Precipitation in the Subtropics: Weather Systems and Climatic Changes

Andries-Jan de Vries[1]
Daniela Domeisen[1,2]

[1)] University of Lausanne, Institute of Earth Surface Dynamics, Lausanne, Switzerland
[2)] ETH Zürich, Institute for Atmospheric and Climate Science, Zürich, Switzerland

andries-jan.devries@unil.ch

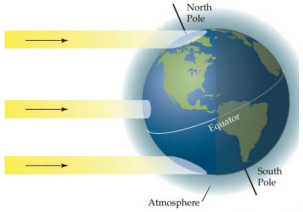
UNIL | Université de Lausanne

Floods and freshwater resources

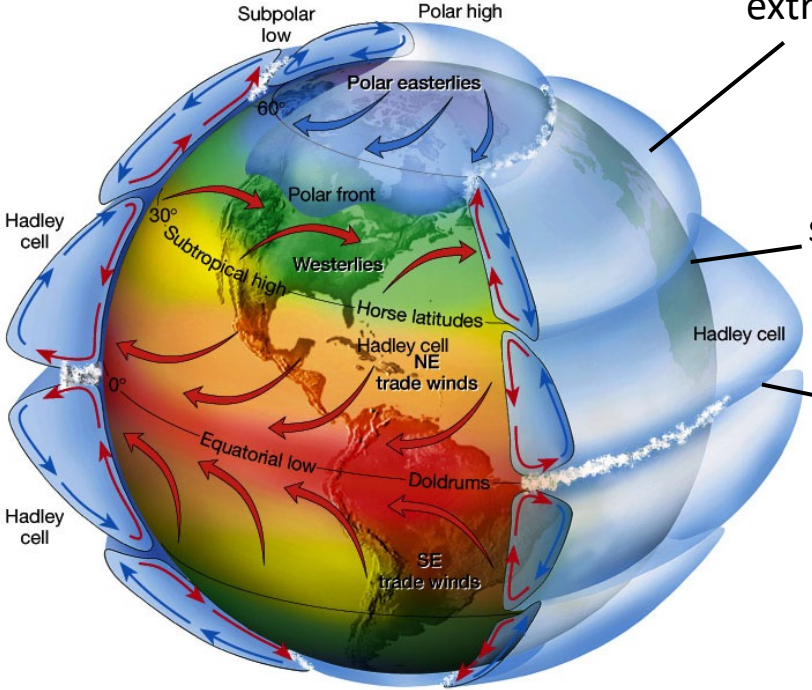
Great Colorado floods September 2013
(*Credit: Terri Cook via Imaggeo)*

Drought in Italy
(*Credit: Andrea Carri via Imaggeo)*

The general circulation and climate zones



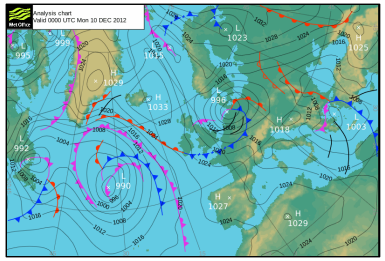
unequal distribution solar insolation
(*sinauer associates, inc.*)



3-D schematic global circulation (*GeoCoops*)

extratropics

westerlies and storm track



(*Met Office*)

subtropics

subsidence

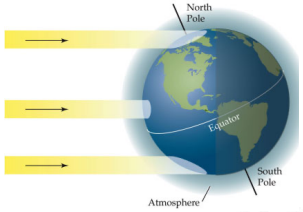
(*Desert Biome*)

tropics

ITCZ & tropical convection

(*Mini Cloud Atlas*)

