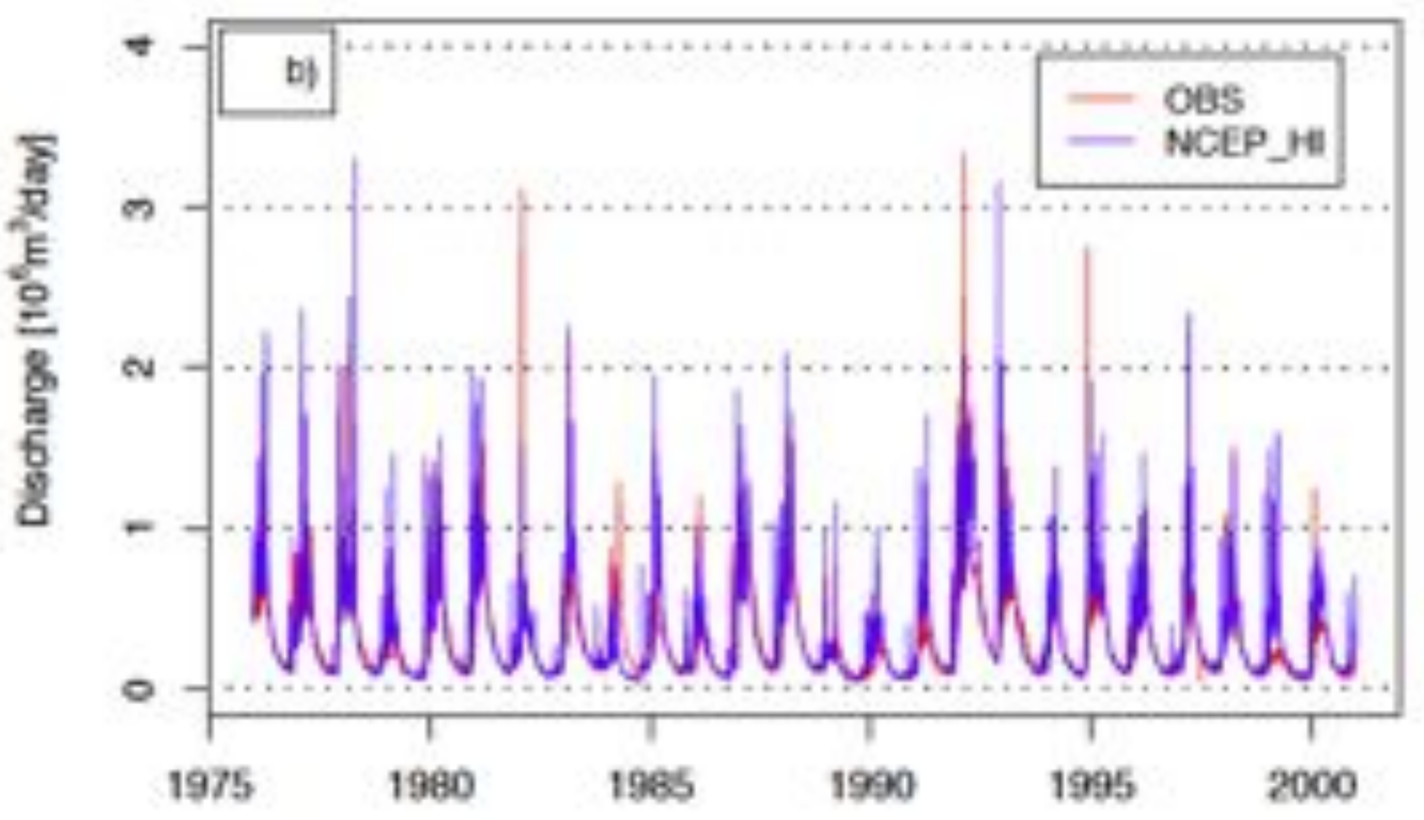
Performance of Hydrological Model



Snir

Climate Change & Water Availability: EM / Near East

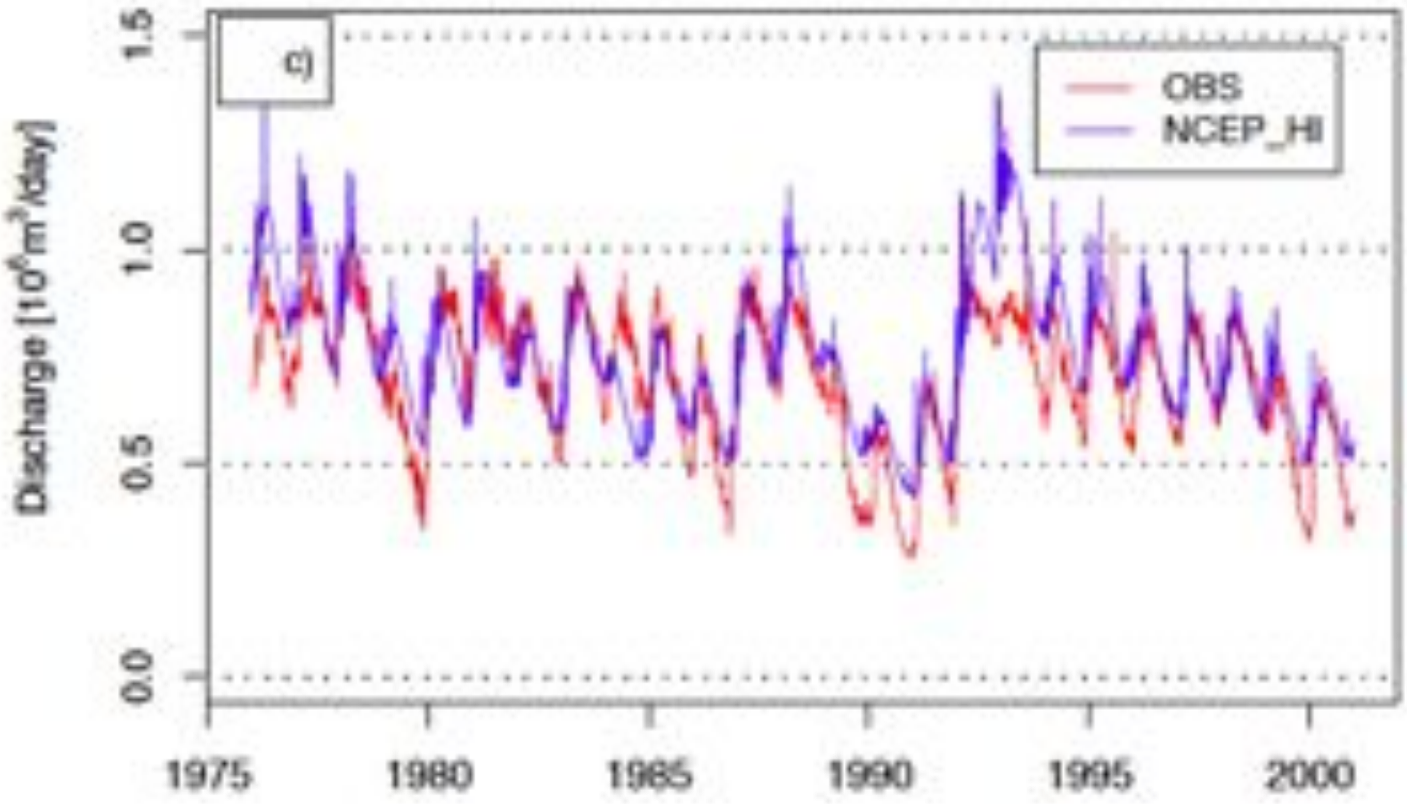
Performance of Hydrological Model



Hermon

