Wasser in einer wärmeren Welt:

zu viel oder zu wenig?

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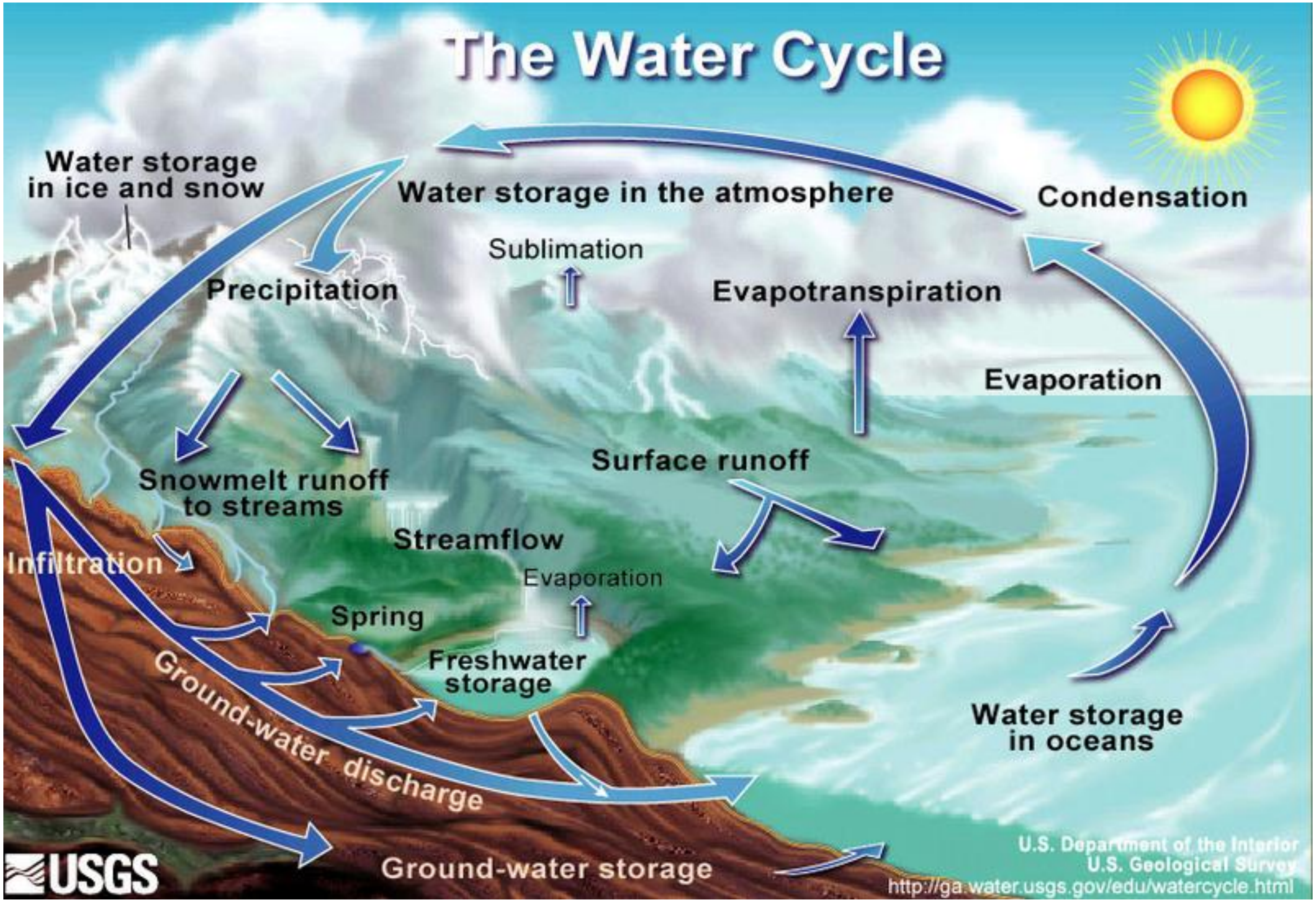
Far Too Much Water: Donau & Elbe, June 2013 …

… and the Opposite: Droughts

Figures Like this Often Introduce Hydrology Talks …



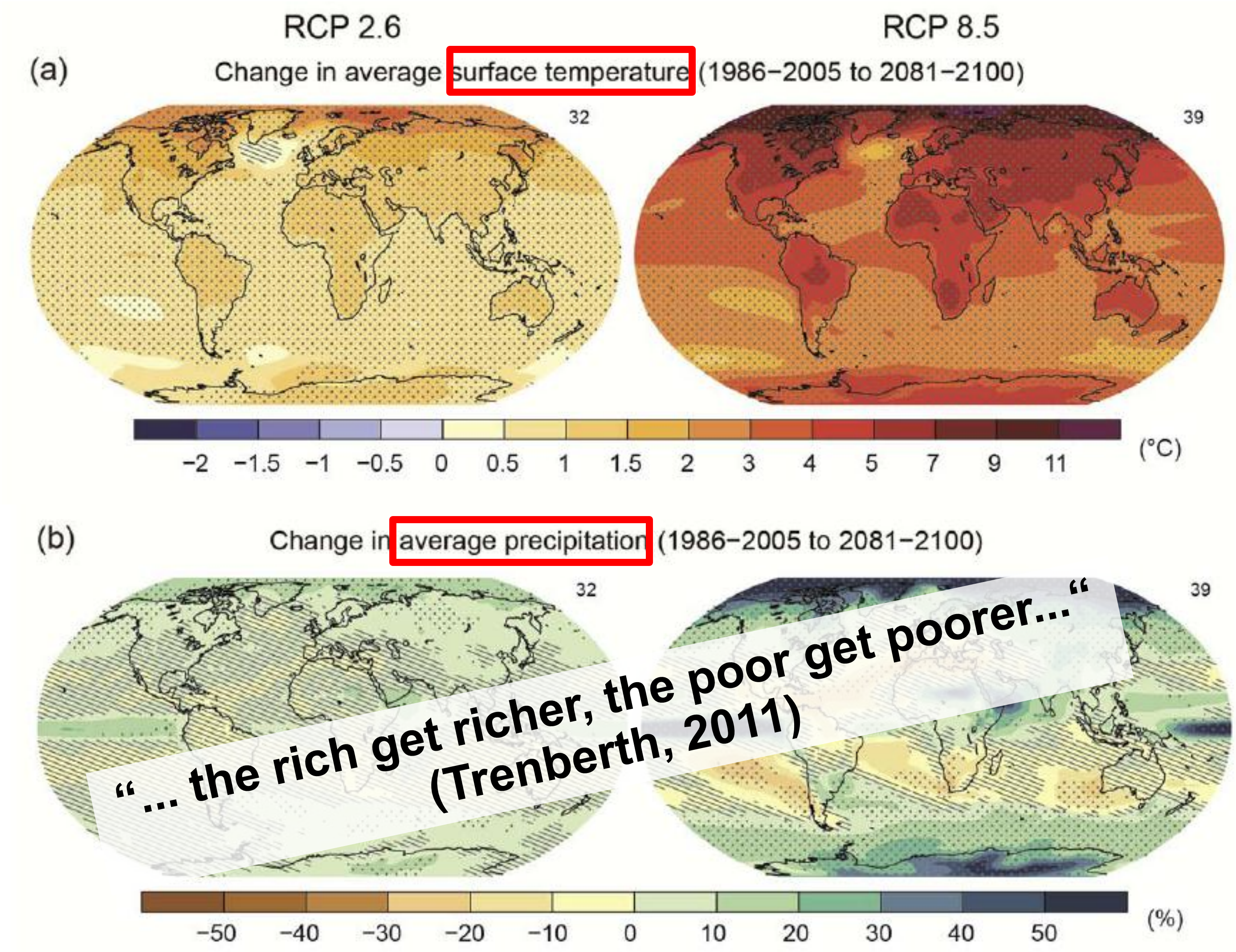
BUT:

