The response of the hydrologic cycle to global warming

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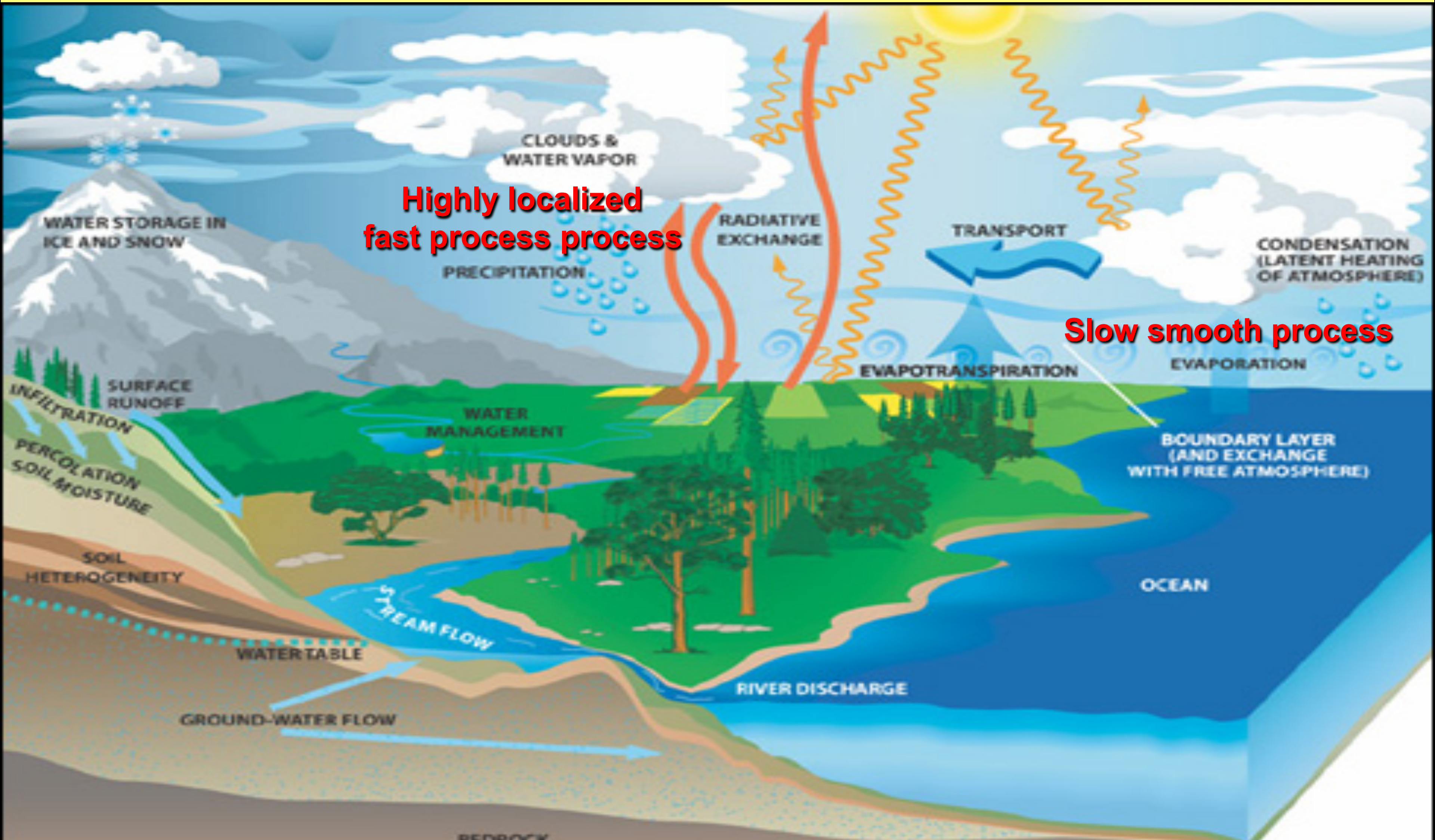
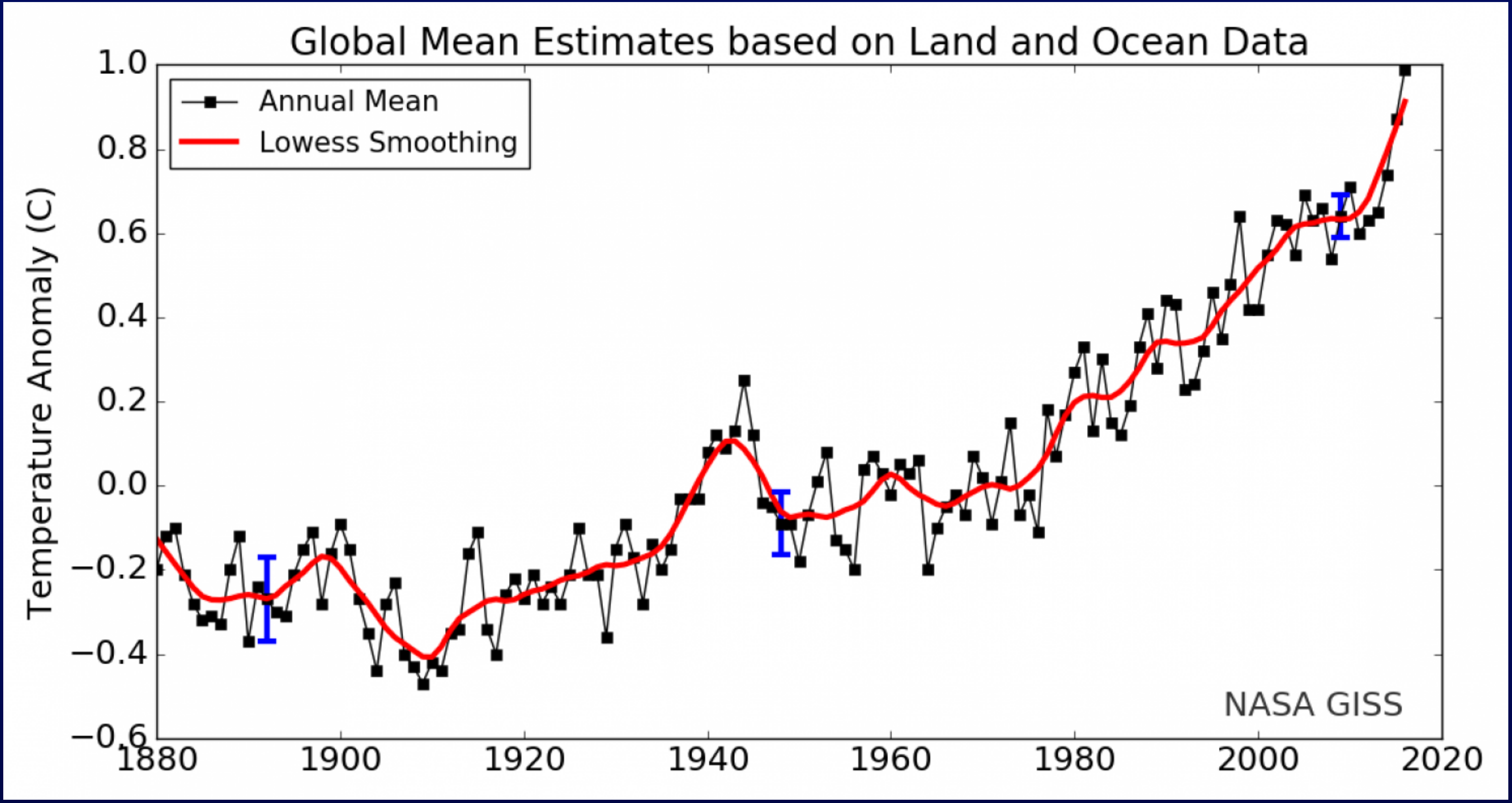
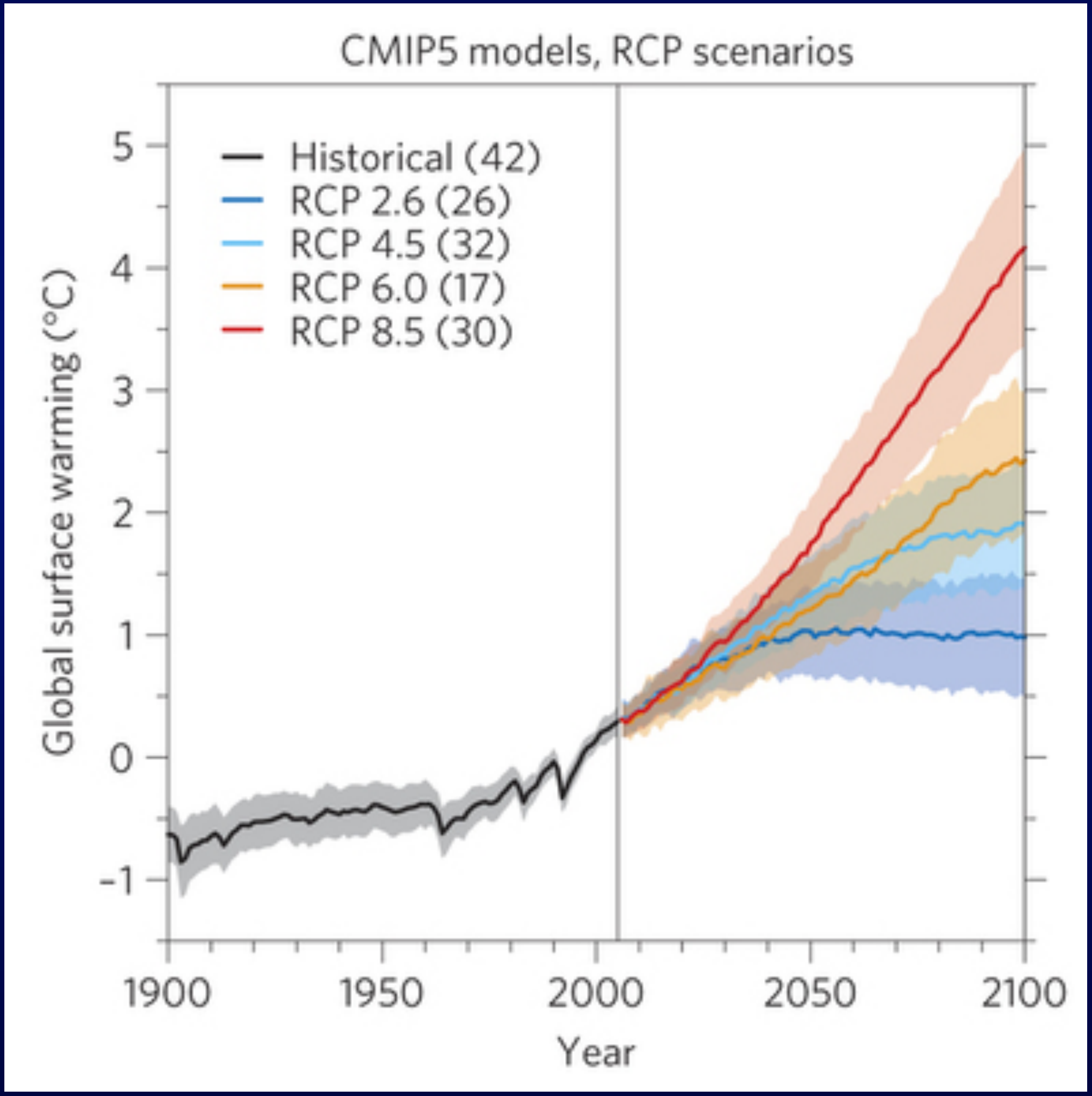
Climate change can profoundly affect the Earth’s hydrologic cycle