Weather systems of precipitation



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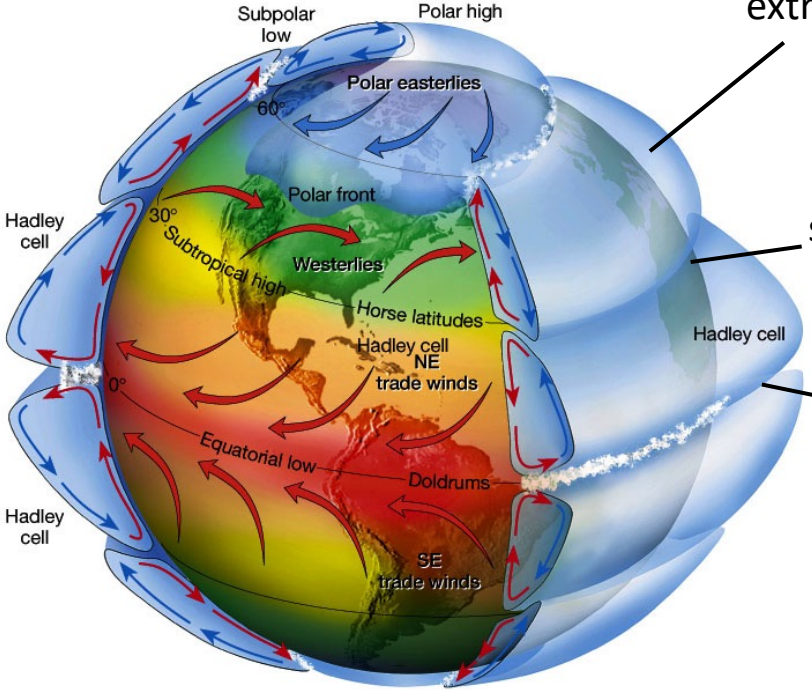
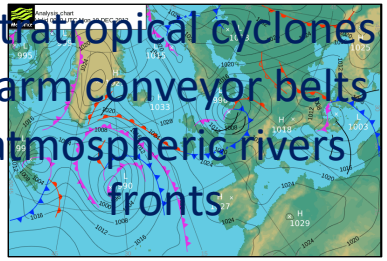


3-D schematic global circulation (*GeoCoops*)

extratropics

western boundary storm track

extratropical cyclones
warm conveyor belts
atmospheric rivers
fronts



(*Met Office*)

subtropics

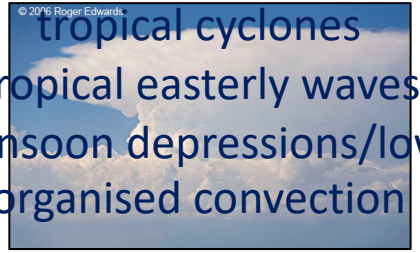
subsidence

(*Desert Biome*)