Climate Change & Water Availability: EM / Near East

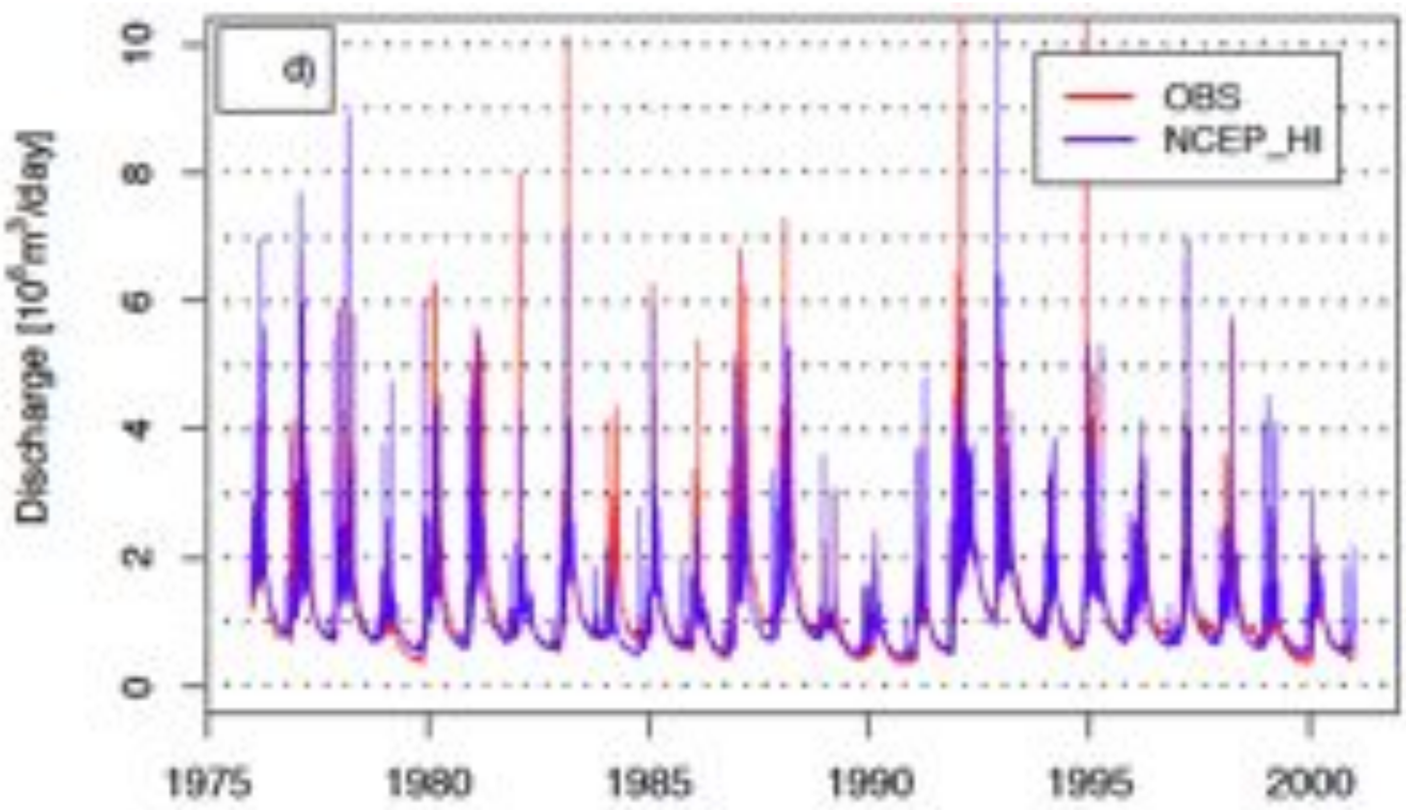
Performance of Hydrological Model



Dan

Climate Change & Water Availability: EM / Near East

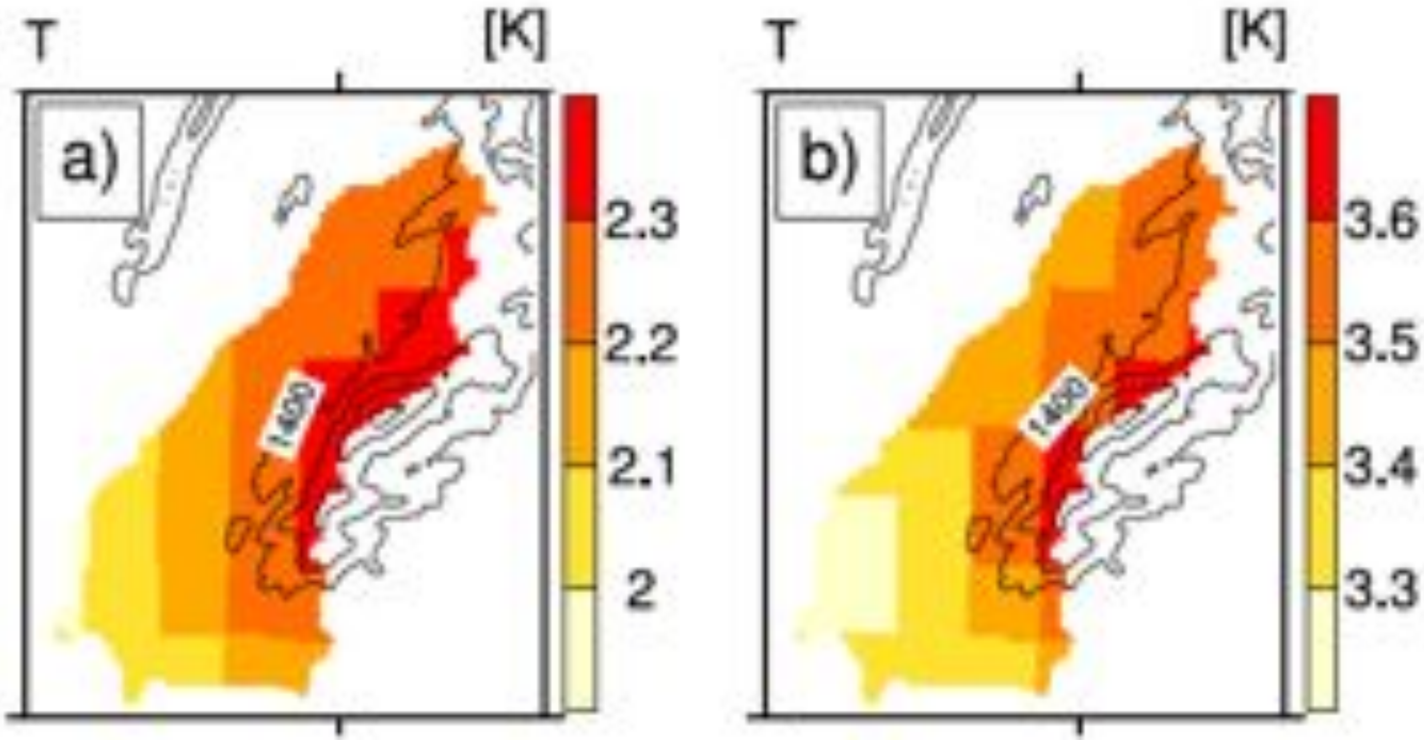
Performance of Hydrological Model