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

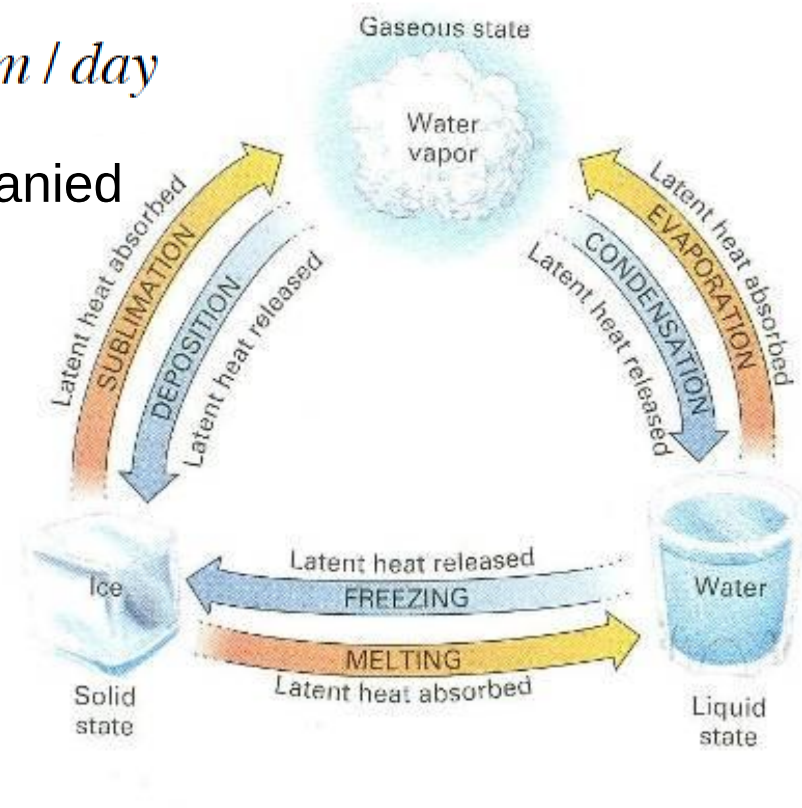
Physical Background

- 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

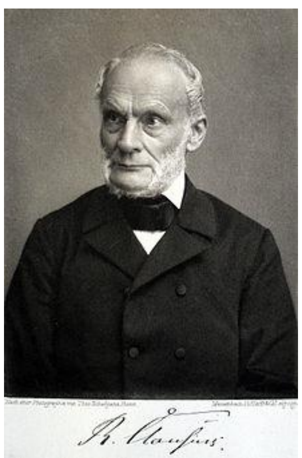


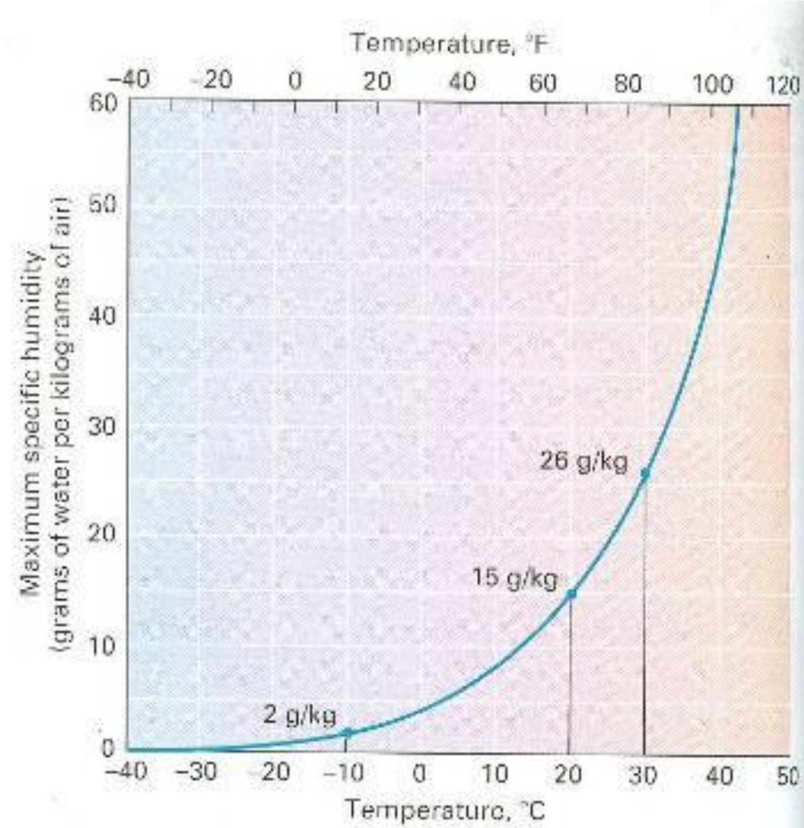
Links Between Water and Energy Cycle

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"?

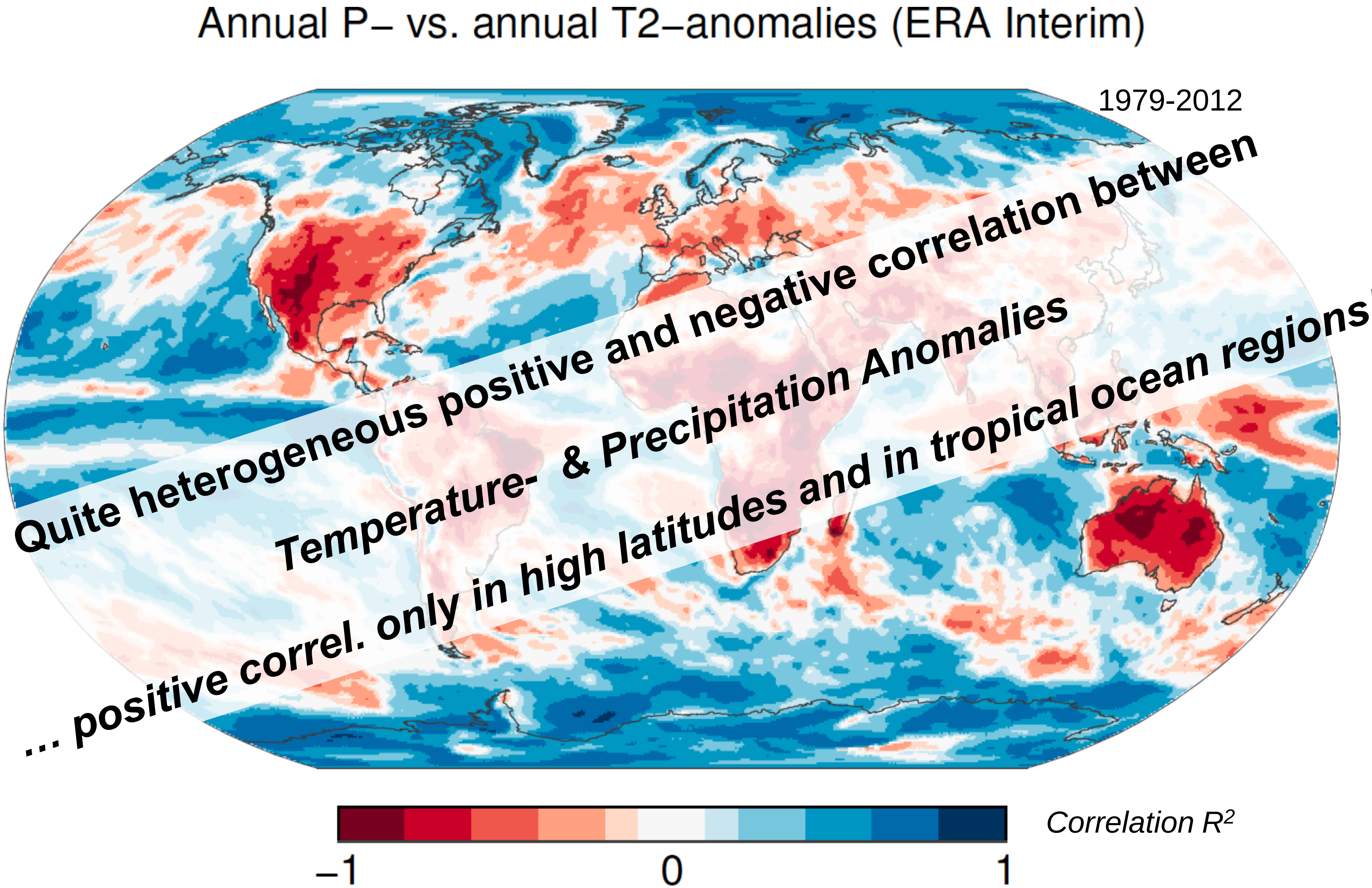
Temperature-precipitation feedback mechanisms