tropics

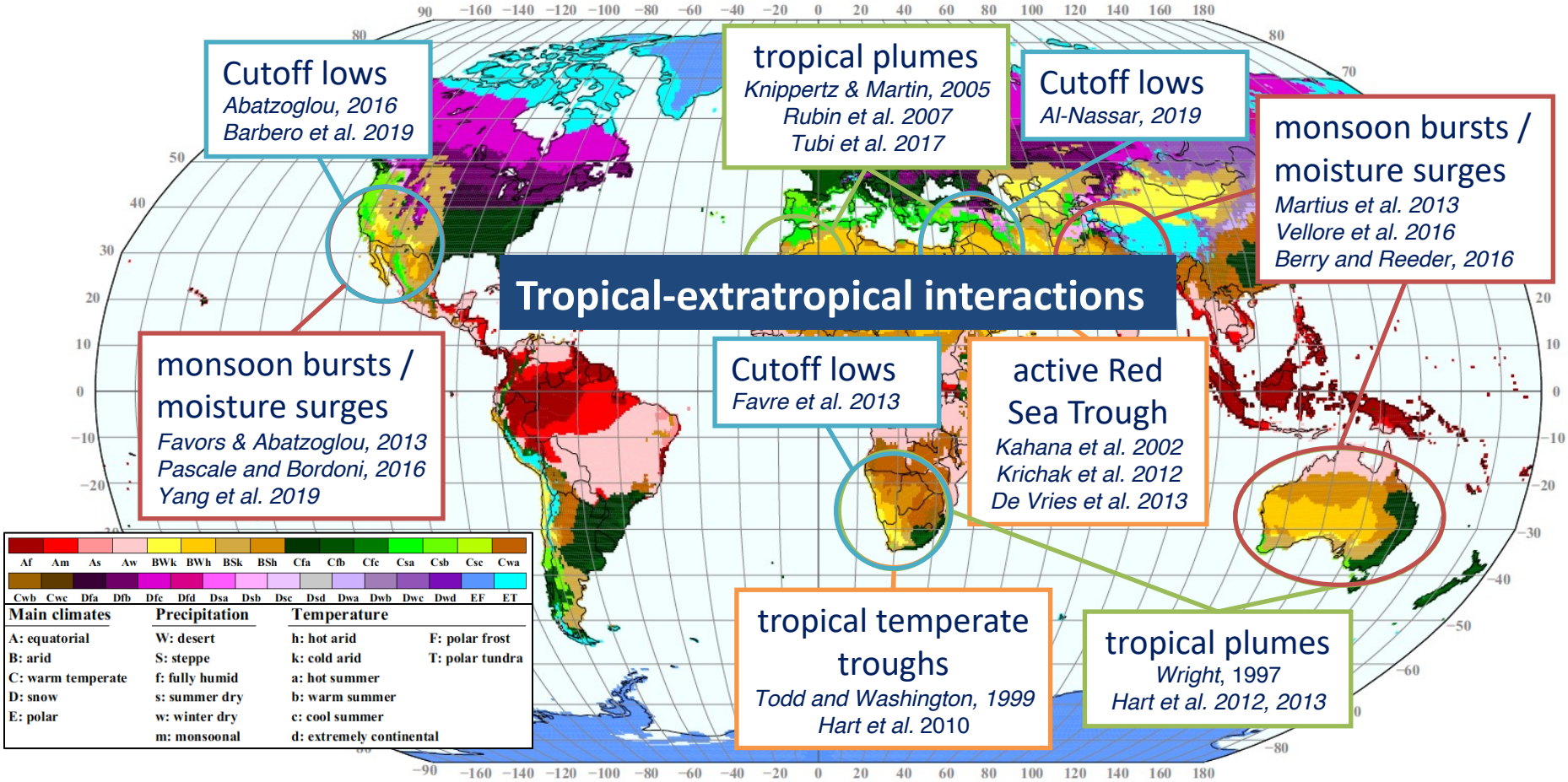
ITCZ & tropical convection

tropical cyclones
tropical easterly waves
monsoon depressions/lows
organised convection



(*Mini Cloud Atlas*)

Weather systems of precipitation in the dry subtropics



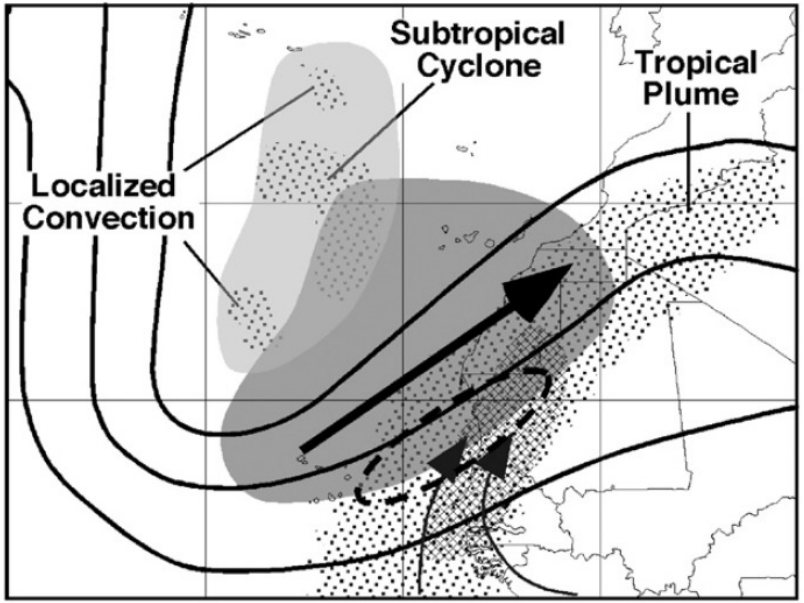
World Map of Köppen-Geiger Climate Classification (*Kottek et al., 2006, Meteorologische Zeitschrift*)