Yoseph Bridge

Climate Change & Water Availability: EM / Near East

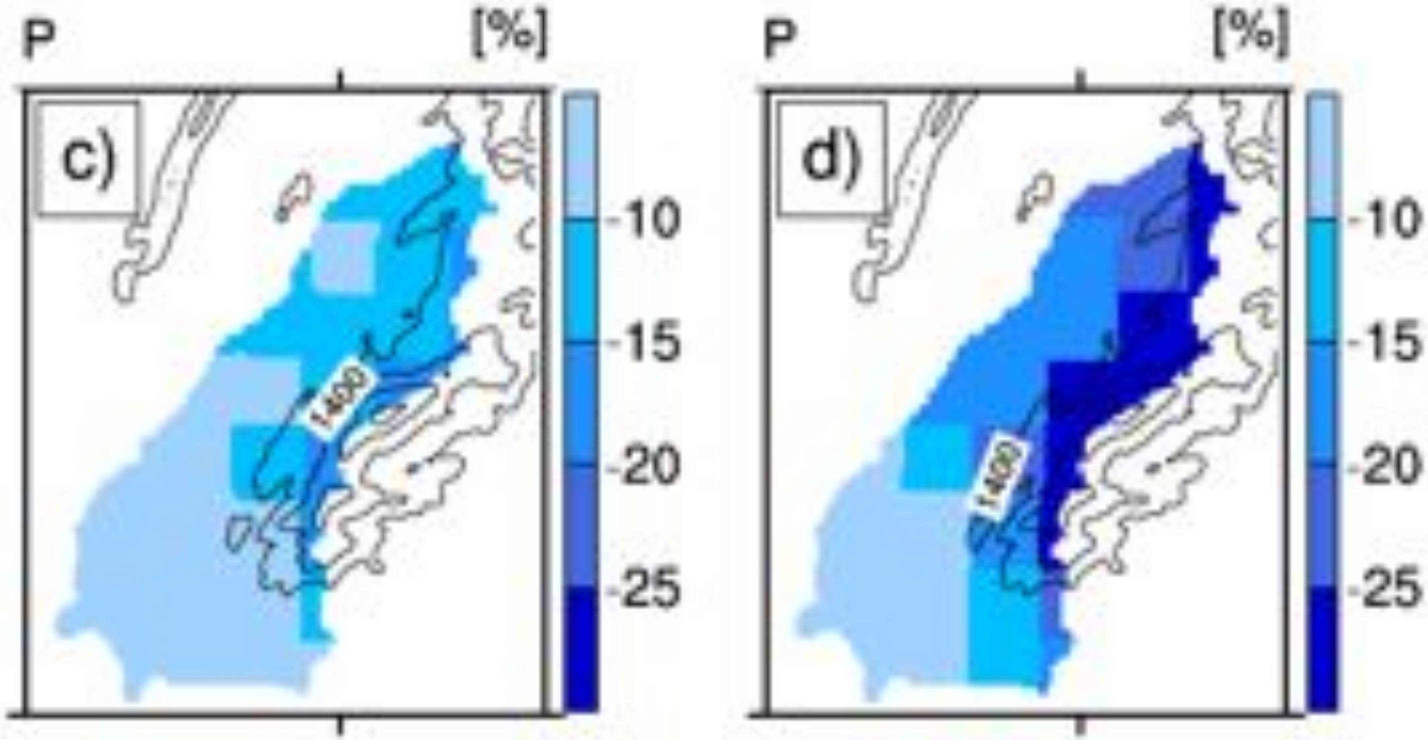
Expected Climate Change Impact for Upper Jordan



Left: 2031-2060 related to 1961-1990
Right: 2070-2099 related to 1961-1990