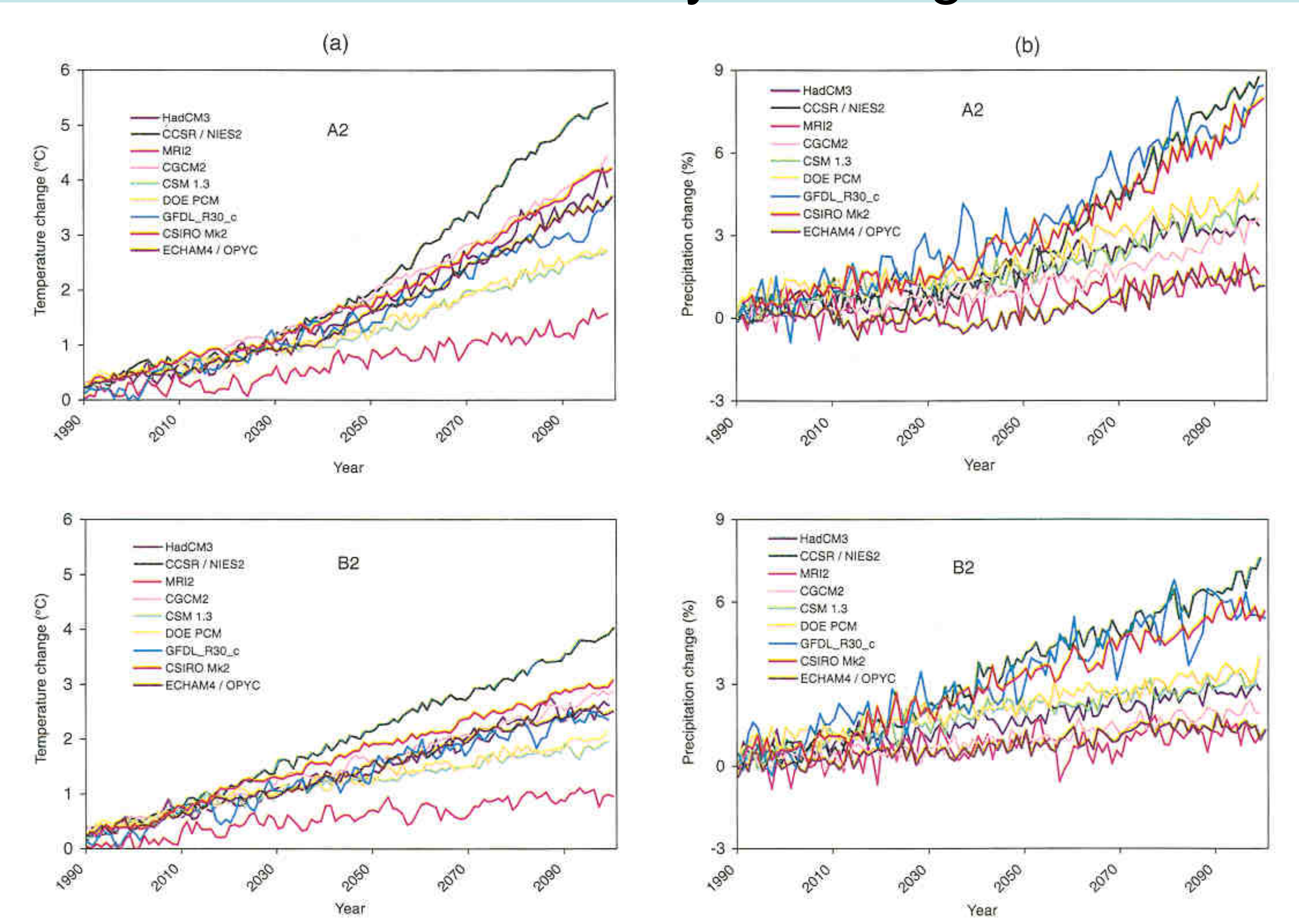
Observed trend in global temperature



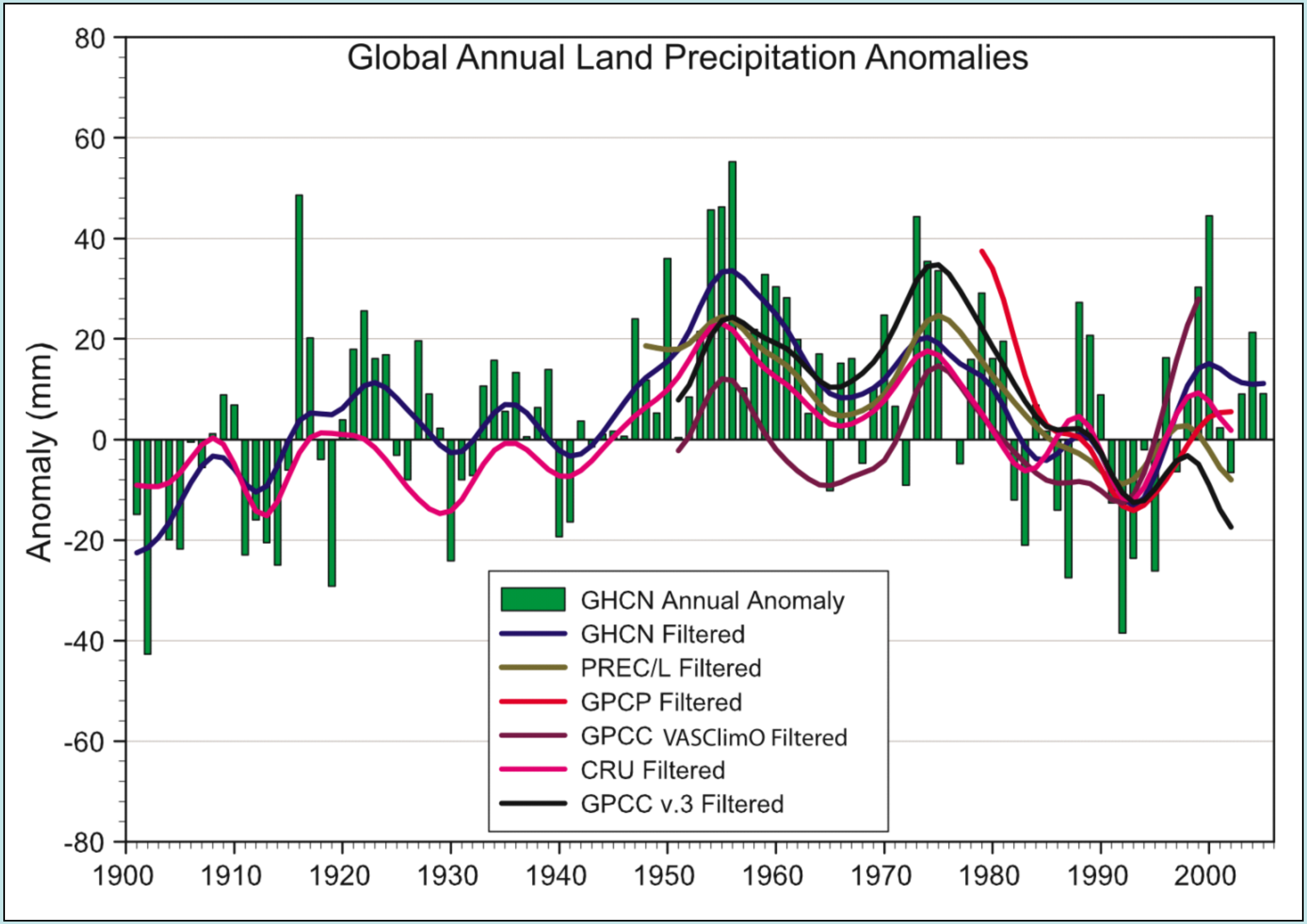
Global temperature projections



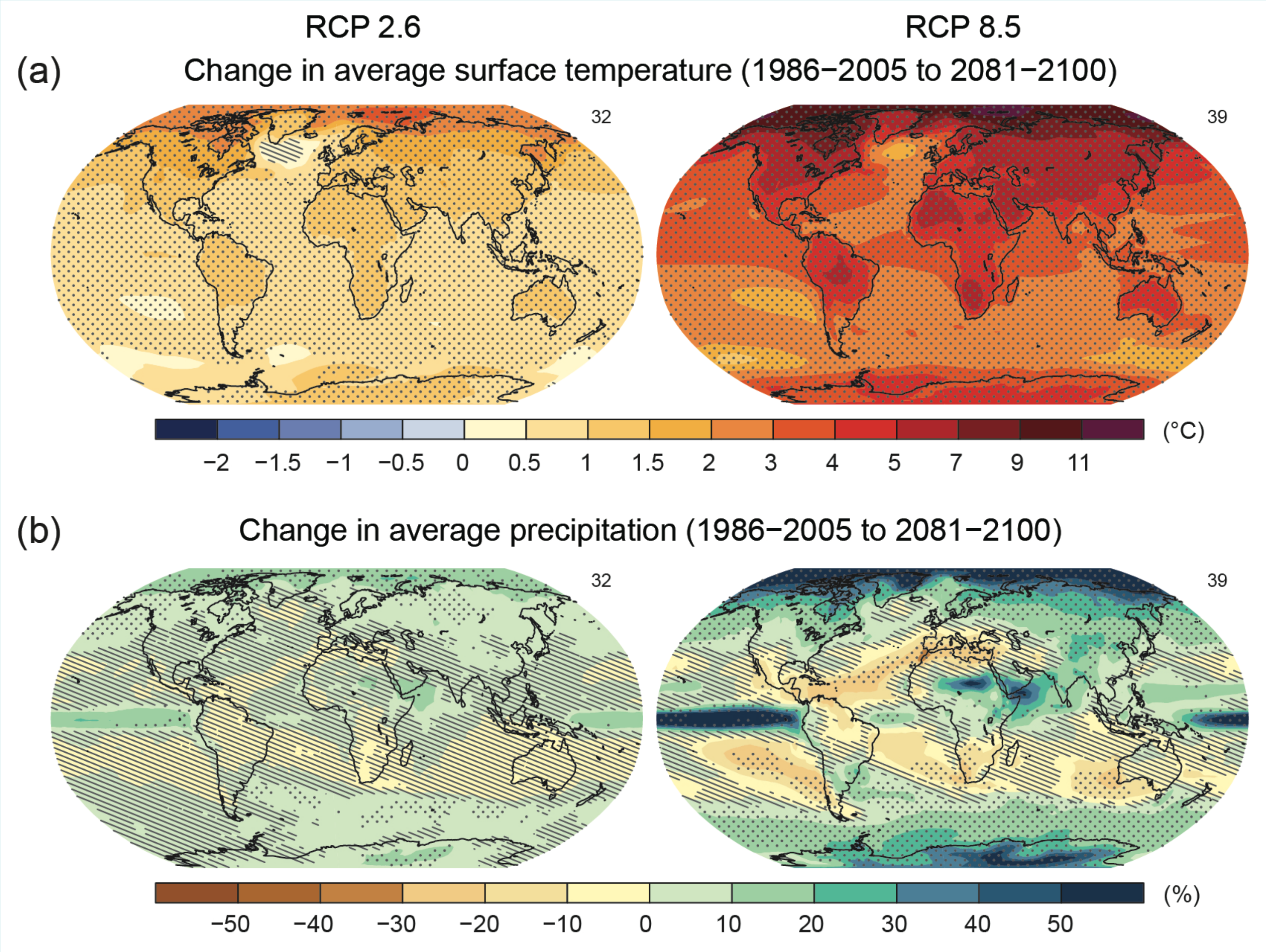
Global warming is generally expected to lead to increased global precipitation while relative humidity remains relatively unchanged