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

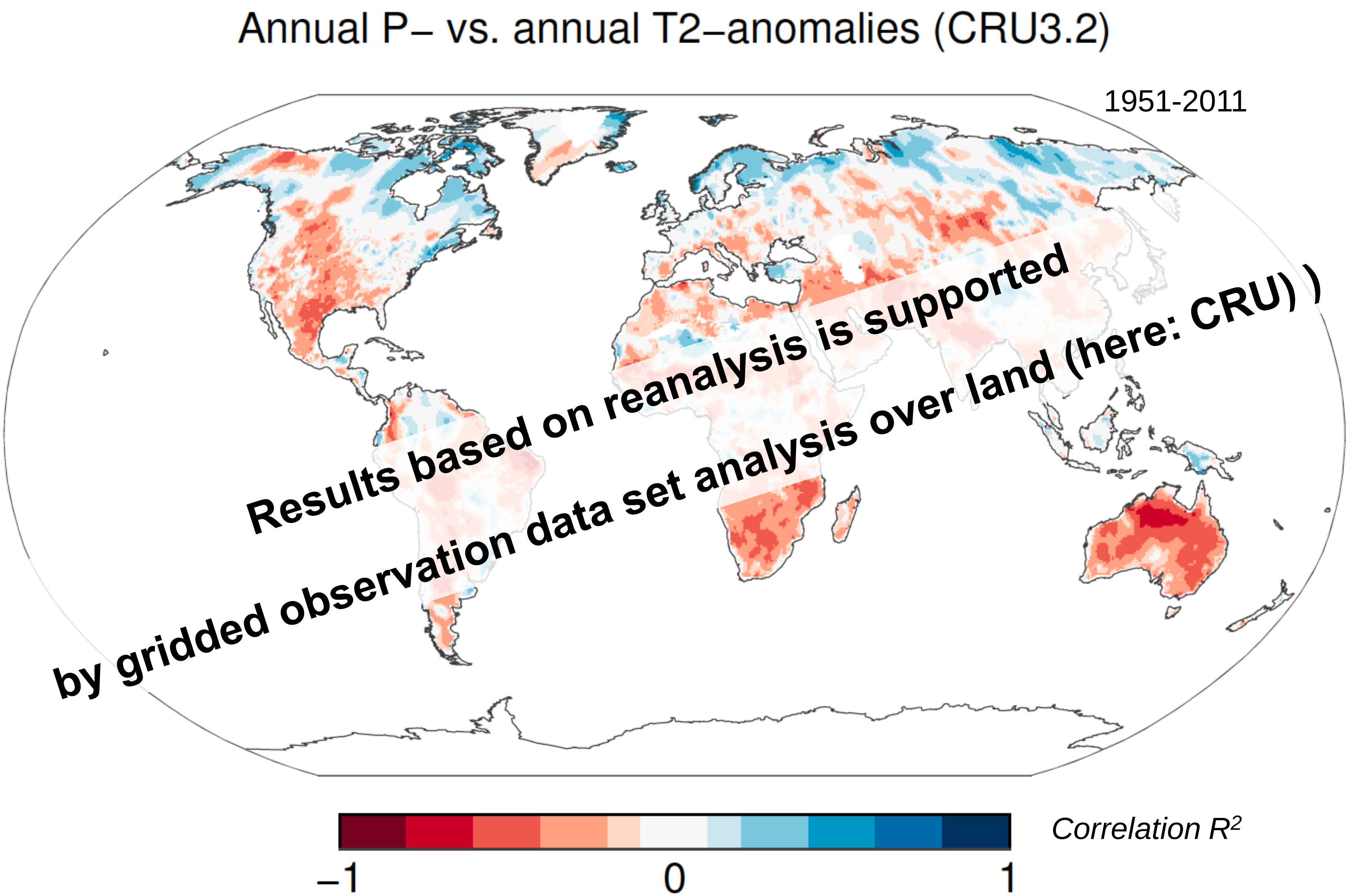
- Every precipitation event accompanied by **energy release**
  into atmosphere (*condensation*)
  -> decreased temperature lapse rate, stabilization of atmosphere
  -> … suppressing further convection
  -> … **decrease of *subsequent* precipitation** possible

- 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, …

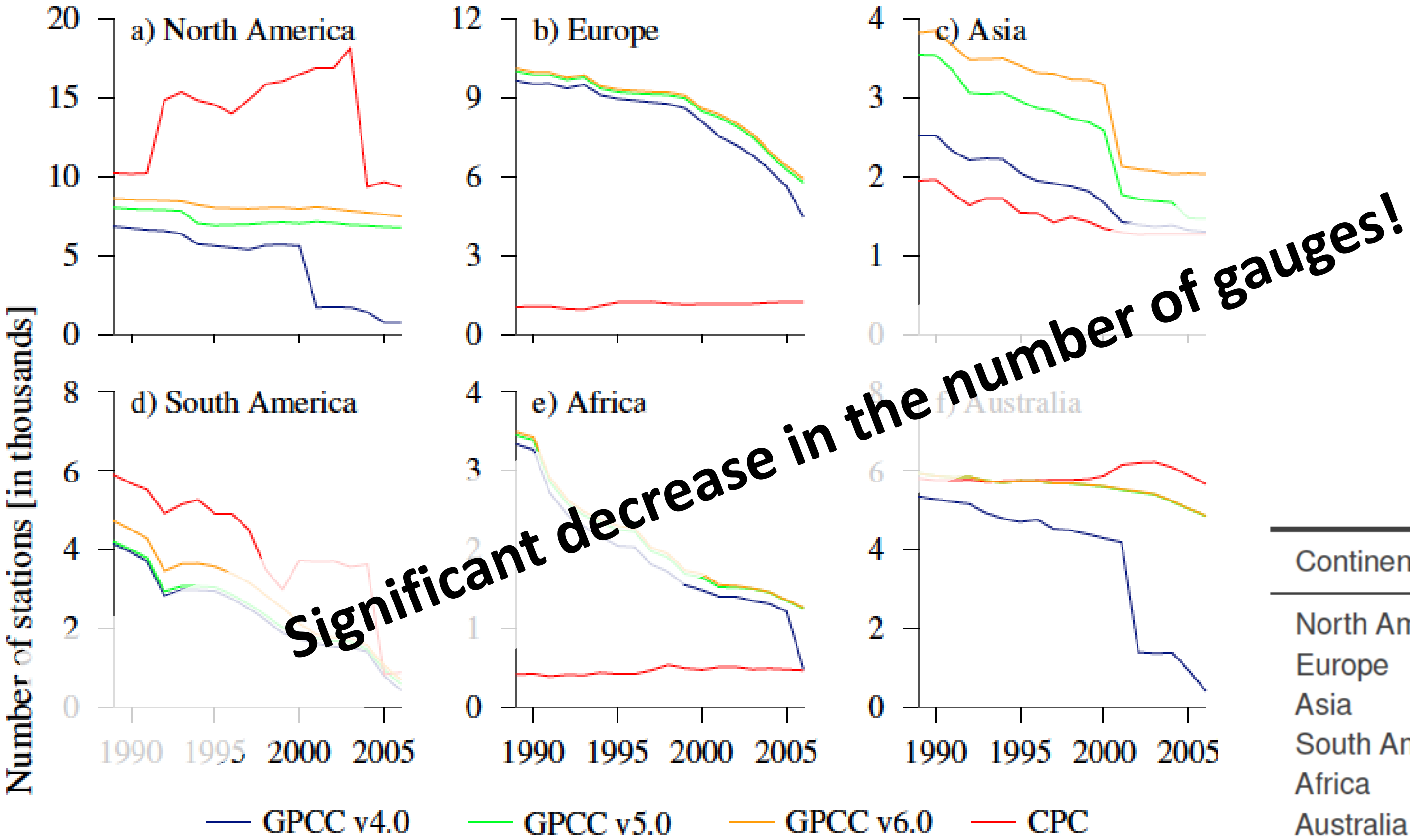
Change of Water Cycle in “Warmer World”?



Change of Water Cycle in "Warmer World"?



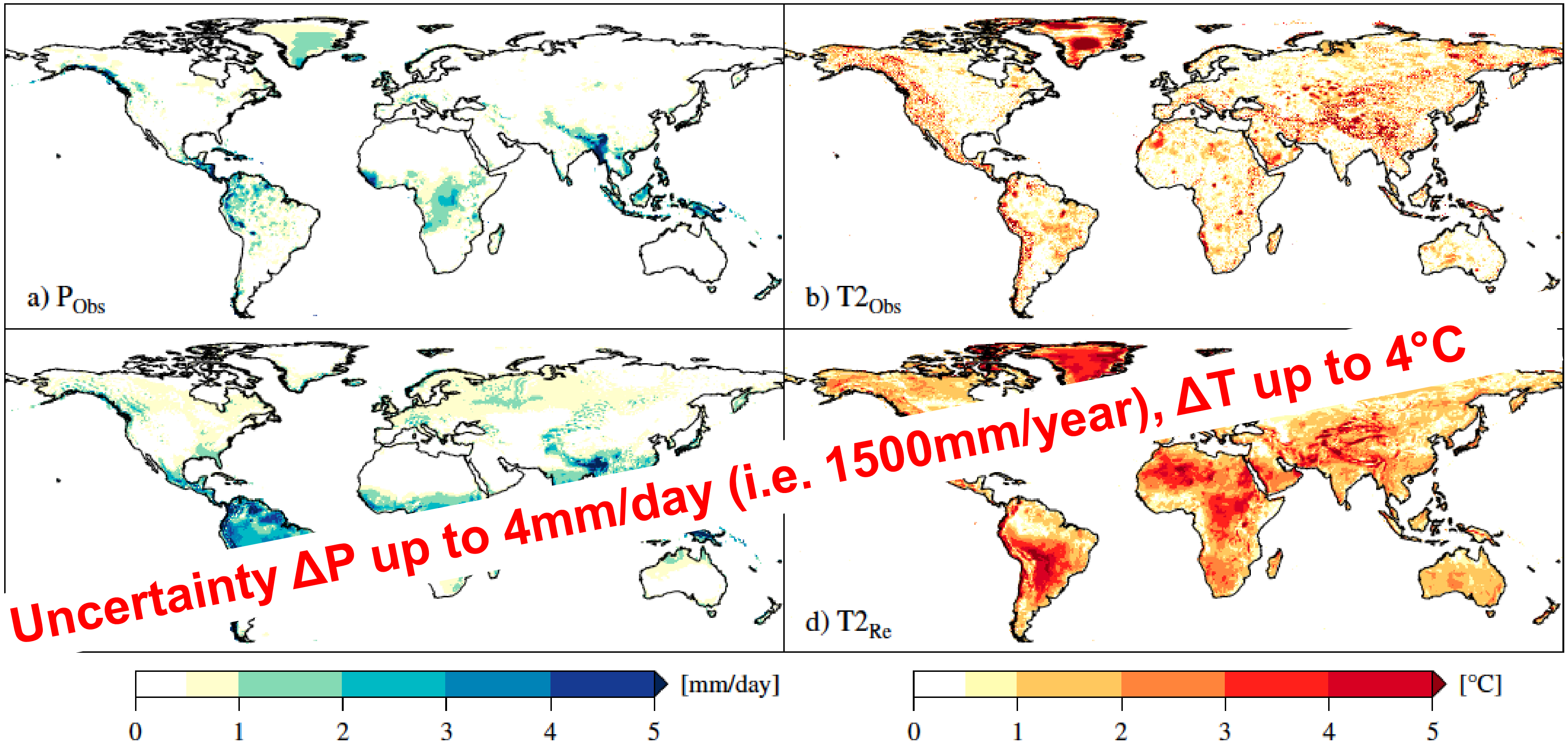
Caution: Significantly Varying Number of Original Data