Climate Change & Water Availability: EM / Near East

Expected Climate Change Impact for Upper Jordan



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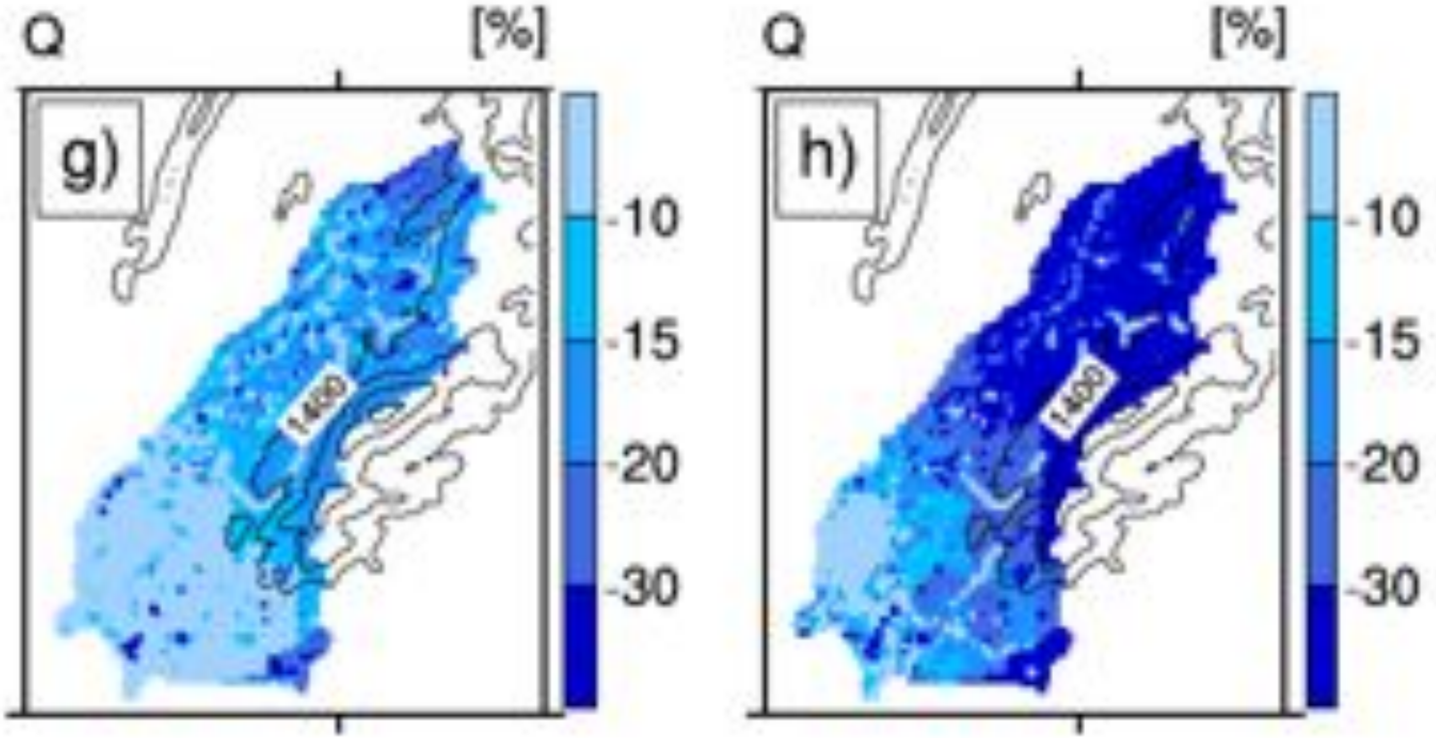
Climate Change & Water Availability: EM / Near East