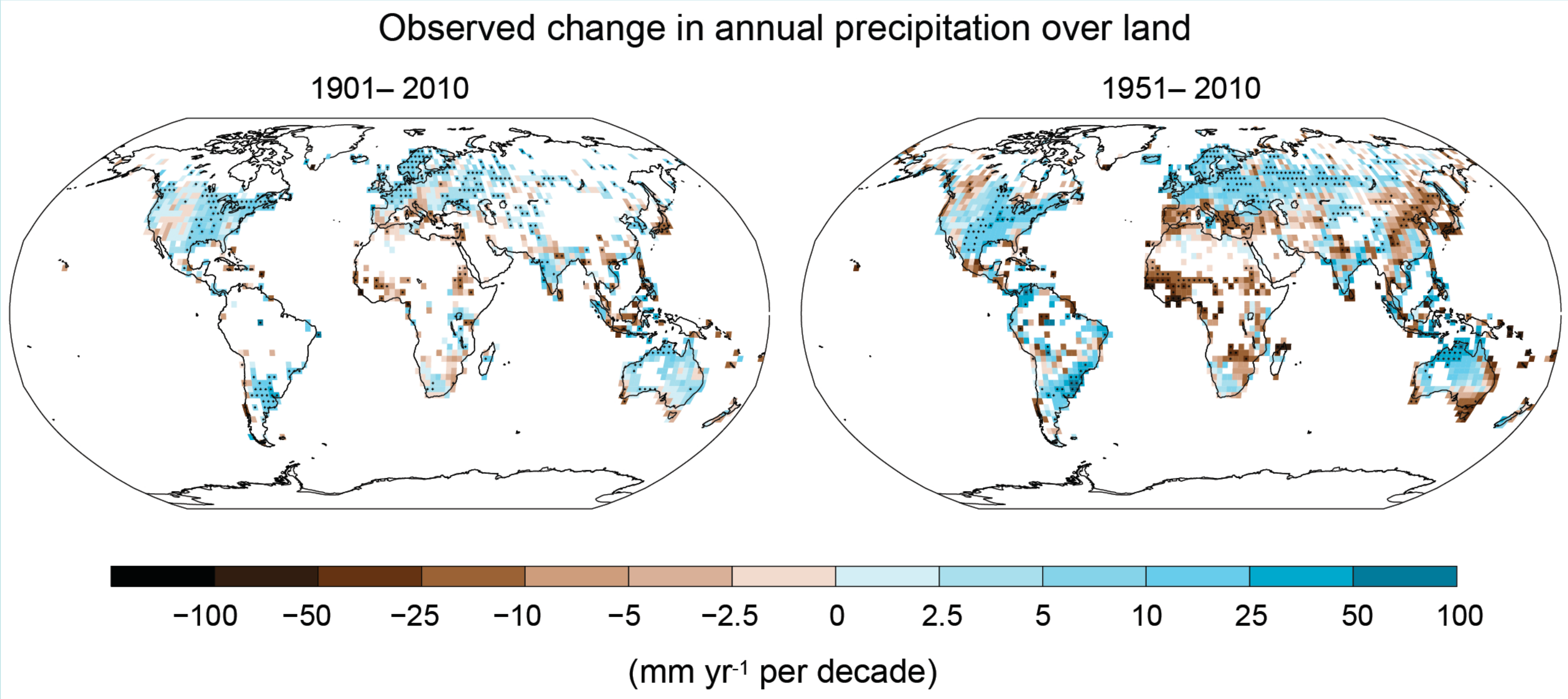
Observed global precipitation trends are still unclear



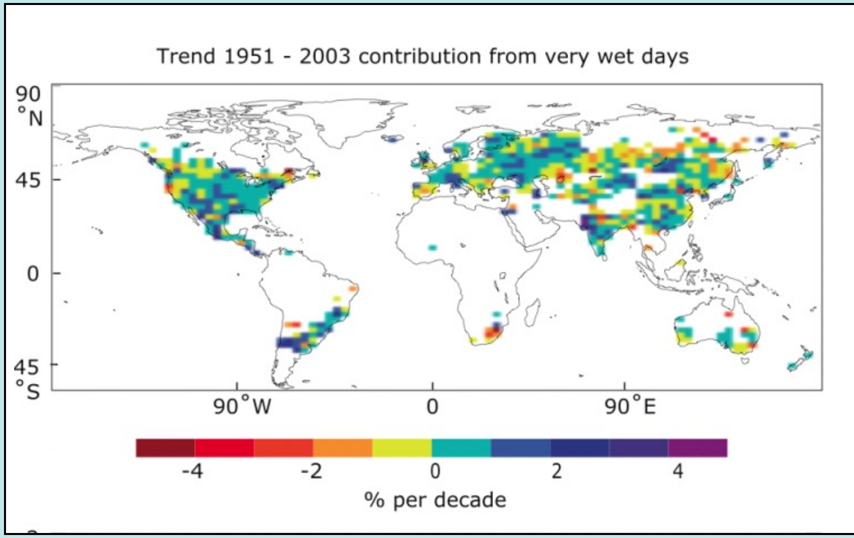
Temperature and precipitation projections show large variability at regional scales



Observed regional precipitation trends

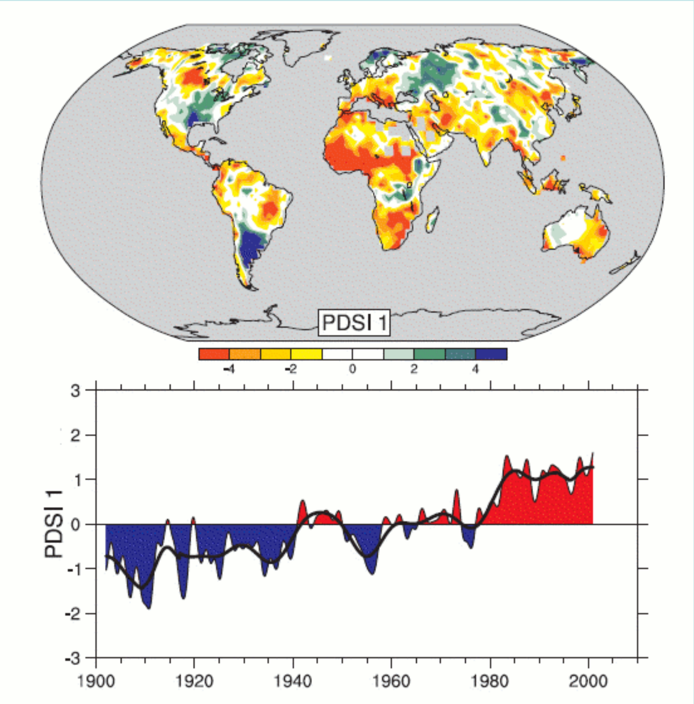


Observed trends in precipitation characteristics

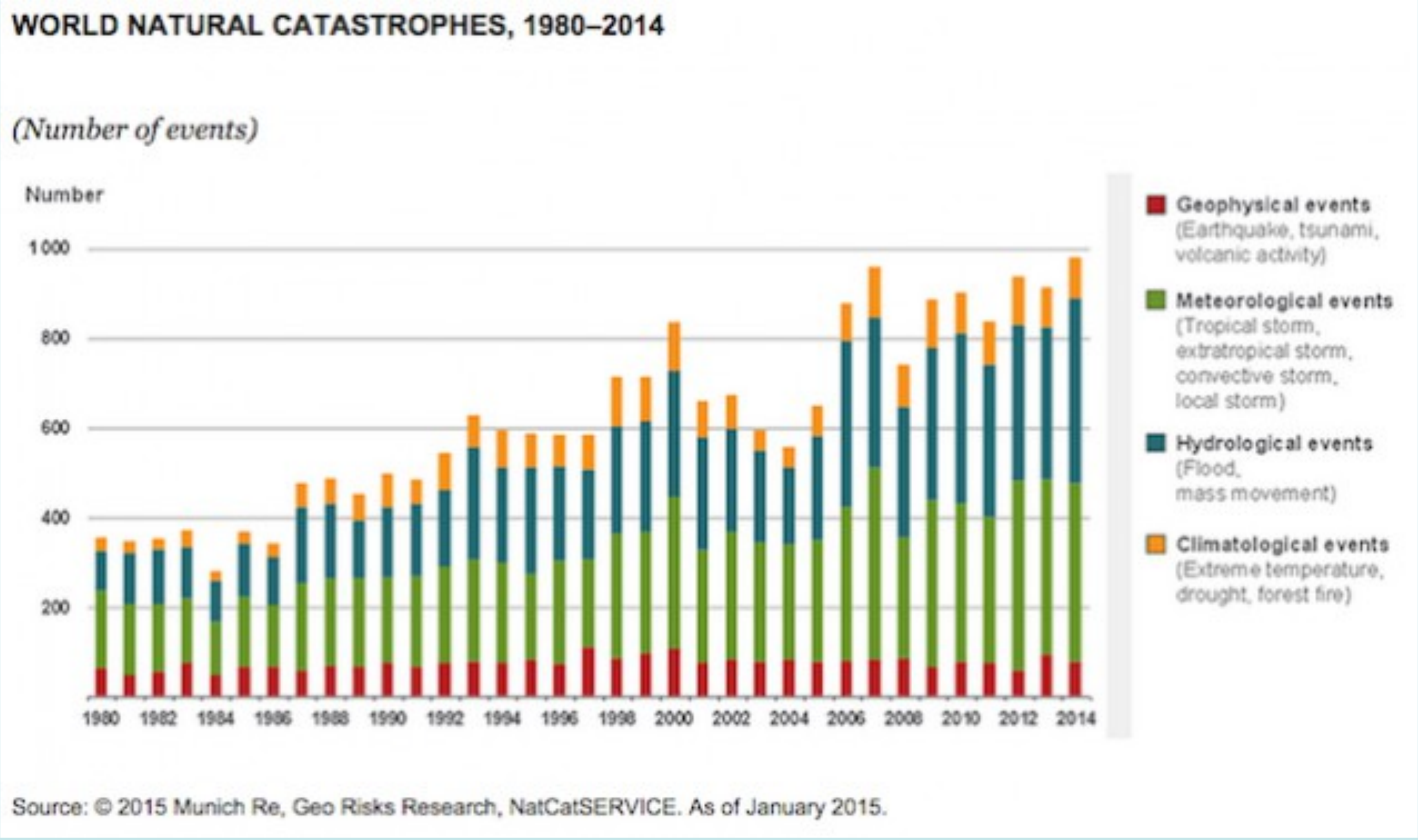


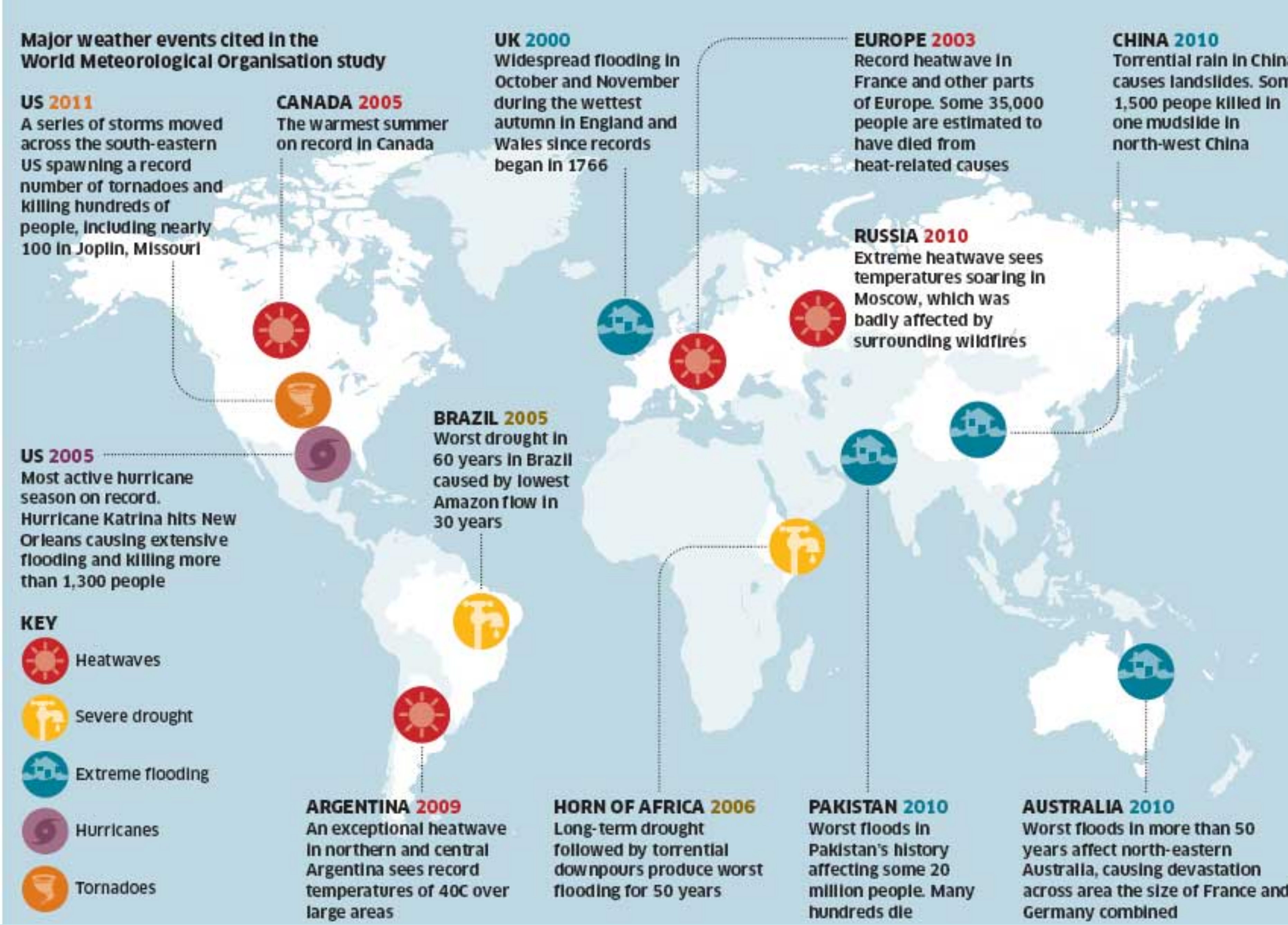
IPCC 2007: "The frequency of heavy precipitation events has increased over most land areas"