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

Lorenz, C. and Kunstmann, H. (2012) The Hydrological Cycle in Three State of the Art Reanalyses: Intercomparison and Performance Analysis. *Journal of Hydrometeorology*, doi:10.1175/JHM-D-11-088.1

How Well Do We Really Know the Water Cycle?



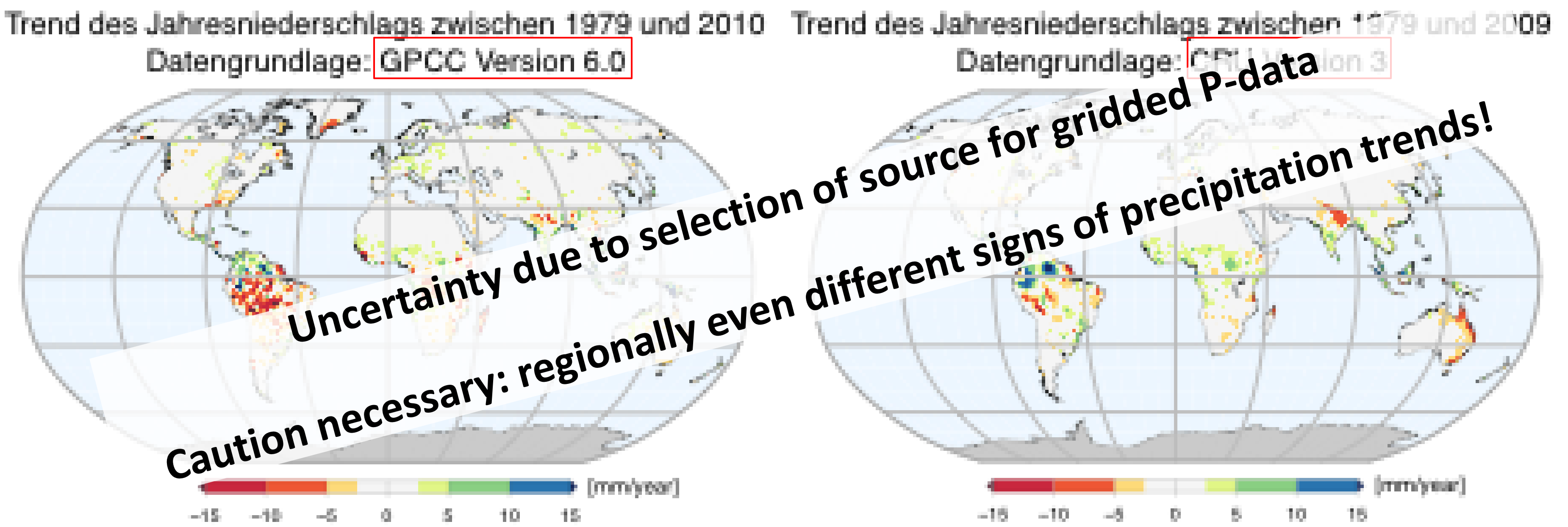
Precipitation observation ensemble: GPCC, GPCP, CPC, CRU, DEL

Temperature observation ensemble: CRU, DEL

Reanalysis ensemble: ERA-Interim, MERRA, CFSR

Lorenz, C. and Kunstmann, H. (2012) The Hydrological Cycle in Three State of the Art Reanalyses: Intercomparison and Performance Analysis. *Journal of Hydrometeorology*, doi:10.1175/JHM-D-11-088.1

Trends from Gridded Observation Data Sets?

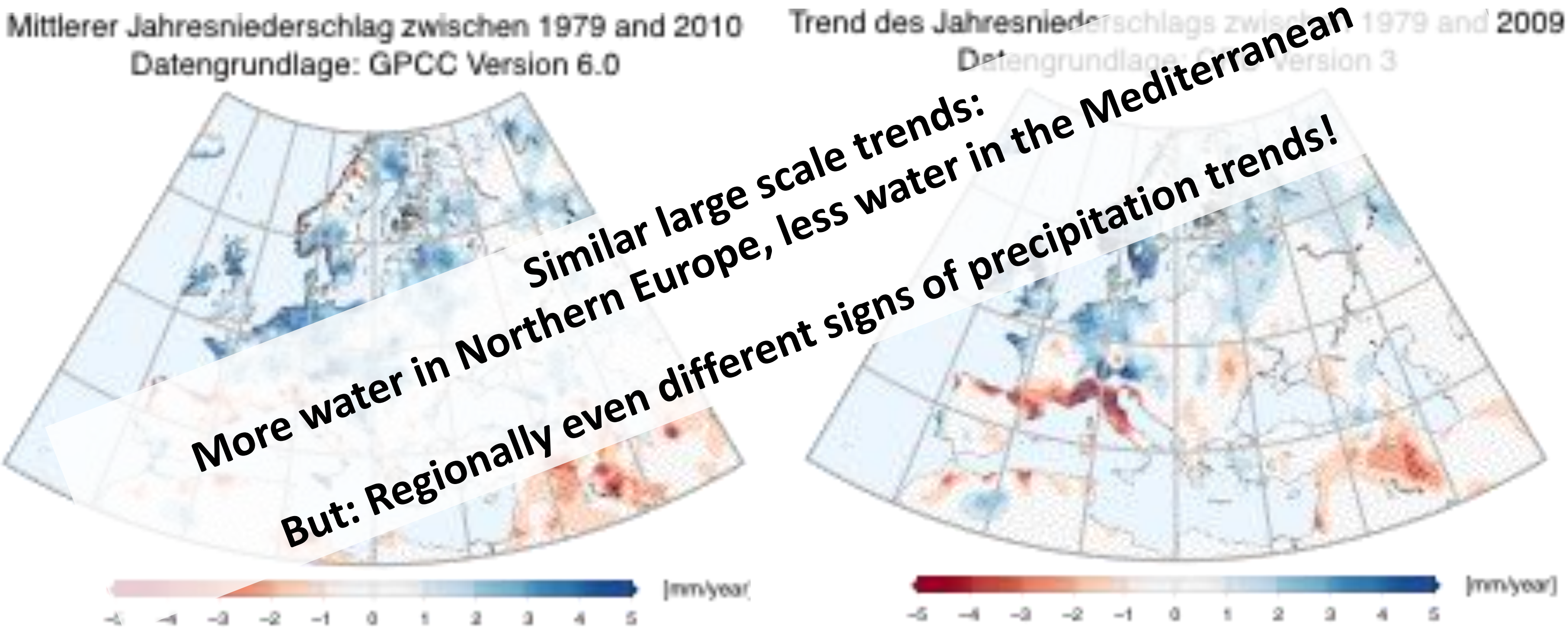


Uncertainty due to selection of source for gridded P-data

Caution necessary: regionally even different signs of precipitation trends!

Trends from Gridded Observation Data Sets?