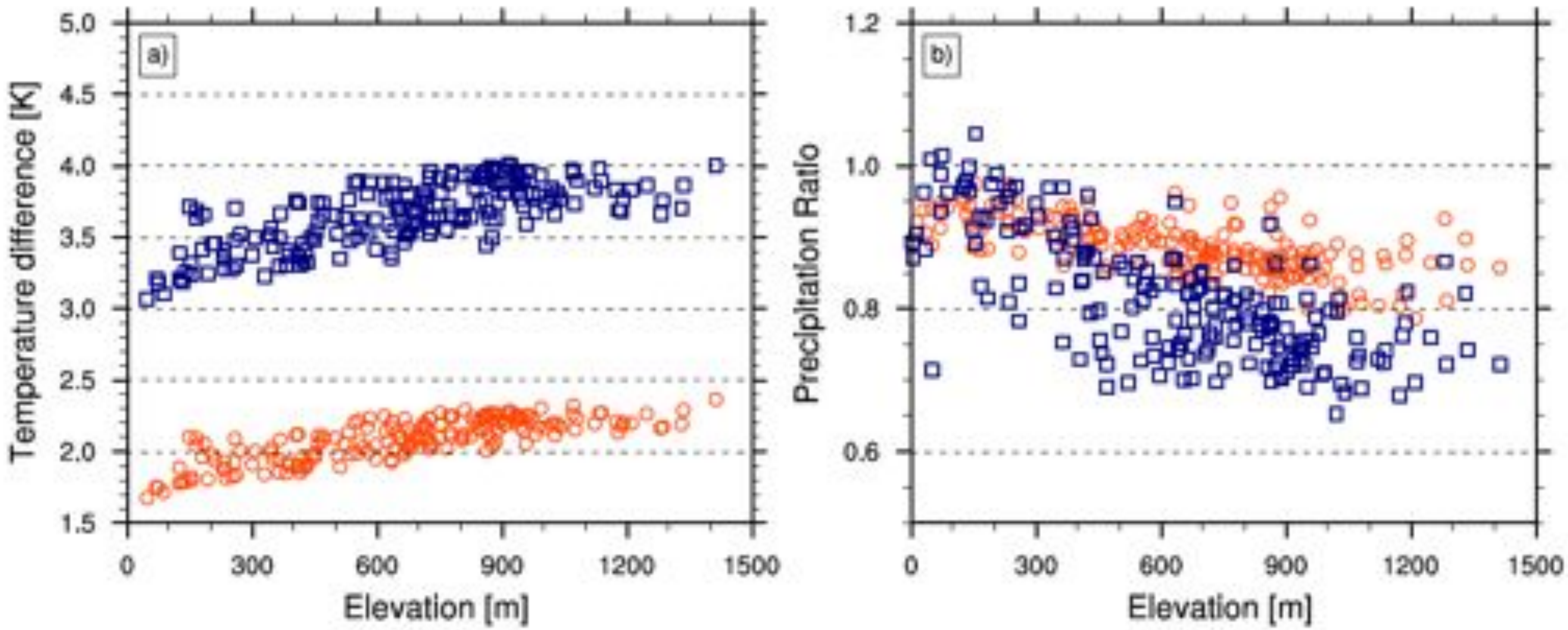
Expected Climate Change Impact for Upper Jordan