IPCC 2007: "More intense and longer droughts have been observed over wider areas since the 1970s"



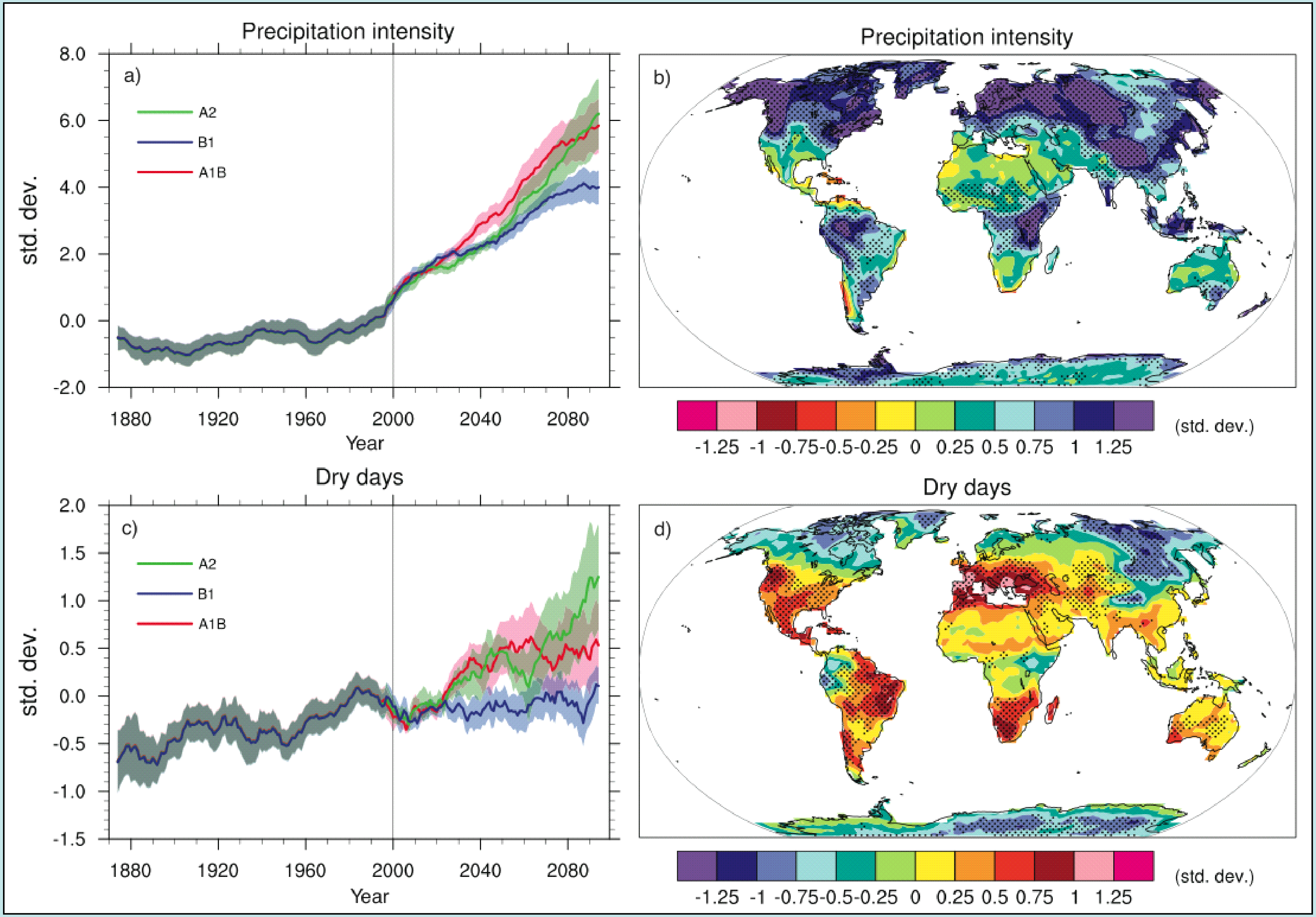
Trend in the global number of catastrophic events

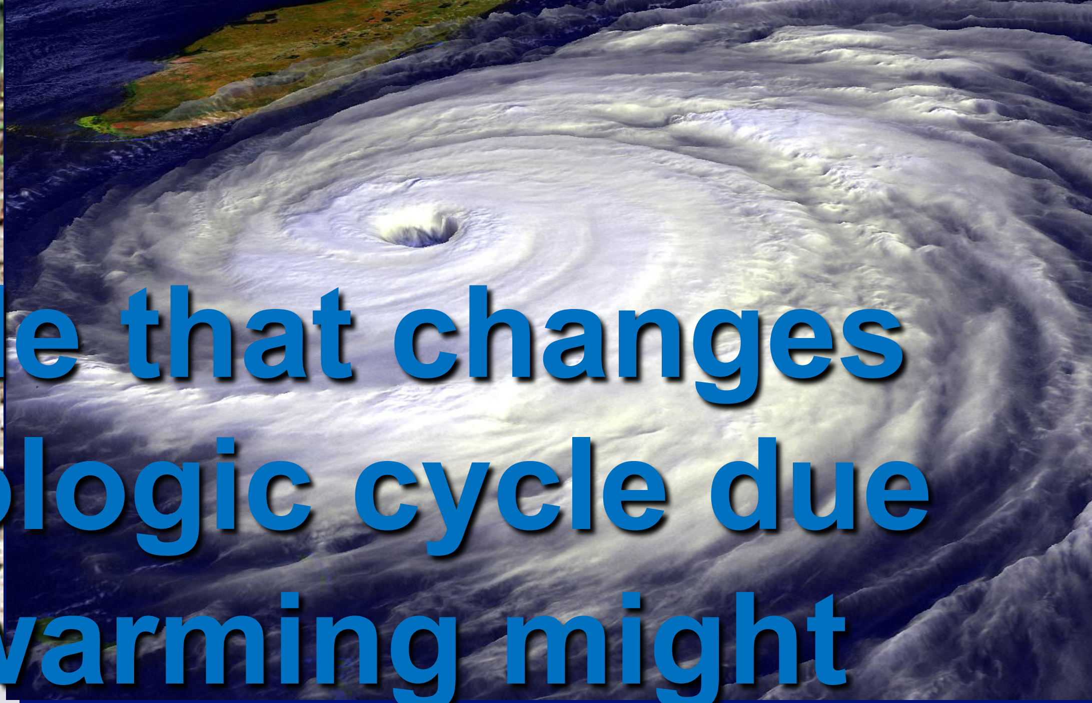




Major weather events cited in the World Meteorological Organisation study
US 2011
A series of storms moved across the south-eastern US spawning a record number of tornadoes and killing hundreds of people, including nearly 100 in Joplin, Missouri
CANADA 2005
The warmest summer on record in Canada
UK 2000
Widespread flooding in October and November during the wettest autumn in England and Wales since records began in 1766
EUROPE 2003
Record heatwave in France and other parts of Europe. Some 35,000 people are estimated to have died from heat-related causes
CHINA 2010
Torrential rain in China causes landslides. Some 1,500 peope killed in one mudslide in north-west China
RUSSIA 2010
Extreme heatwave sees temperatures soaring in Moscow, which was badly affected by surrounding wildfires
BRAZIL 2005
Worst drought in 60 years in Brazil caused by lowest Amazon flow in 30 years
US 2005
Most active hurricane season on record. Hurricane Katrina hits New Orleans causing extensive flooding and killing more than 1,300 people
KEY
Heatwaves
Severe drought
Extreme flooding
Hurricanes
Tornadoes
ARGENTINA 2009
An exceptional heatwave in northern and central Argentina sees record temperatures of 40C over large areas
HORN OF AFRICA 2006
Long-term drought followed by torrential downpours produce worst flooding for 50 years
PAKISTAN 2010
Worst floods in Pakistan's history affecting some 20 million people. Many hundreds die
AUSTRALIA 2010
Worst floods in more than 50 years affect north-eastern Australia, causing devastation across area the size of France and Germany combined

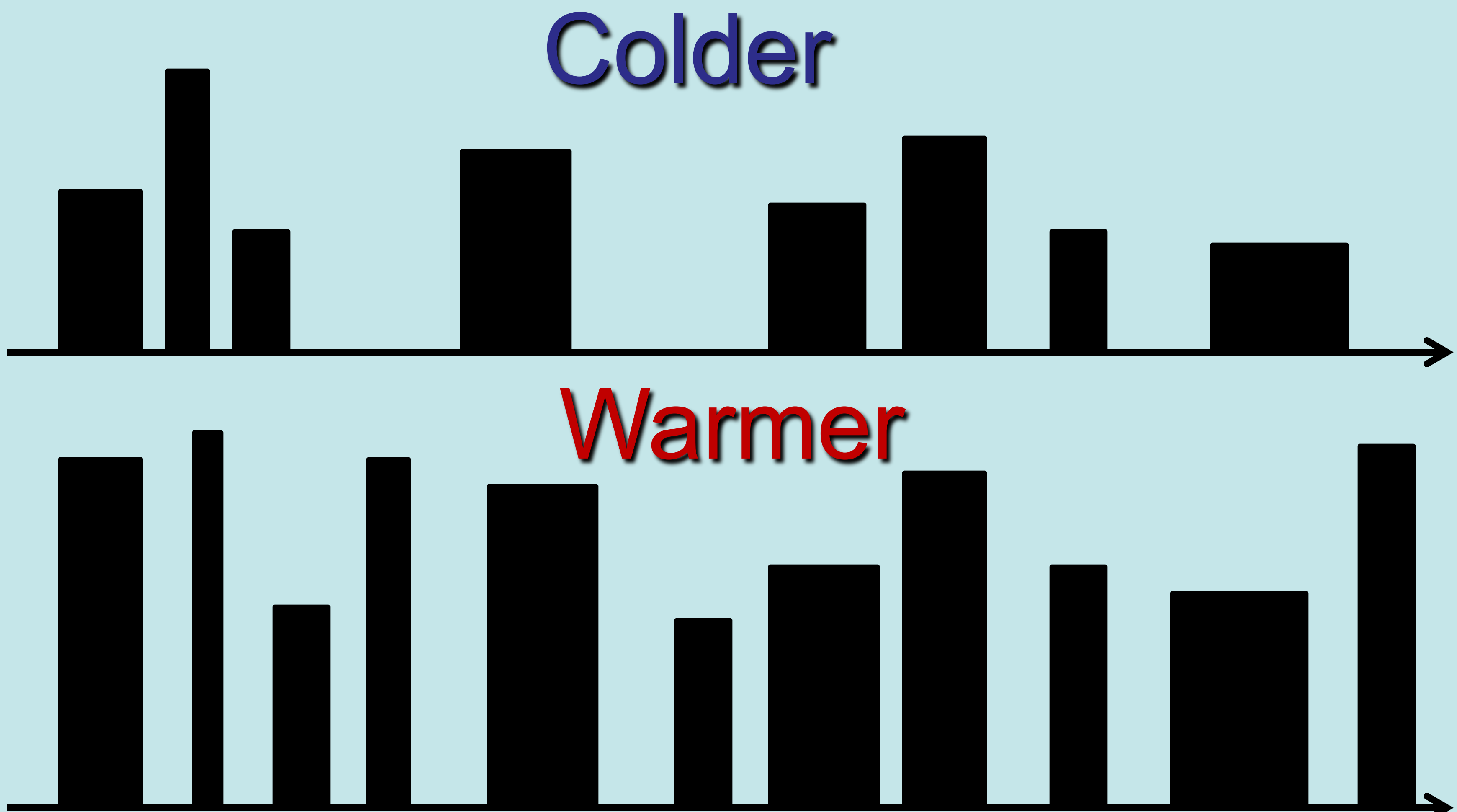
Projected changes in precipitation characteristics IPCC (2007)