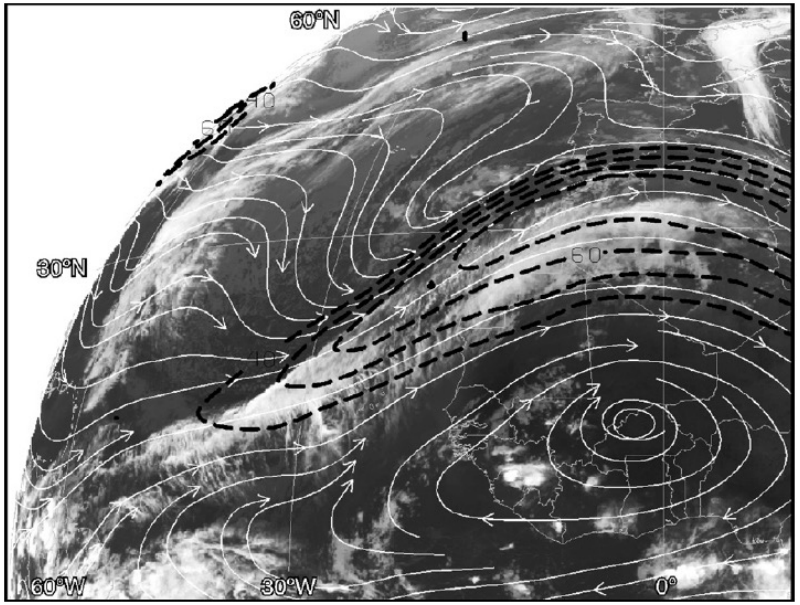
The subtropics: regional examples

Tropical plumes

"Elongated upper- and midlevel cloud bands that reach from the tropics in a poleward-eastward direction"

- equatorward-eastward Rossby wave trains
- upper-level trough intrusion into low latitudes
- pronounced subtropical jet stream
- poleward-eastward moisture transport
- QG ascent, inertial instability, convective instability





Northwest Africa: meteosat infrared image at 0000 UTC, 31 March 2002 and streamlines and isotachs on 345-K isentropic surface

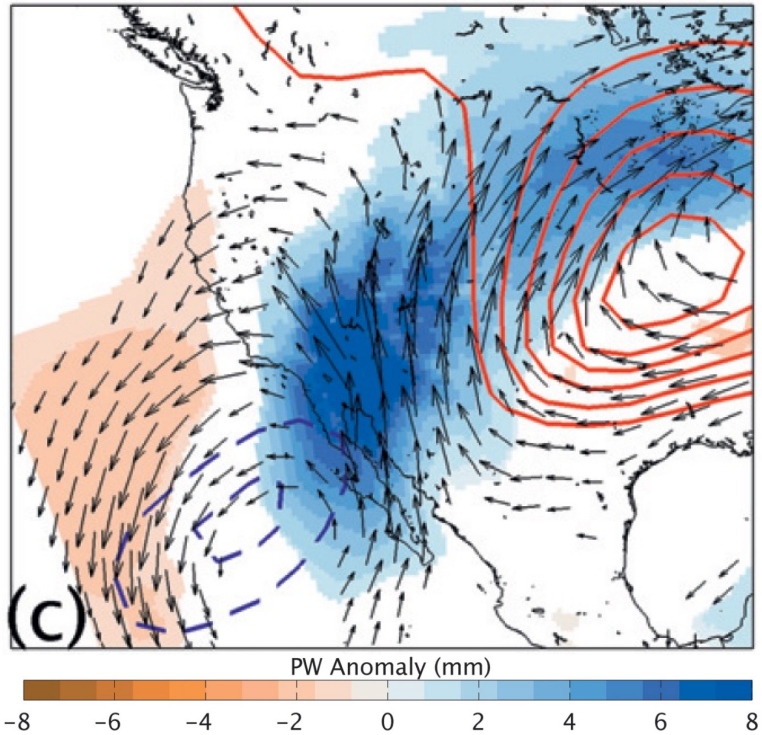
Schematic of the synoptic situation during precipitation events over West Africa in connection with tropical plumes

Knippertz, 2007 (DAO)