Left: 2031-2060 related to 1961-1990
Right: 2070-2099 related to 1961-1990

Climate Change & Water Availability: EM / Near East

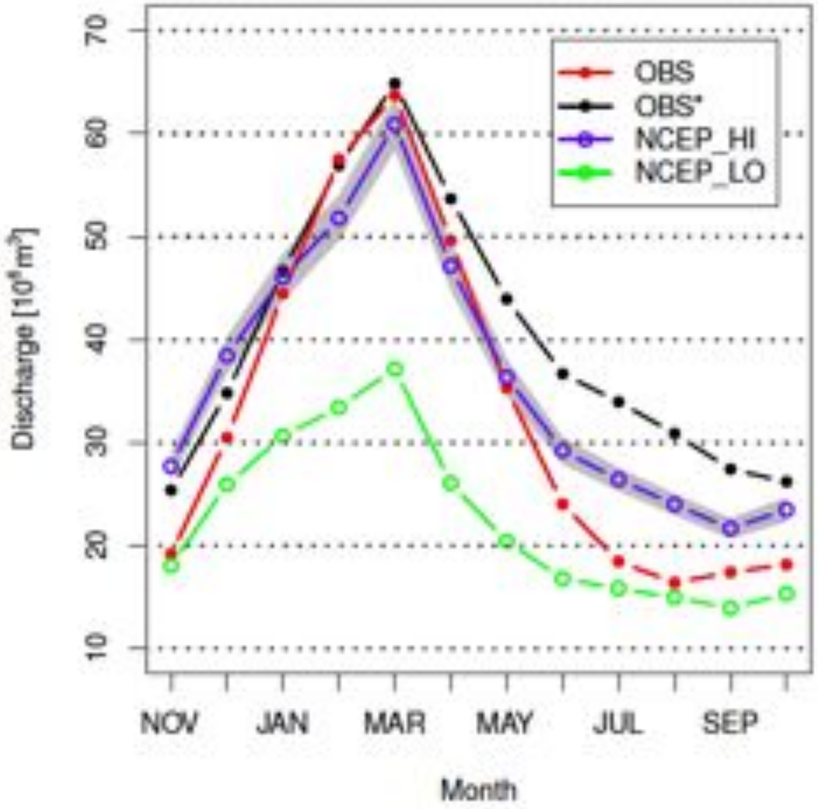
Elevation dependence of future climate change signal



* 2031-2060 related to 1961-1990
* 2070-2099 related to 1961-1990

Climate Change & Water Availability: EM / Near East

Simulated present and future Upper Jordan River discharge



Climate Change & Water Availability: EM / Near East

Summary

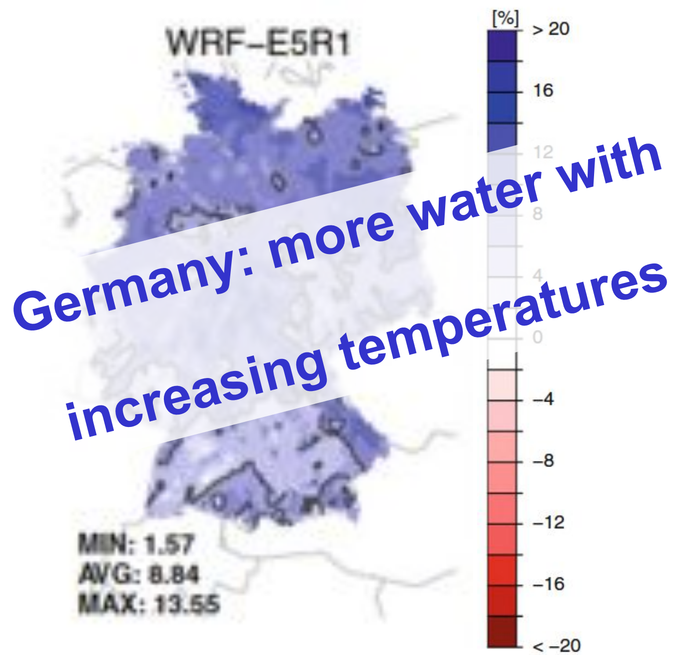
- temperature increase up to 4°C
- around 20% less precipitation till 2100
- increase in strong precipitation
- increase in consecutive dry days
- 25% less water in UJR until 2100

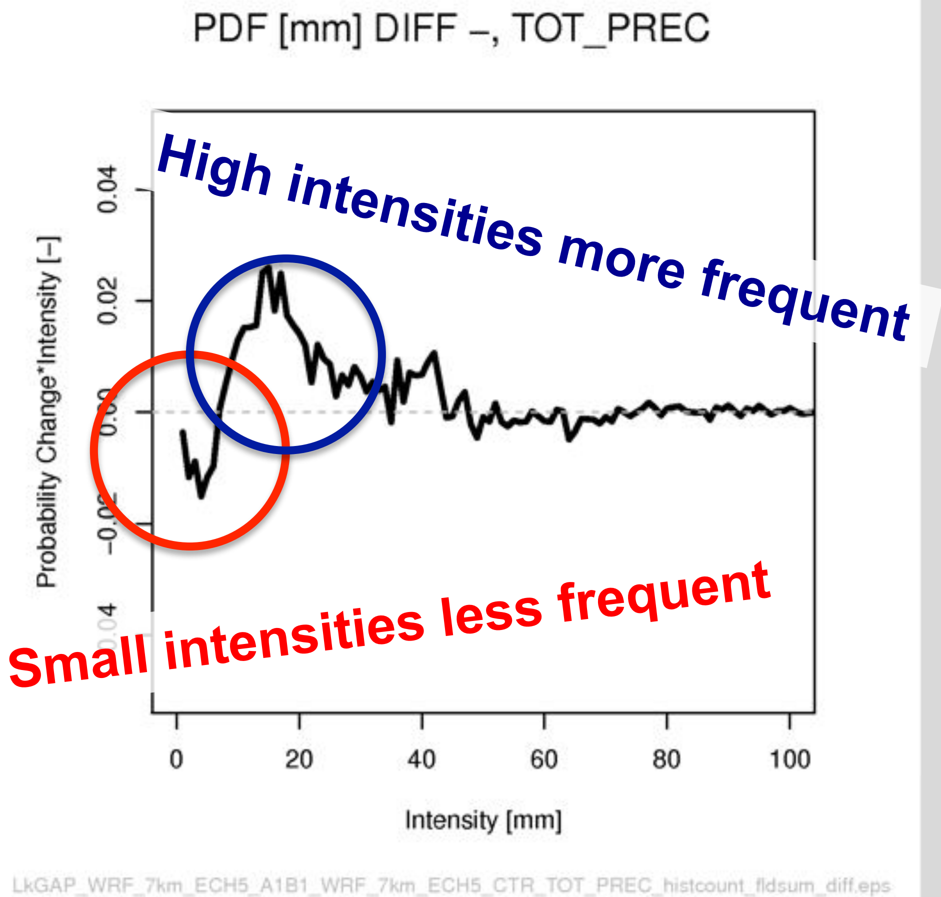
… less water with increasing temperatures