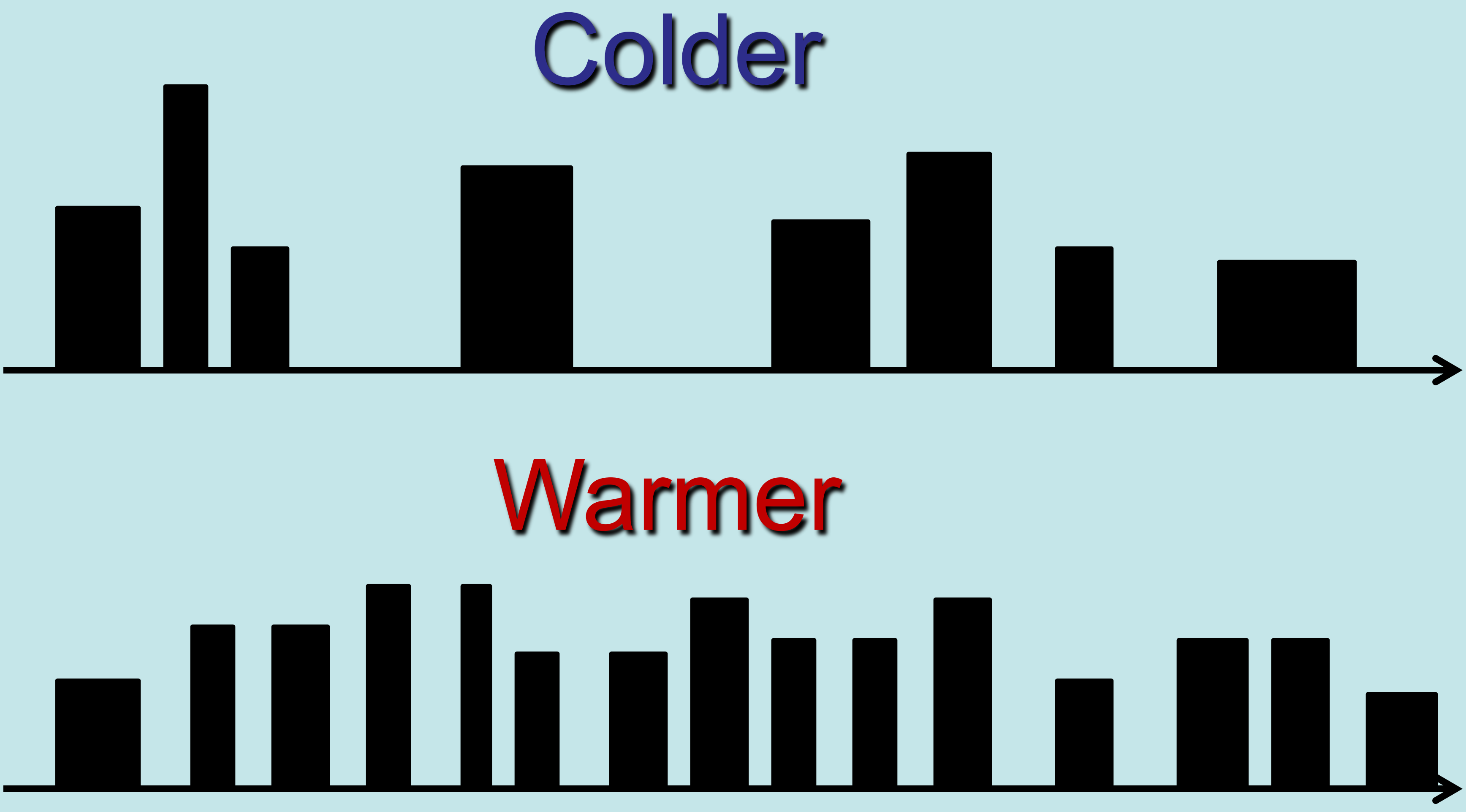



Is it possible that changes in the hydrologic cycle due to global warming might manifest themselves primarily as changes in hydroclimatic regimes?

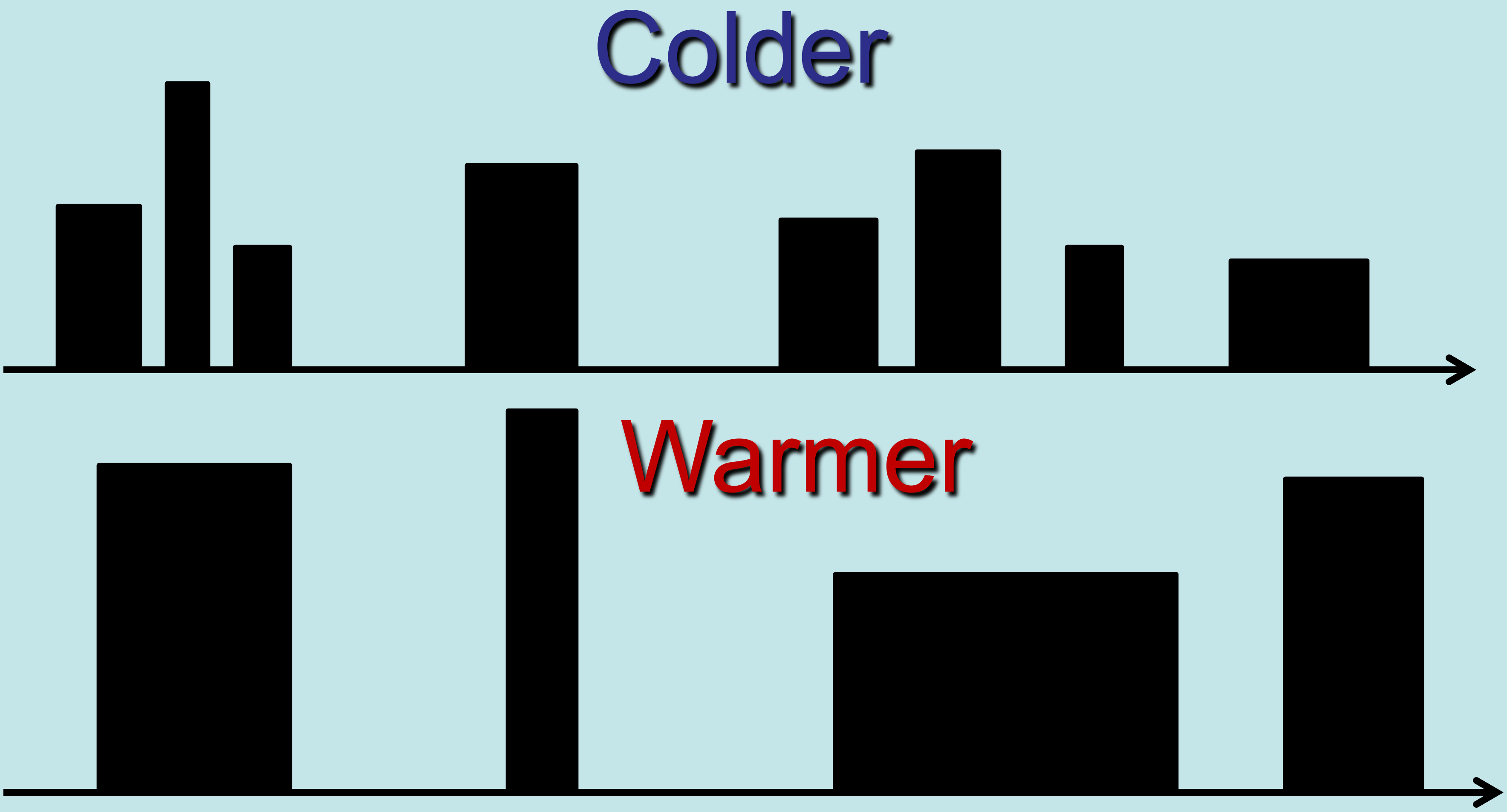

Global warming might lead to more intense, more frequent events



… or to less intense, more frequent events



… or yet to more intense, less frequent events



Giorgi et al. (2011), hypothesis:

The increases in dry day frequency and precipitation intensity are deeply interconnected and can be seen as a combined hydroclimatic signature of global warming

Define an index of hydroclimatic intensity that combines precipitation intensity and dry spell length

$$HY\text{-}INT = I \cdot DSL$$

I = Normalized Precipitation Intensity

DSL = Normalized Dry Spell Length

HY-INT is NOT an index of extremes

HY-INT is calculated from daily precipitation on an annual basis

Giorgi et al. (2014):

Extend the work of Giorgi et al. (2011) using new models (CMIP5) and observations along with an analysis multiple interconnected hydroclimatic indices

SDII= Mean intensity of precipitation events

R95= Fraction of precipitation above the 95th percentile

DSL= Mean dry spell length

WSL= Mean wet spell length

PA= Precipitation area

HY-INT~ SDII x DSL

All indices are calculated on an annual basis

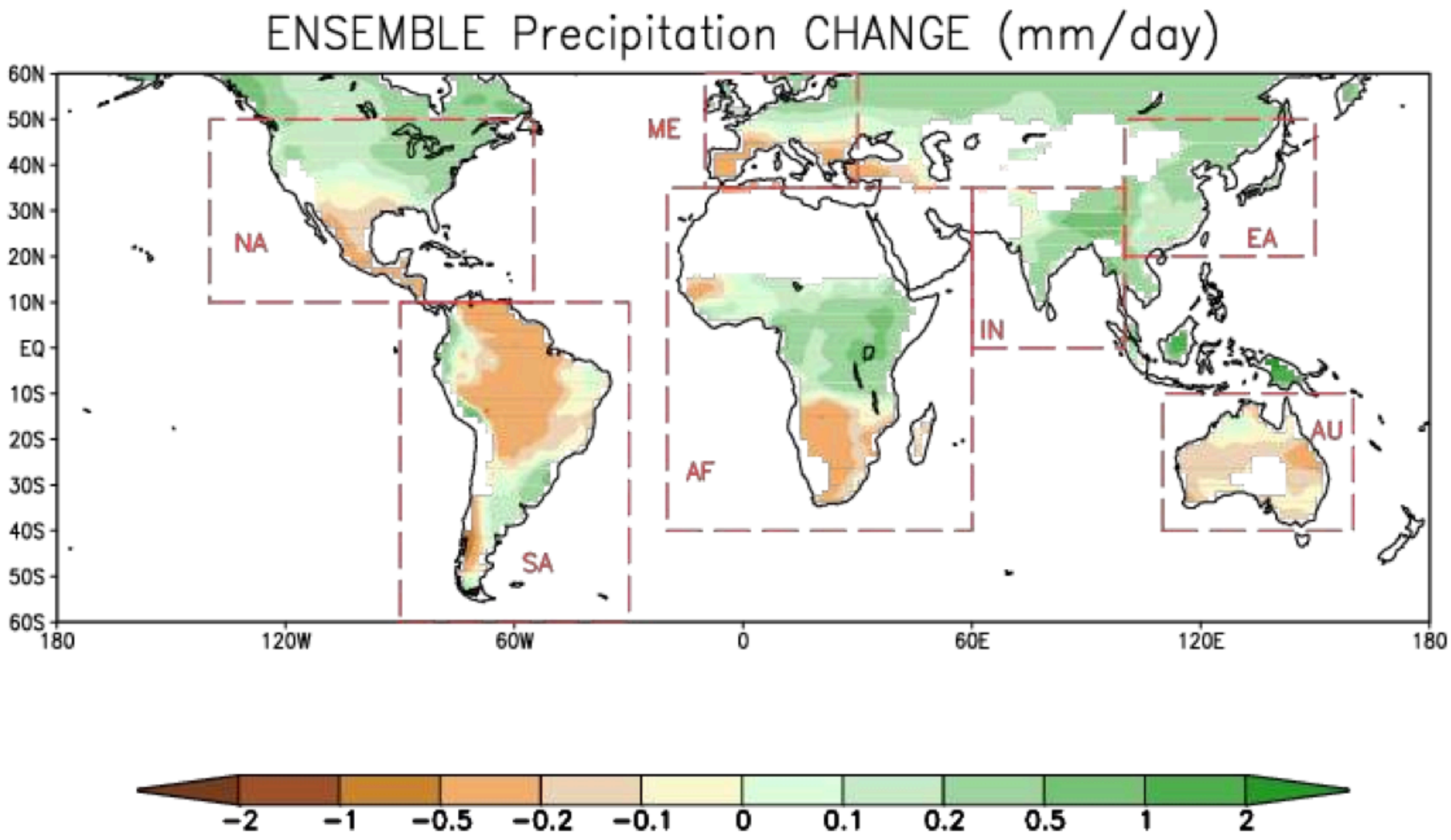
CMIP5 models analyzed (RCP8.5)