Monsoon bursts / moisture surges

Surges of monsoonal moisture into southwest North America

- Coupling of tropical easterly & midlatitude Rossby waves

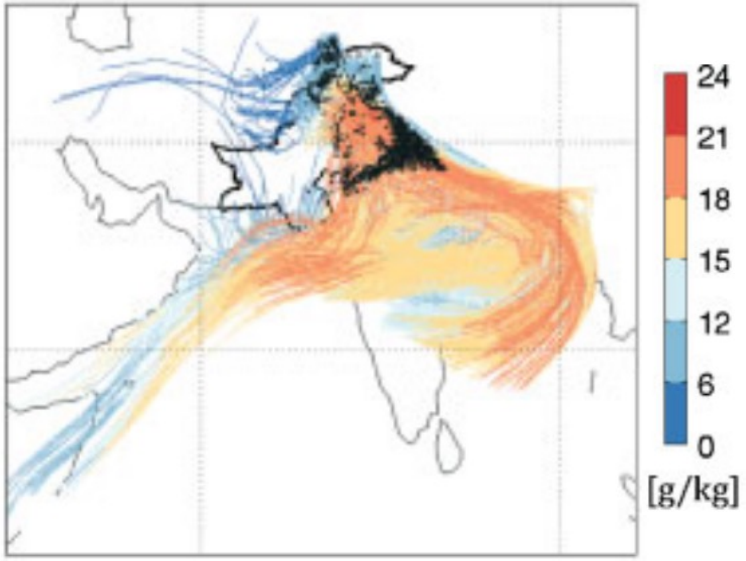


Composite precipitable water anomaly (shaded), IVT (vectors), 500-hPa geopotential height standardized anomaly (contours)

Favors and Abatzoglou, 2013 (MWR)

July 2010 floods in Pakistan

- > 2,000 fatalities
- extratropical breaking waves
- monsoonal moisture

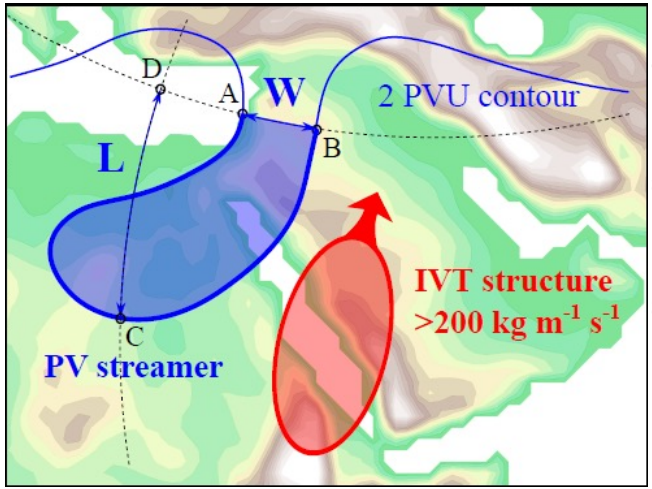


Backward trajectories for air parcels with RH>95%
29 July 2010, 0600 UTC

Martius et al. 2013 (QJRMS)

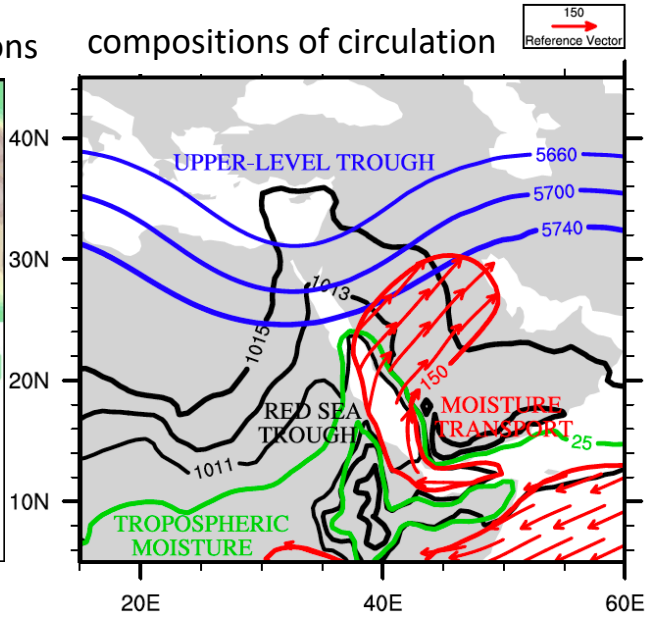
Tropical-extratropical interactions in the Middle East