Climate Change & Precipitation: Germany & Alpine Space

Expected Precipitation Change, 2021/2050 vs 1971/2000

ECHAM5, A1B, WRF@7km

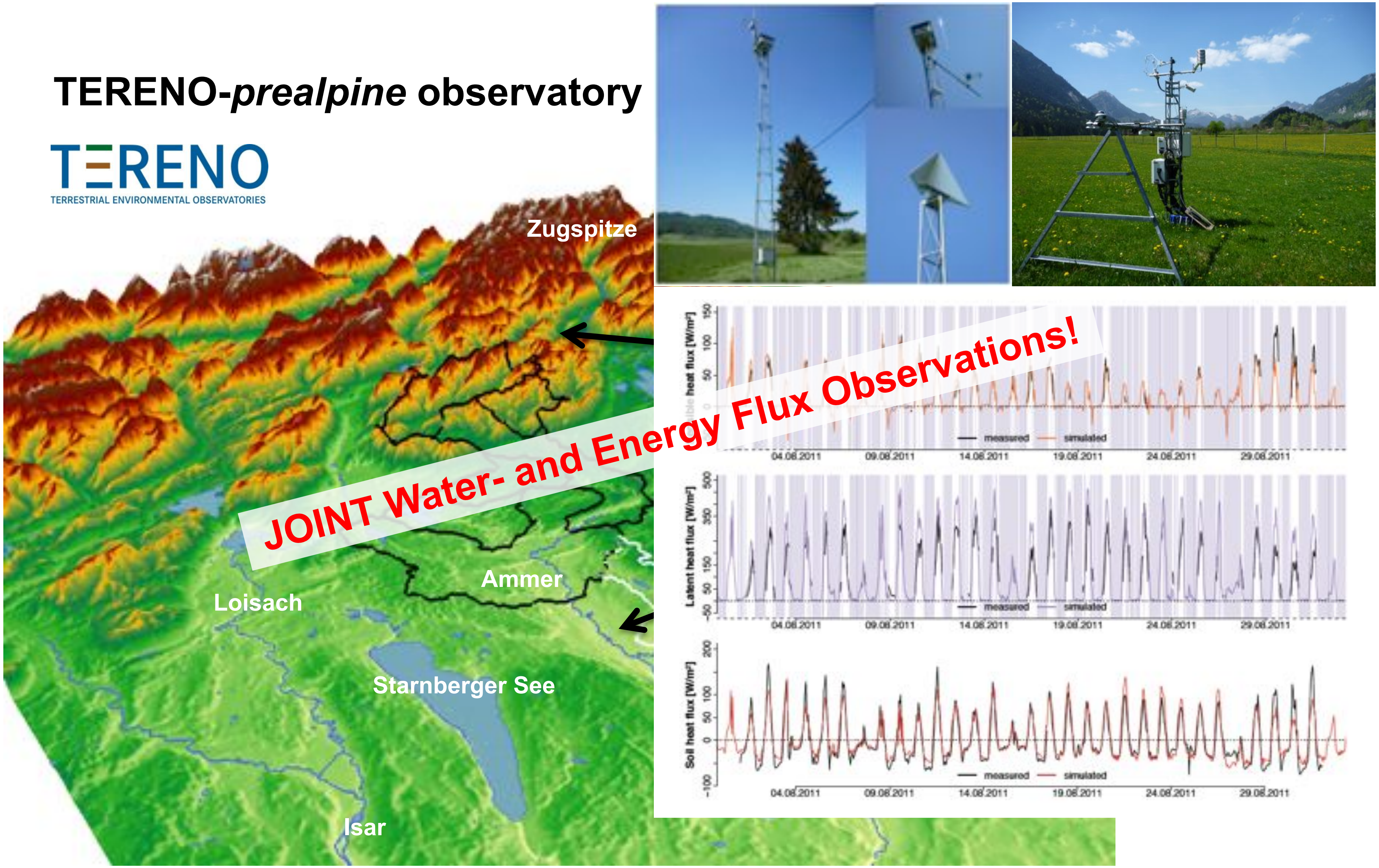




Outlook: Necessity for Long Terms Observatories -TERENO

TERENO-*prealpine* observatory

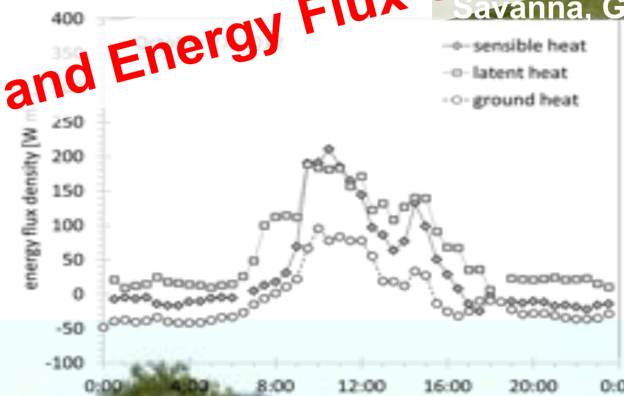
TERENO
TERRESTRIAL ENVIRONMENTAL OBSERVATORIES



Outlook: Necessity for Long Terms Observatories -WASCAL

West African Science Service Centre for Climate Change & Adapted Land Use

JOINT Water- and Energy Flux Observations!