MODELS	INSTITUTE	HORIZONTAL RESOLUTION IN DEGREES	REFERENCES
MPI-ESM-MR	Max Planck Institute for Meteorology,, Hamburg, Germany	1.875° x 1.875°	Jungclaus, J. H. et al. (2013), Characteristics of the ocean simulations in the Max Planck Institute Ocean Model (MPIOM) the ocean component of the MPI-Earth system model, *Journal of Advances in Modeling Earth Systems,*
HadGEM2-ES	Met Office Hadley Centre, Exeter, UK	1.875° × 1.25°	Jones, C. D. et al. (2011), The HadGEM2-ES implementation of CMIP5 centennial simulations, *Geosci. Model Dev., 4*, 543-570.
GFDL-ESM2M	NOAA/Geophysical Fluid Dynamics Laboratory, Princeton University, Princeton, New Jersey	2° x 2.5°	Delworth, T. L. et al. (2006), GFDL's CM2 Global Coupled Climate Models. Part I: Formulation and Simulation Characteristics**,** *J. Climate*, 19, 643–674**.**
CCSM4	NCAR, Boulder, CO	0.9° x 1.250°	Gent, P. R. et al. (2011), The Community Climate System Model Version 4, *J. Climate, vol.24*,pp. 4973–4991.
EC-EARTH	KNMI, De Bilt, The Netherlands	1.125° x 1.125°	Hazeleger, W. et al. (2012), EC-Earth V2.2: description and validation of a new seamless earth system prediction model, *Climate Dynamics*, *Vol. 39*, *Issue 11*, pp. 2611-2629.
IPSL-CM5A-MR	LMD/IPSL, Paris, France	1.5° x 1.27°	Dufresne, J.-L. et al. (2013), Climate change projections using the IPSL-CM5 Earth System Model: from CMIP3 to CMIP5, *Clim. Dynamics , 40(9-10)*, pp. 2123-2165.
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan	2..8° x 2.8°	Watanabe, S. et al. (2011), MIROC-ESM 2010: model description and basic results of CMIP5-20c3m experiments, *Geosci. Model Dev., 4*, 845-872.
CSIRO-MK3.6.0	The Centre for Australian Weather and Climate Research, CSIRO Marine and Atmospheric Research,	1.875° x 1.875°	Collier, M. A. et al. (2011), The CSIRO-Mk3.6.0 Atmosphere-Ocean GCM: participation in CMIP5 and data publication, *19th International Congress on Modelling and Simulation, Perth, Australia,* 12–16.
CNRM-CM5	CNRM-GAME and Cerfacs, France	1.4° x 1.4°	Voldoire, A. et al. (2011), The CNRM-CM5.1 global climate model: description and basic evaluation, Climate Dynamics, vol. 40(9): 2091-2121.
CanESM2	Los Alamos National Laboratory, Los Alamos, New Mexico, USA	2..8° x 2.8°	Chylek, P. et al. (2011), Observed and model simulated 20^{th} century Arctic temperature variability: Canadian Earth System Model CanESM2, *Atmos. Chem. Phys. Discuss., 11,* 22893–22907.

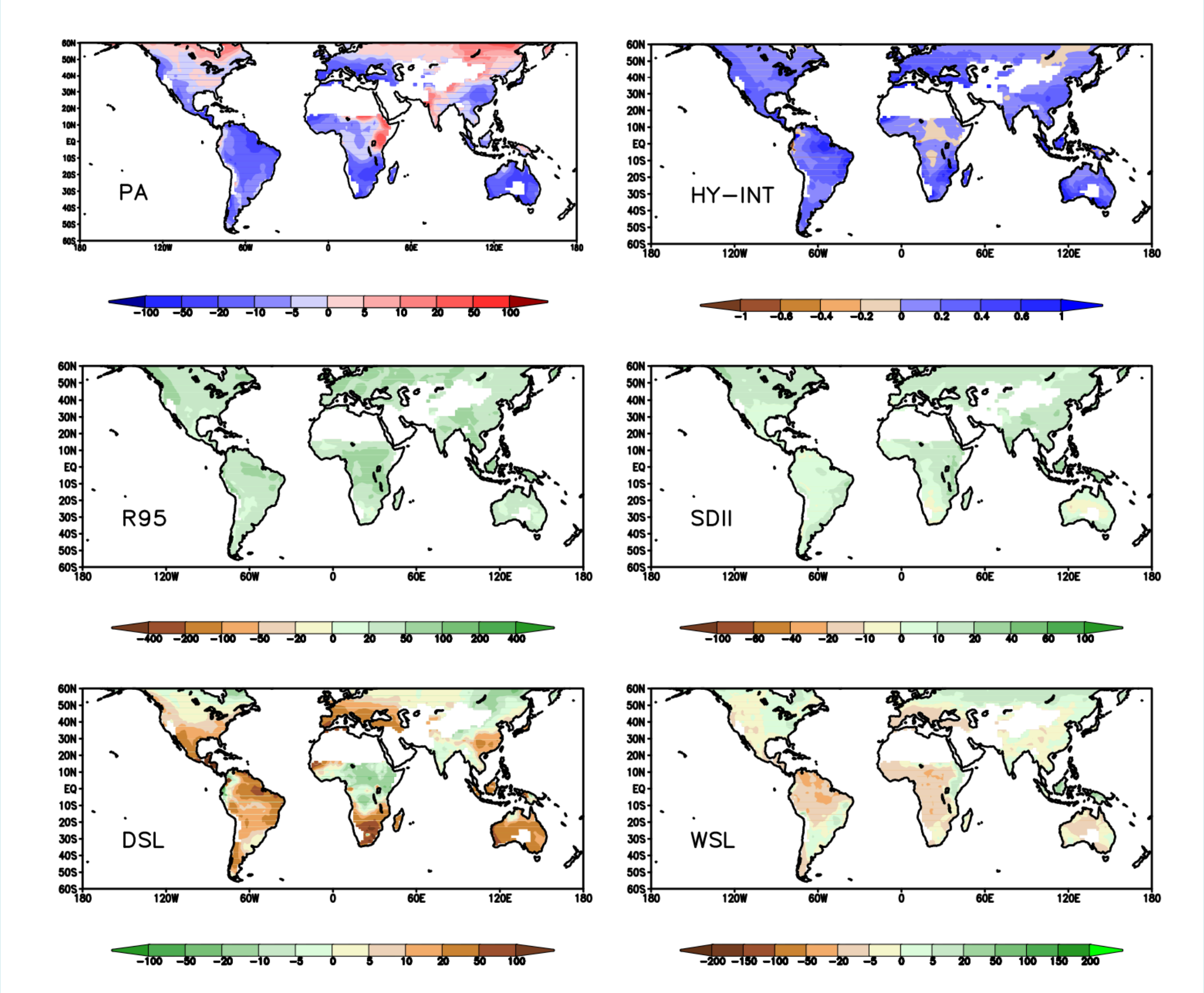
Observations:
Climate Prediction Center (CPC) Unified Gauge-Based Analysis of Global Daily Precipitation

Gauge-based, land only
Global coverage
0.5 Degree resolution
1979-2005 period
Chen et al. (2008a,b)

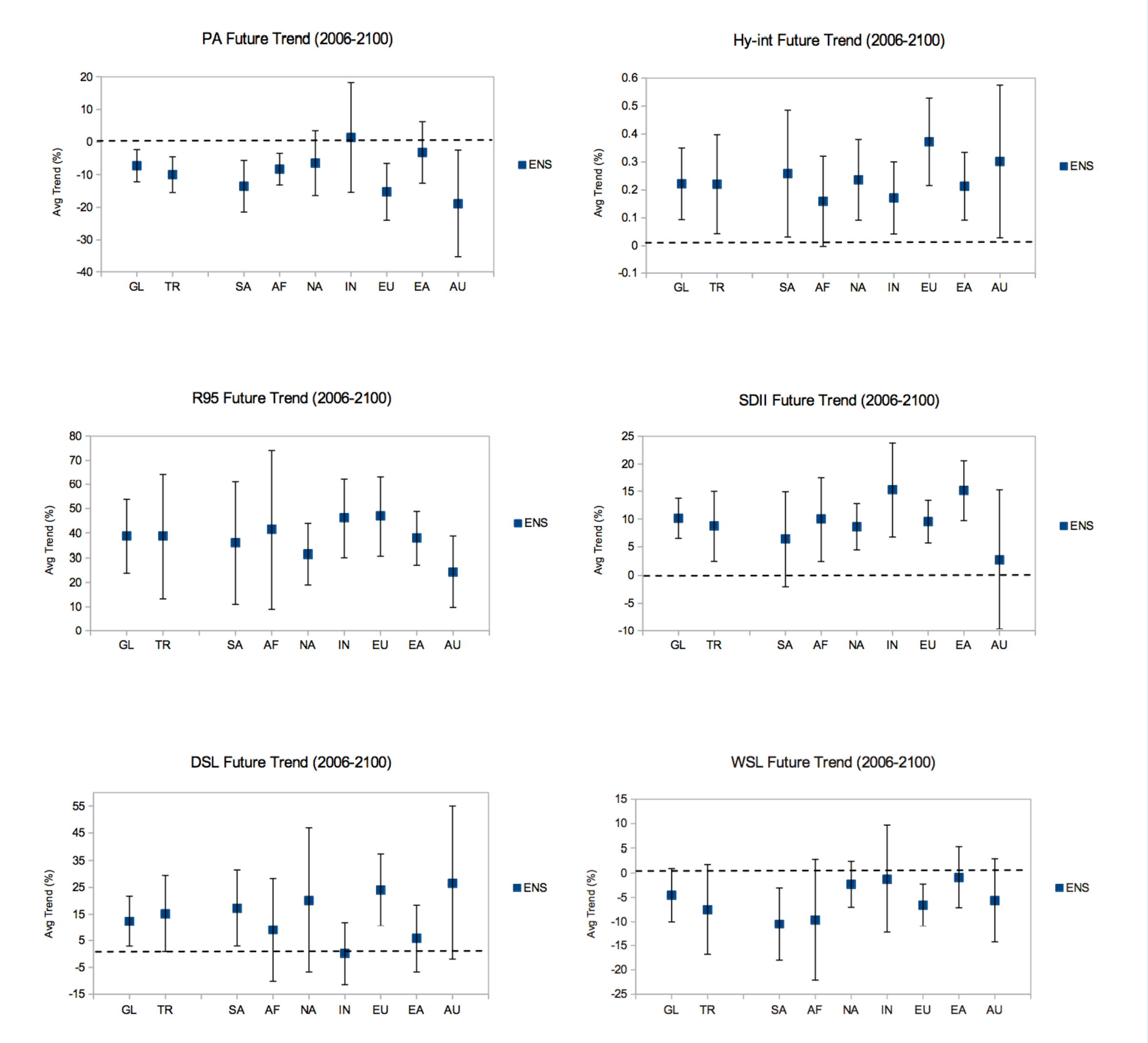
Ensemble average precipitation change for the selected CMIP5 models