Schematic tropical-extratropical interactions



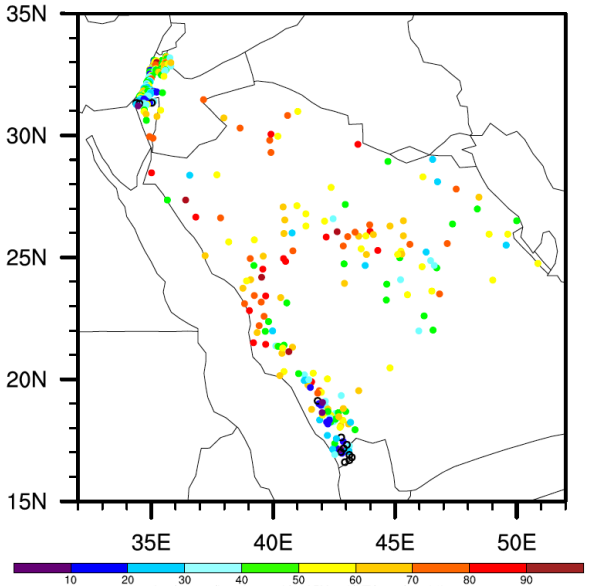
midlatitude forcing &
tropical moisture transport

compositions of circulation



SLP (hPa), **500-hPa Z (gpm)**,
IVT (kg m^{-1} s^{-1}) and **TCW (kg m^{-2})**

stations Israel & Saudi Arabia

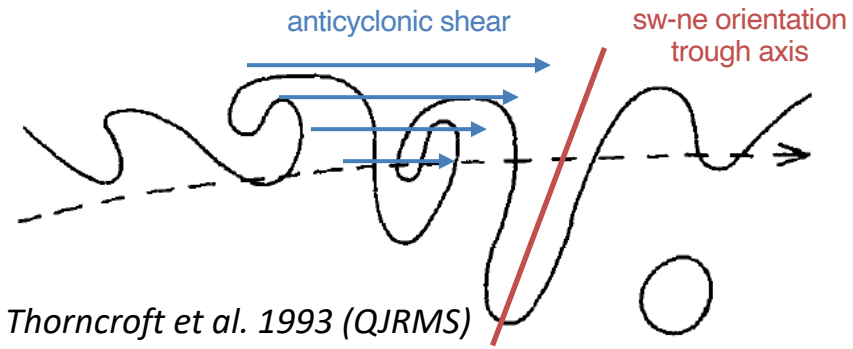


Fractions (%) of top 10 extreme precipitation days associated with tropical-extratropical interactions

De Vries et al. 2018 (JGR-A)

Rossby wave breaking

Rossby wave breaking (RWB): identification



Thorncroft et al. 1993 (QJRMS)

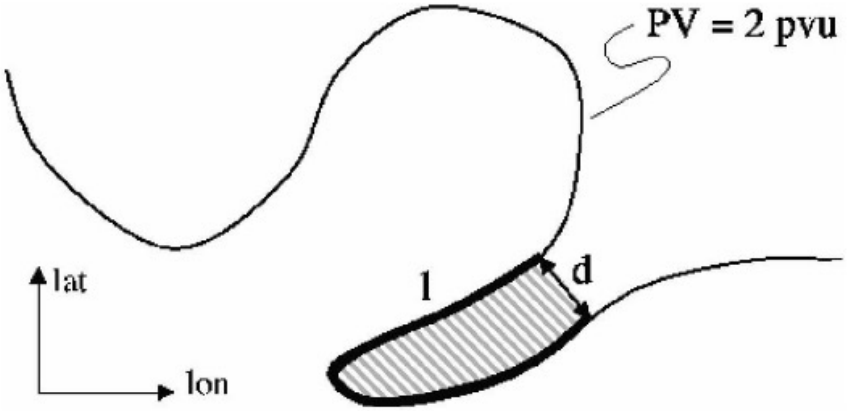
Potential Vorticity (PV):