Europe



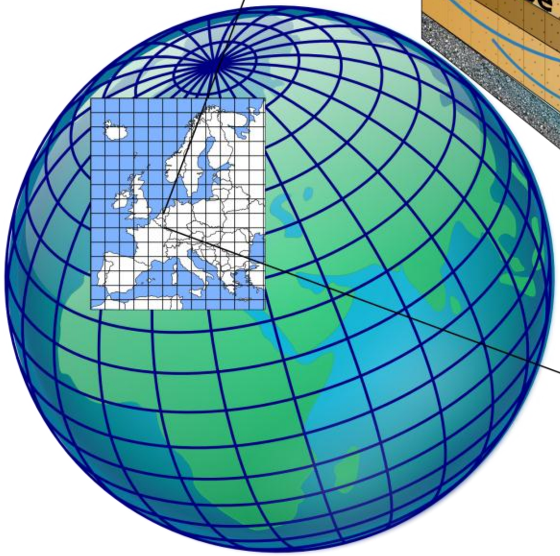
Similar large scale trends:

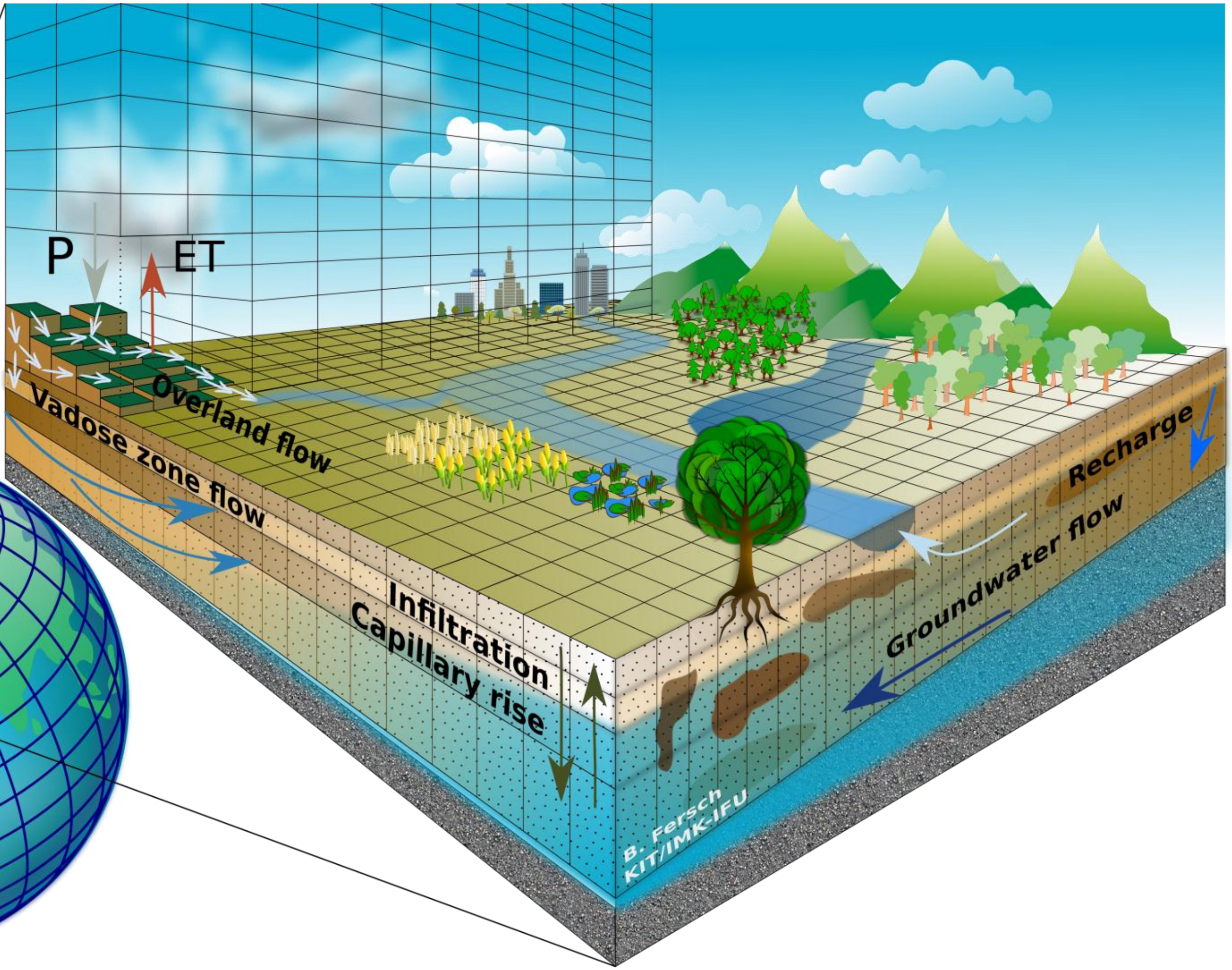
More water in Northern Europe, less water in the Mediterranean

But: Regionally even different signs of precipitation trends!

Regionalization Global Climate Scenarios for Hydrological Impact Analyses by Complex Earth System Models

High Performance Computing

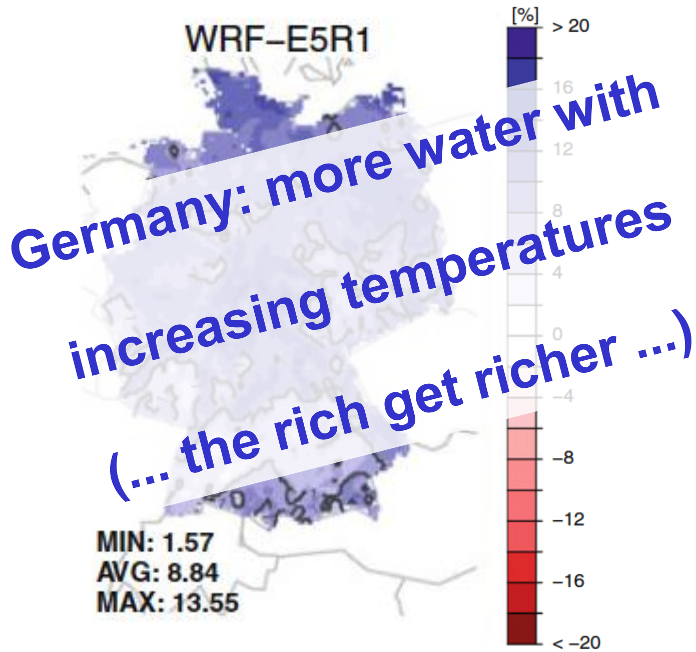


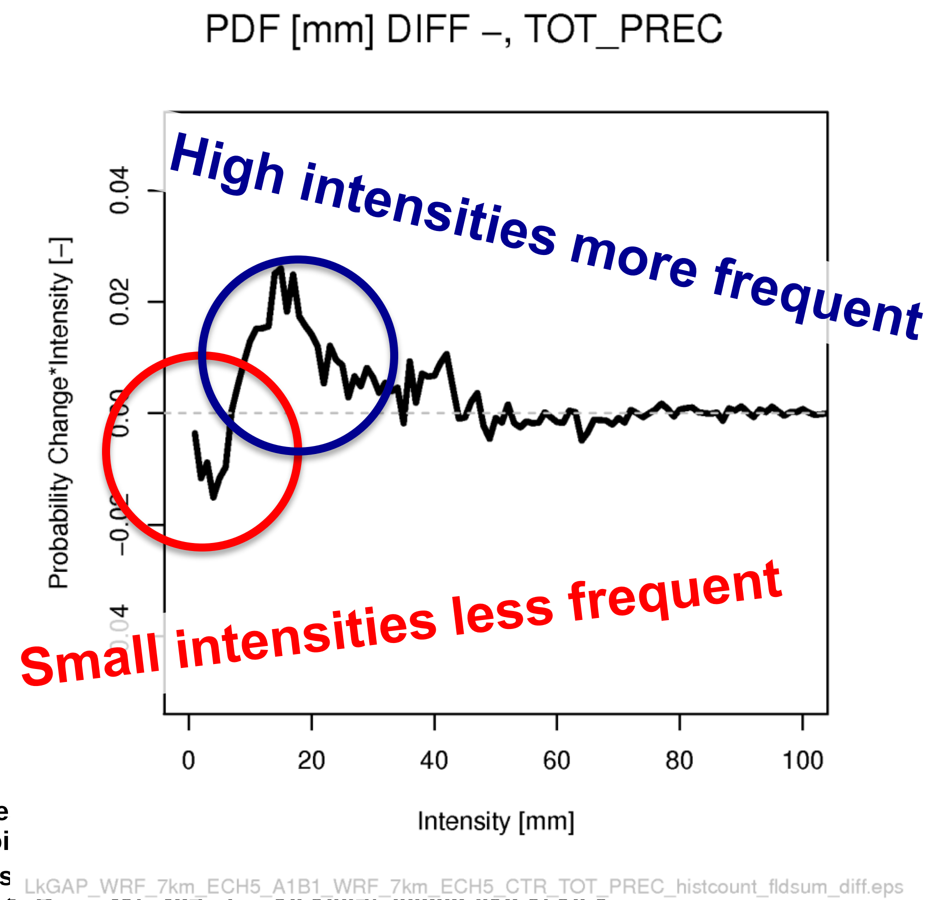


Climate Change & Precipitation: Germany & Alpine Space

Expected Precipitation Change, 2021/2050 vs 1971/2000

ECHAM5, A1B, WRF@7km





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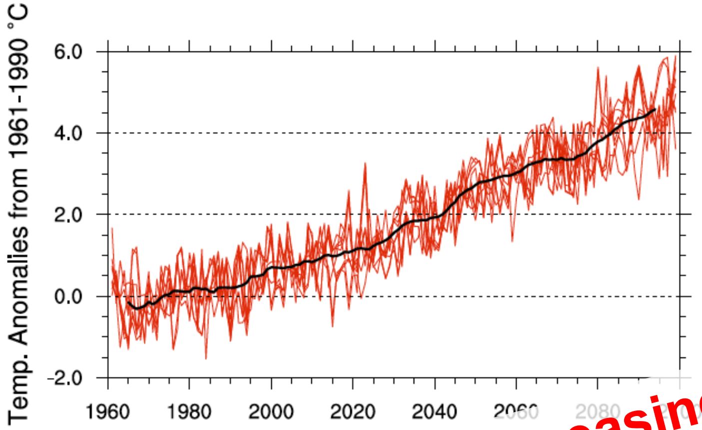
Wagner, S. Berg, P., Schädler, G., Kunstmann, H. (2013), High res
Projected Climate Changes, *Climate Dynamics,* Volume 40, Issue 1, Page 415-427, doi: 10.1007/s00382-012-1510-1