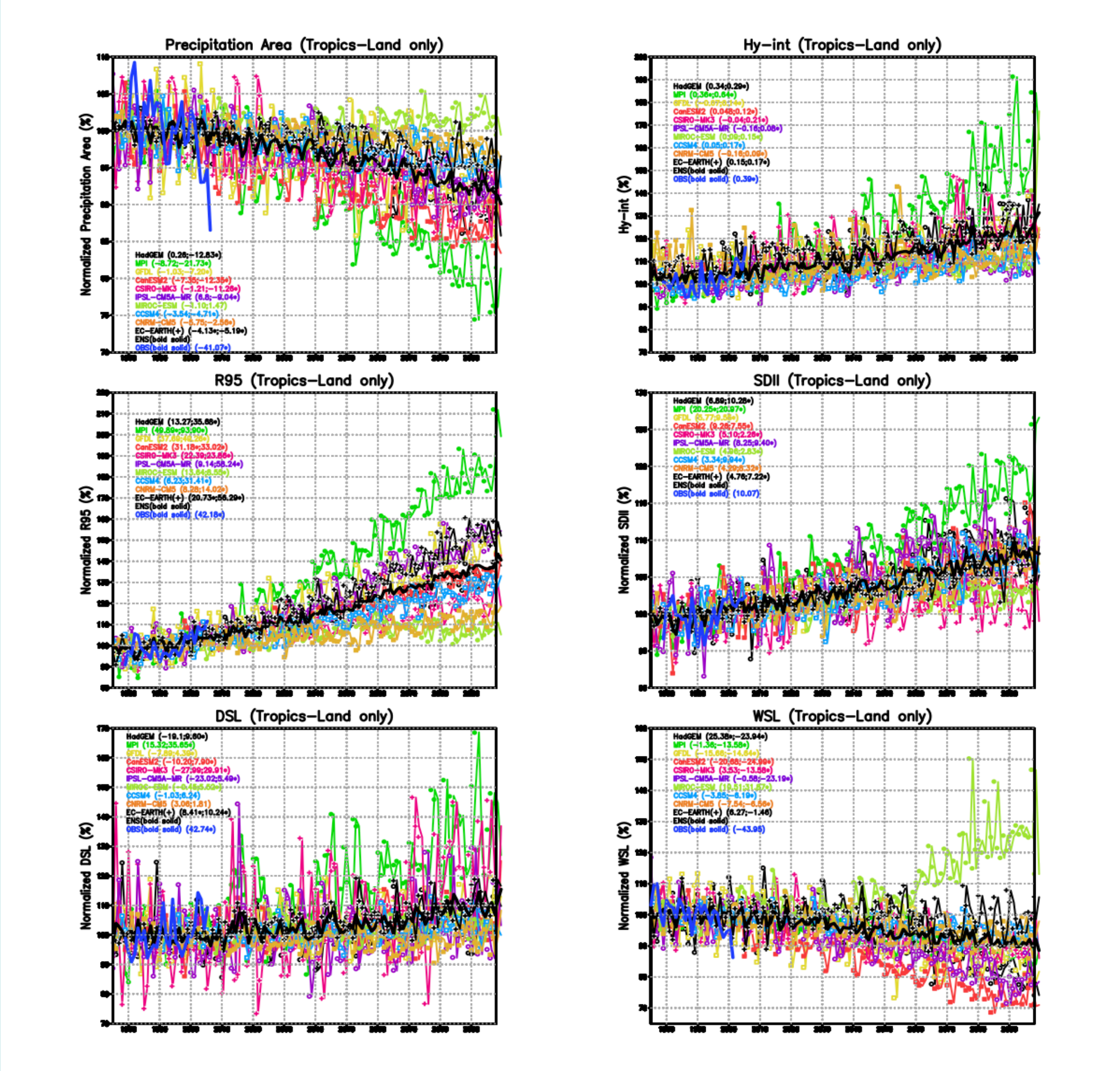
Ensemble average trend in the 6 indices for the future period 2005-2100 (RCP8.5)



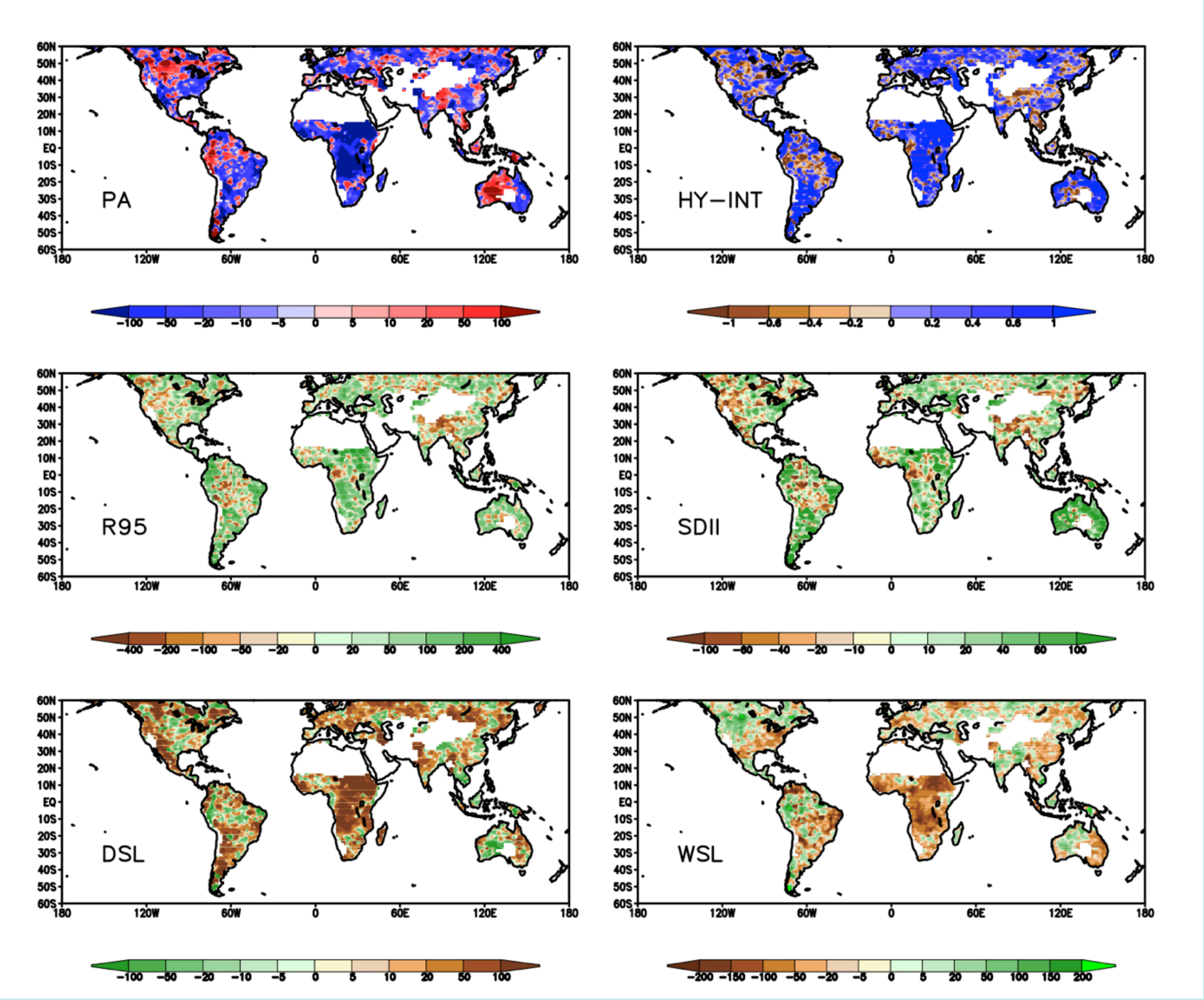
Ensemble average and inter-model SD of the trend in the six indices (2005-2100,RCP8.5) over different regions



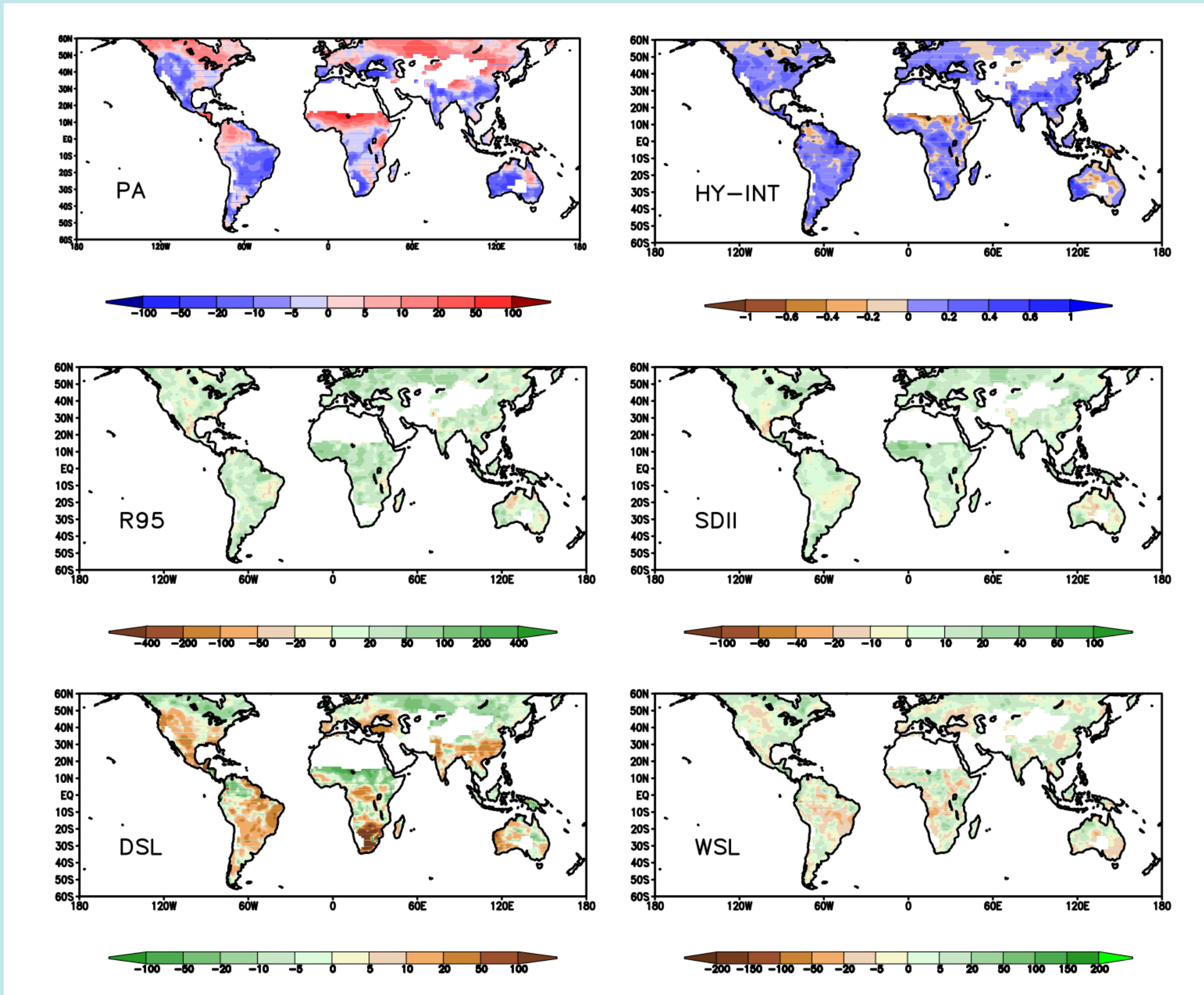
Time evolution of the six indices averaged over the tropical region (RCP8.5)



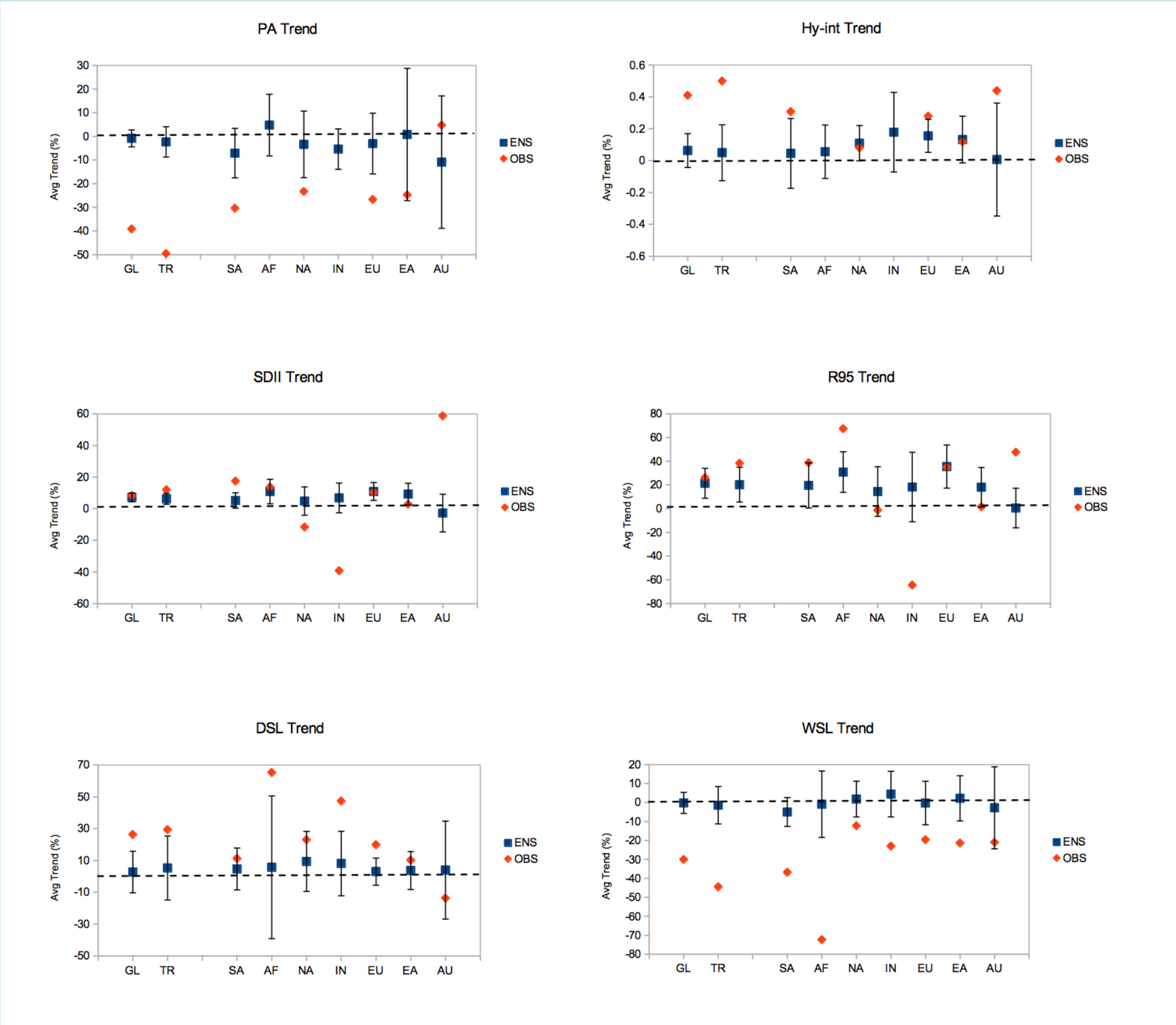
Observed trend in the 6 indices for the period 1979-2005