WASCAL

West African Science Service Center for Climate Change and Adapted Land Use

Bundesministerium für Bildung und Forschung

Summary and Conclusions

- **Change and intensification of water cycle**
  -> Complex interplay between local moisture processes & large scale dynamics
  -> Change of precipitation amplitudes in both directions

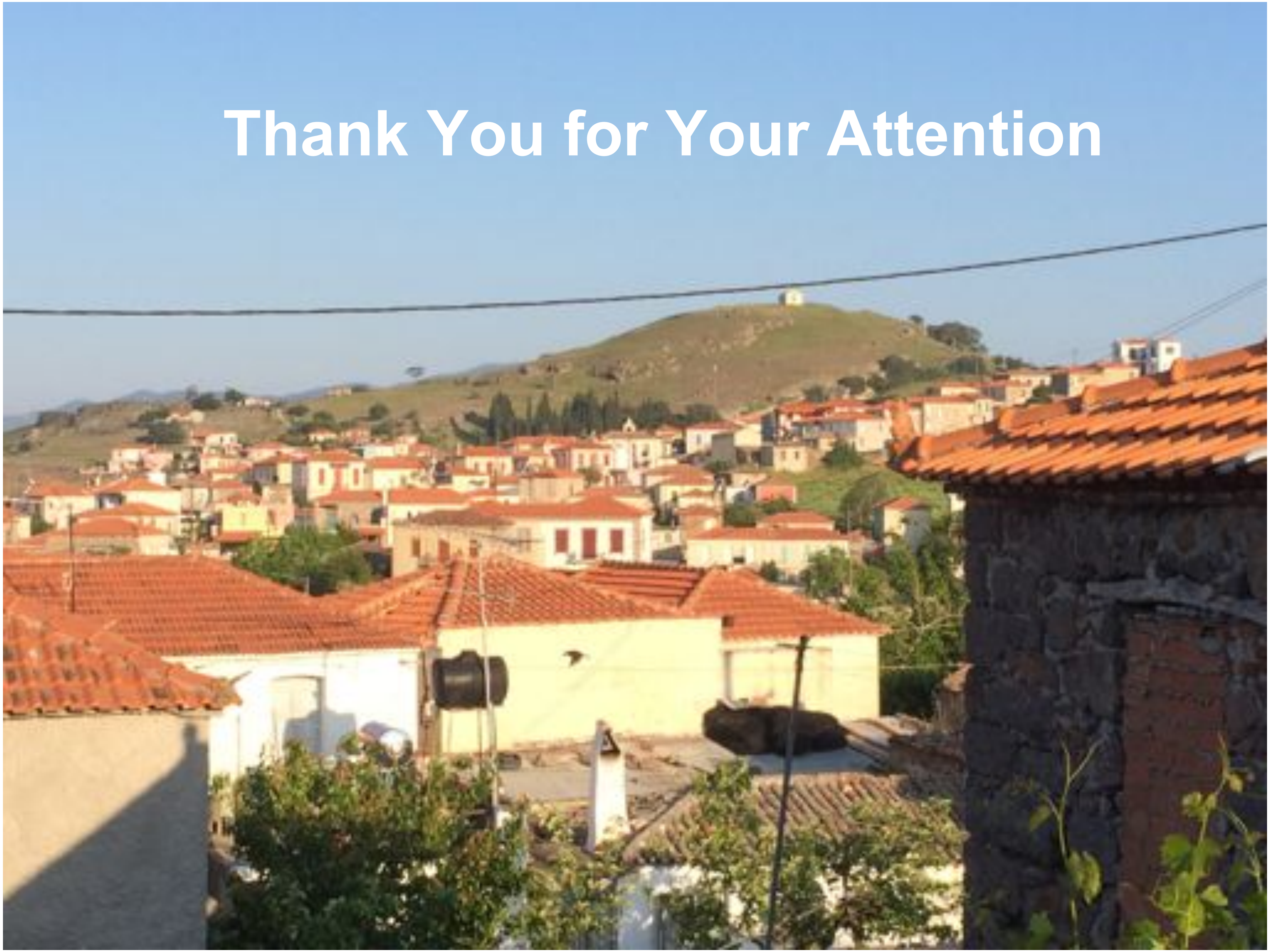
- **Still major knowledge gaps in understanding water cycle, not only on large scales, also on small scales**

- Climate change impact studies: **-> "too much"** water problem for regions like Germany, **"not enough"** water problem for regions like the EM/NE

- Necessity for comprehensive hydrometeorological testbeds: **monitoring water cycle far beyond precipitation, temperature, streamflow**

- **Combined modeling and observation efforts** as prerequisite for future improvement of regional water cycle analysis & -quantification

- **Last but not least**
  -> *climate change* is only ONE threat to *changing water availability*
  -> biggest driver: *population increase* & *disproportionate consumption*
  -> additional *awareness* needed for decreasing *water availability*!


Thank You for Your Attention