Ott, I., Duethmann, D., Liebert, J., Berg, P., Feldmann, H., Ihringer J., Kunstmann, H., Merz, B., Schädler, G., Wagner, S. (2013), High resolution climate change impact analysis on medium sized river catchments in Germany: An ensemble assessment, *Journal of Hydrometeorology*, doi: 10.1175/JHM-D-12-091.1

Climate Change & Precipitation: Syria & Figeh Spring

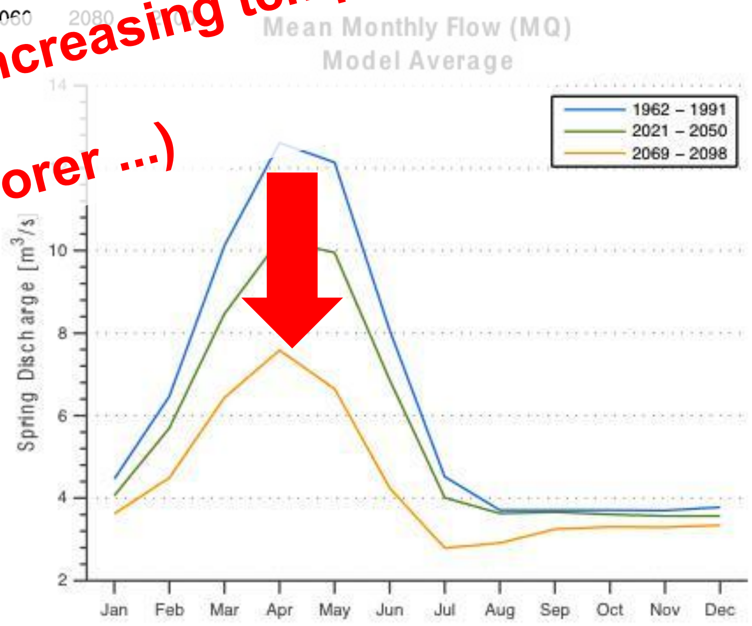


ECHAM5 & HadCM3, A1B
MM5@18km

Syria & Damascus: less water with increasing temperatures

(... the poor get poorer ...)

Impact analysis via hydrological model for Figeh Spring
(first one at all!)

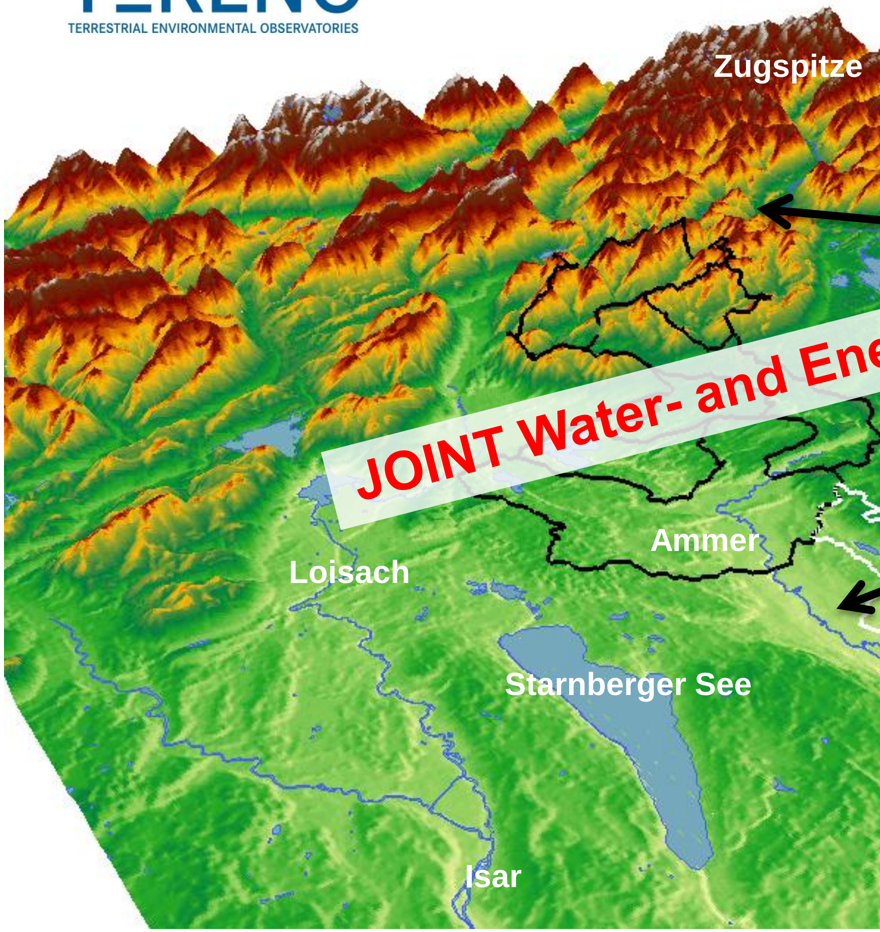


Smiatek G., Kaspar, S. Kunstmann H. (2013), Hydrological climate change impact analysis for the Figeh Spring in Damascus area, Syria, *Journal of Hydrometeorology*, doi: 10.1175/JHM-D-12-065.1.

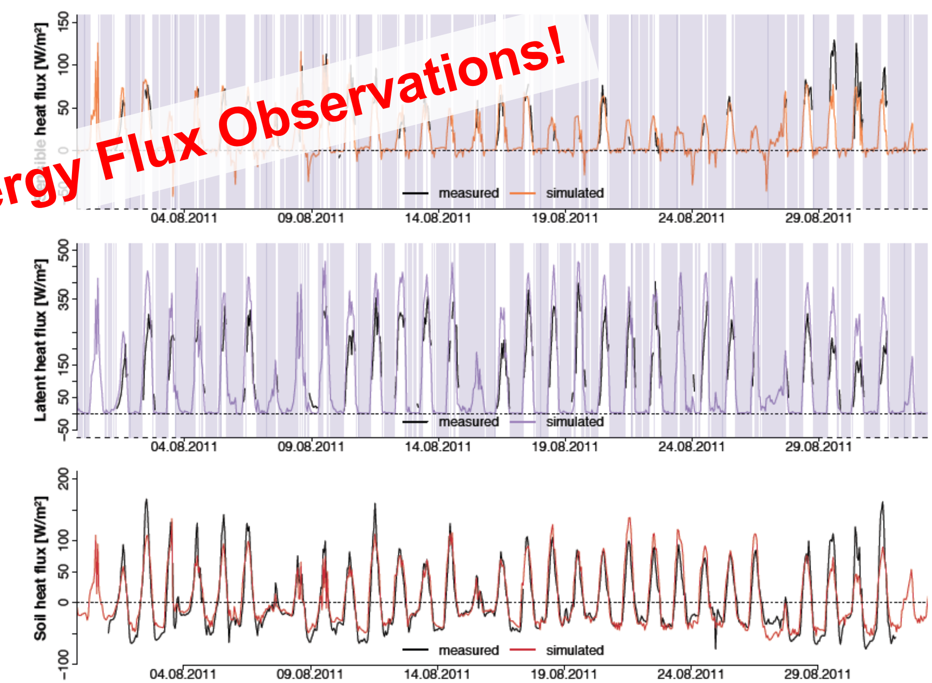
Necessity for Long Terms Observatories: TERENO

TERENO-*prealpine* observatory

TERENO
TERRESTRIAL ENVIRONMENTAL OBSERVATORIES



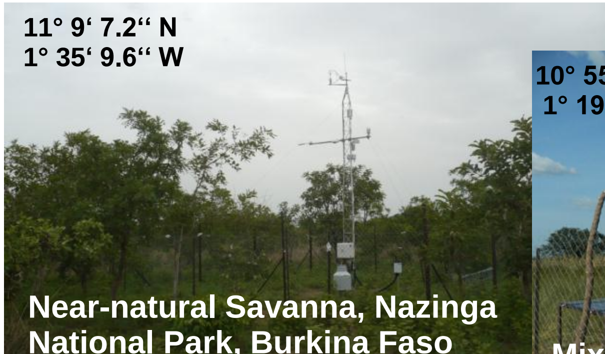
JOINT Water- and Energy Flux Observations!