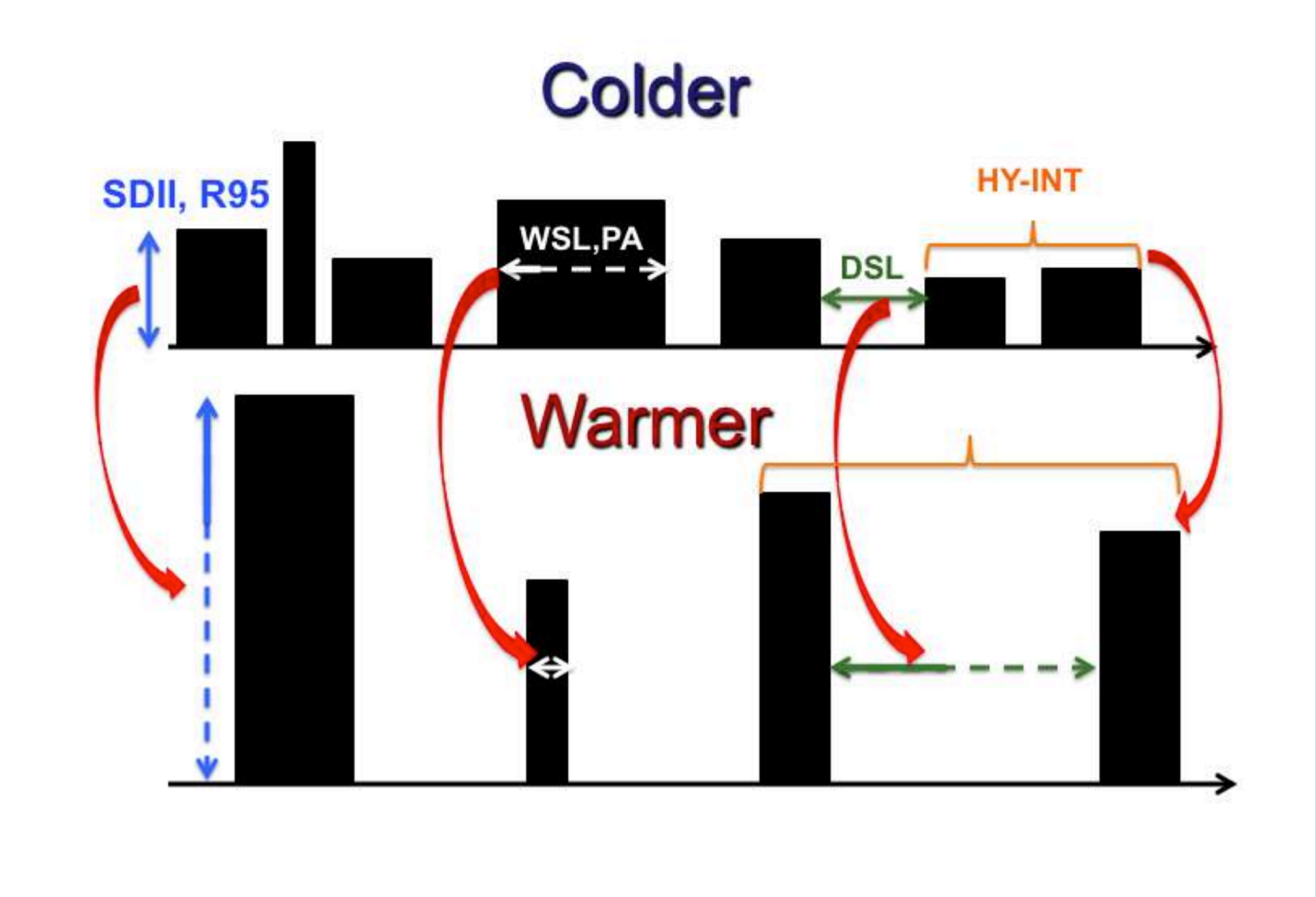
Ensemble average simulated trend in the 6 indices for the period 1976-2005



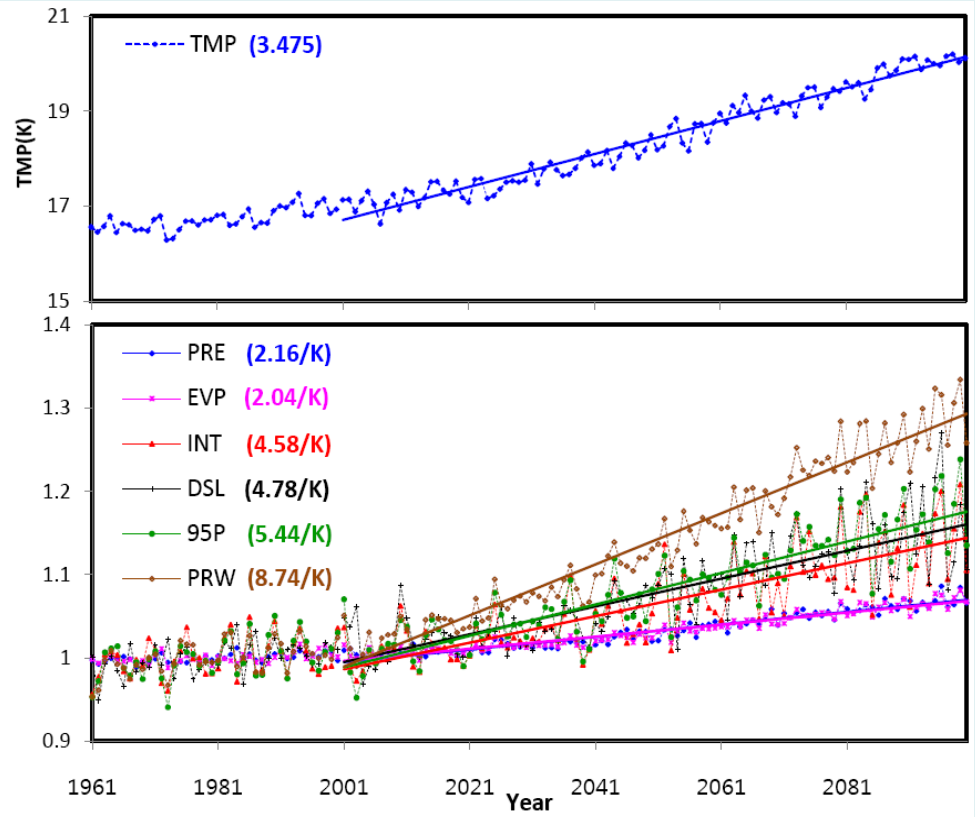
Observed, ensemble average and inter-model SD of the trend in the six indices (1976-2005) over different regions



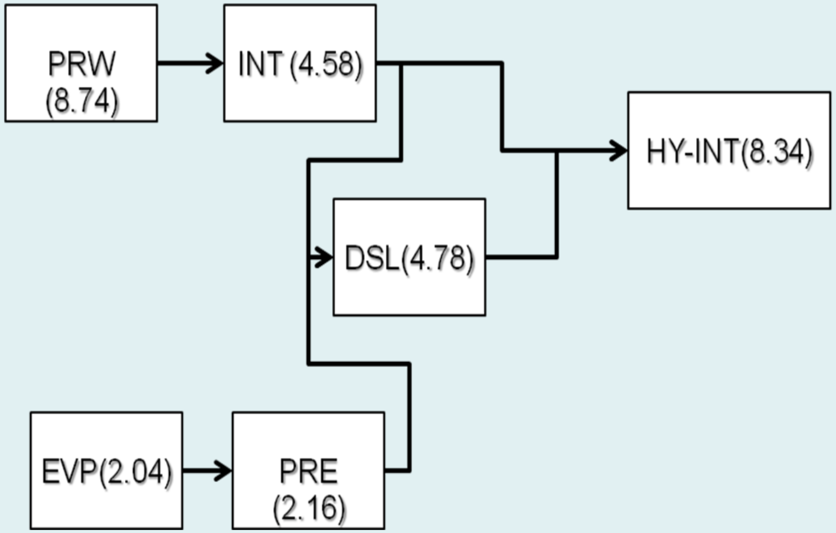
Hydroclimatic response to global warming emerging from the analysis of multiple interconnected indices



A diagnostic explanation of this response. ECHAM5 model, A1B scenario

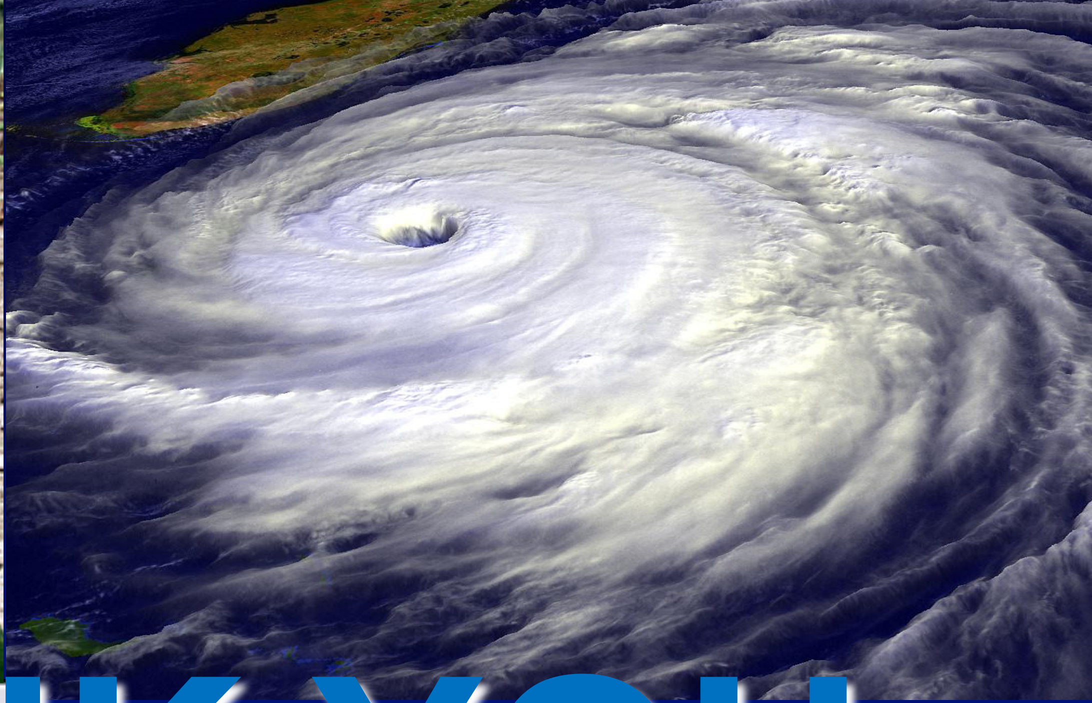


% change per degree of global warming



Summary

- A regime shift towards more intense, shorter, less frequent and less widespread precipitation events appears to be a robust response to global warming
- Observations for the late decades of the 20th century appear to generally confirm this response
- The HY-INT, R95 and (to a lesser extent) PA indices show the most spatially consistent and pronounced response
- This finding has applications in model evaluation and detection/attribution work (in addition to hydrologic impacts)
- Understanding of this hydroclimatic shift might provide key information on the inherent behavior of the Earth's hydrologic cycle, tropical convection likely playing a key role in it

THANK YOU