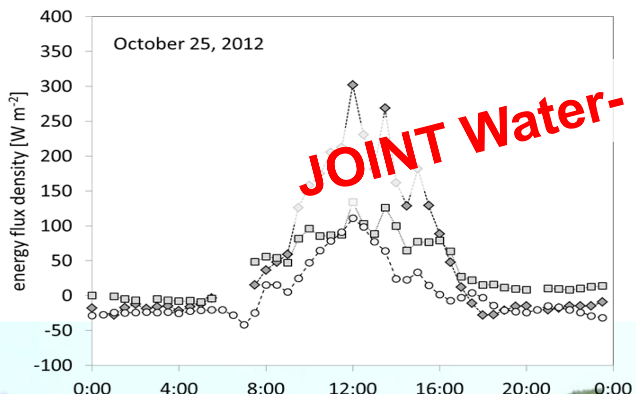
Kunstmann et al., (2013), IAHS publ. 359, pp. 221-225
Hingerl et al. (2013), *Journal of Hydrometeorology*, submitted

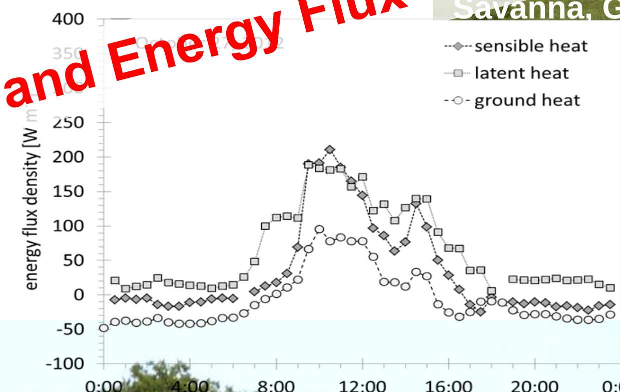
Necessity for Long Terms Observatories: WASCAL

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

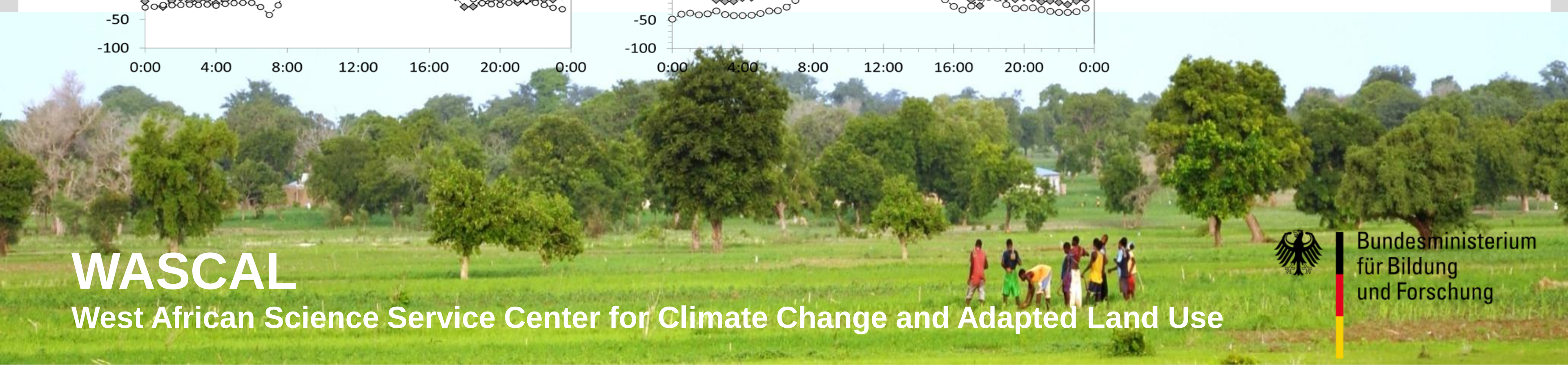


JOINT Water- and Energy Flux Observations!





Bliefernicht et al. (2013), IAHS publ. 359, pp. 226-332



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**

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

- Increasing numbers of observatories: examples **TERENO** and **WASCAL**!

- **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*!


Vielen Dank für die Aufmerksamkeit
... und an Christof Lorenz, Benjamin Fersch, Sven Wagner, Luitpold Hingerl, Jan Bliefernicht, Gerhard Smiatek, Richard Knoche
KIT/IMK-IFU & Uni Augsburg

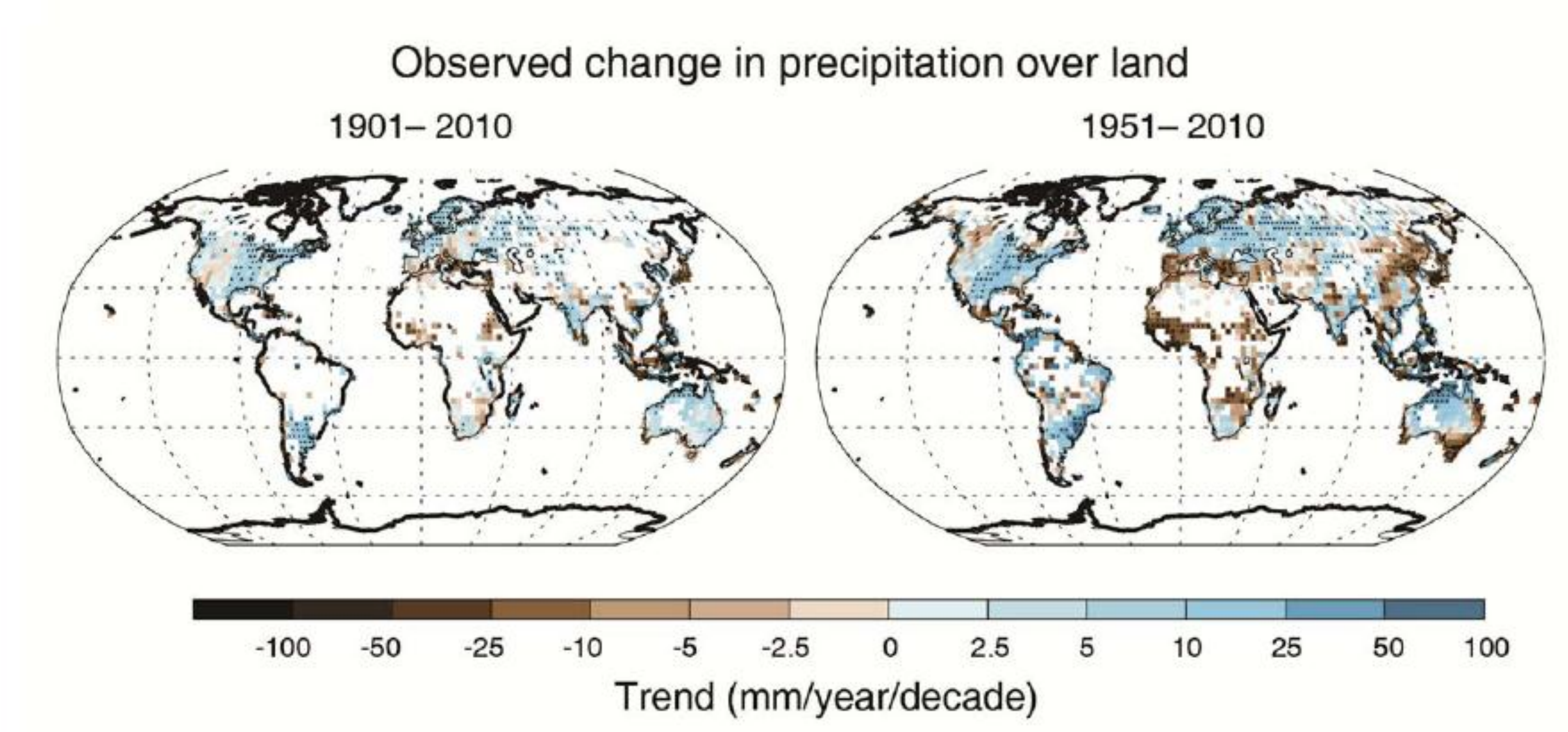
How well do we know the water cycle?

Reanalysis	Institution	Available time-period	Horizontal Resolution	Vertical levels	Top level	Temporal resolution
ERA-Interim	ECMWF	1979 - present	T255 (≈ 78 km)	60	0.1 hPa	6 h, 1 d, 1 m
MERRA	NASA	1979 - present	$1/2° \times 2/3°$	72	0.01 hPa	6 h, 1 d, 1 m
CFSR	NCEP Climate Forecast System CFSR Reanalysis (1979 - 2010)	1979 - present	T382 (≈ 38 km)	64	0.26 hPa	1 h, 6 h, 1 m

	Variables	Hor. resolution	Period	Output times	Version number
GPCC	P	$0.5° \times 0.5°$	1901 - 2009	monthly	4.0
GPCP	P	$2.5° \times 2.5°$	1979 - 2009	monthly	2.1
CRU	P,$T2$	$0.5° \times 0.5°$	1901 - 2009	monthly	3.0
CPC	P	$0.5° \times 0.5°$	1979 - present	daily	1.0
DEL	P,$T2$	$0.5° \times 0.5°$	1900 - 2008	monthly	2.01

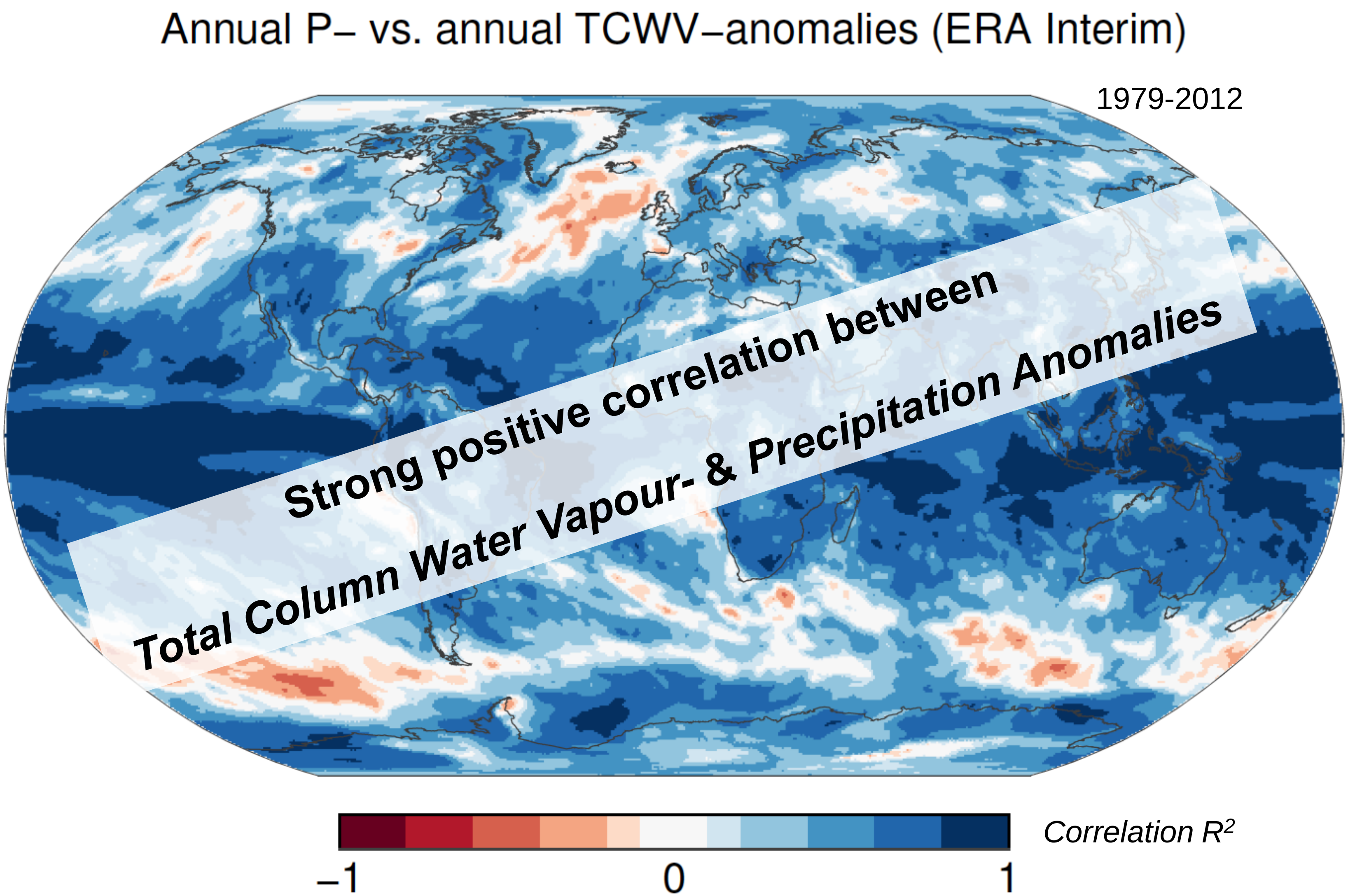
GPCC: Global Precipitation Climatology Centre
GPCP: Global Precipitation Climatology Project
CRU: Climate Research Unit
CPC: Unified gauge based analysis of Global Daily Precipitation from Climate Prediction Centre
DEL: University of Delaware Air Temperature & Precipitation

Large Scale Patterns of Changes in “Warmer World”



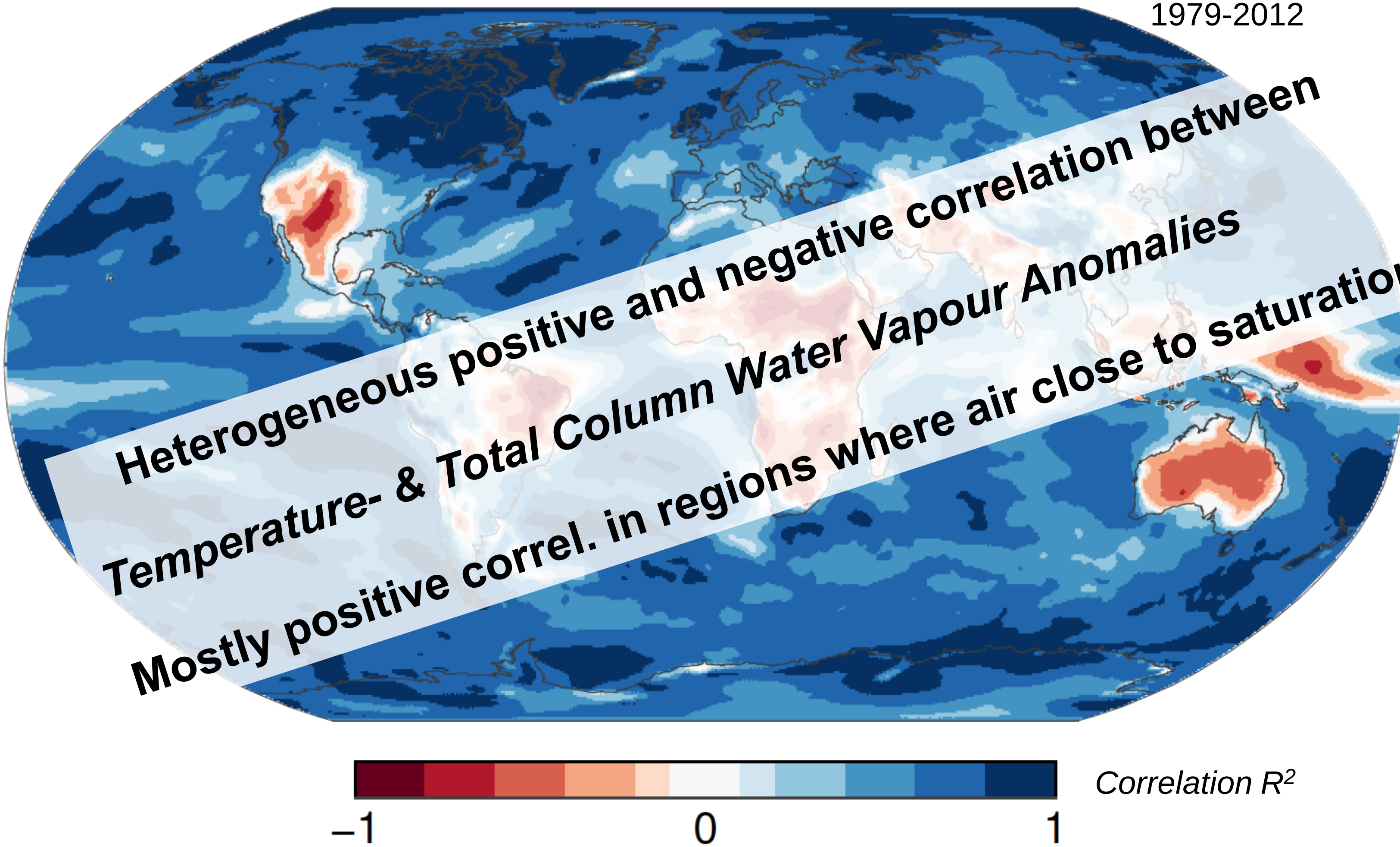
IPCC, AR5 (2013)

Intensification of Water Cycle in "Warmer World"?



Intensification of Water Cycle in “Warmer World”?

Annual T2– vs. annual TCWV–anomalies (ERA Interim)



Heterogeneous positive and negative correlation between

Temperature- & Total Column Water Vapour Anomalies

Mostly positive correl. in regions where air close to saturation