1) Materially conserved in an adiabatic flow
2) "Invertibility" principle

$$PV = \rho^{-1} \varsigma_a \cdot \nabla \theta$$

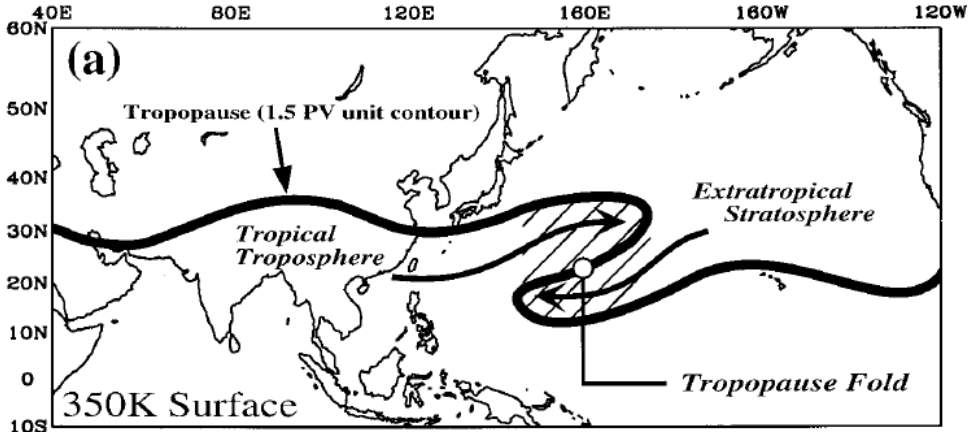
Hoskins et al. 1985

identification: PV streamers & cutoffs



Wernli and Sprenger, 2007 (JAS)

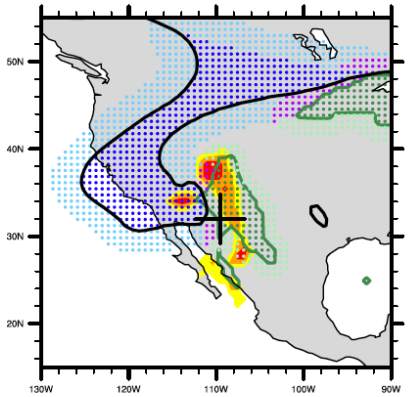
Meridional overturning of PV contours



Postel and Hitchman, 1999 (JAS)

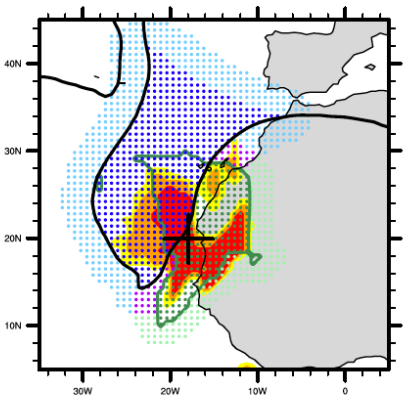
Example cases of catastrophic floods

Colorado, 10 Sep 2013; 9 deaths



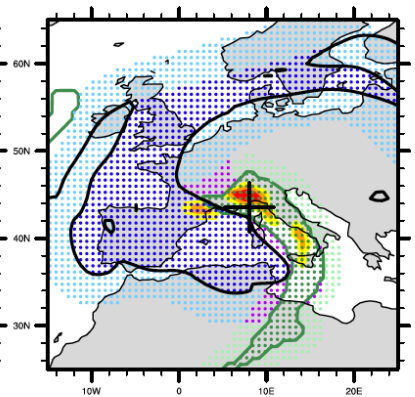
Gochis et al. 2013

NW Africa, 10 Jan 2002; 25 deaths



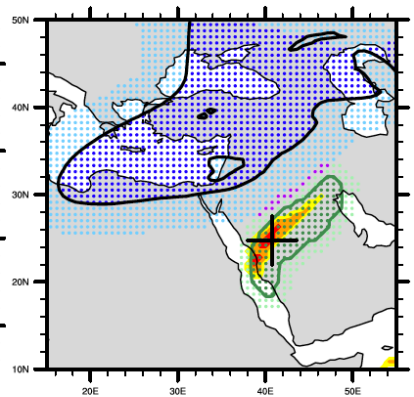
Knippertz and Martin 2005

Alps, 15 Oct 2000; 16 deaths



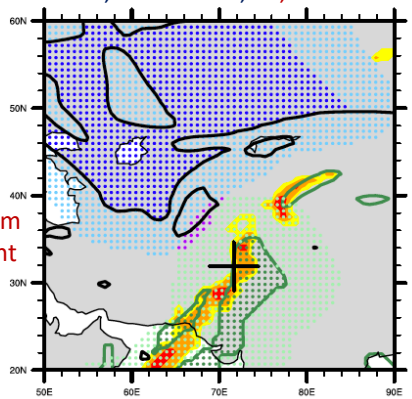
Froidevaux and Martius 2006

Jeddah, 25 Nov 2009; 161 deaths



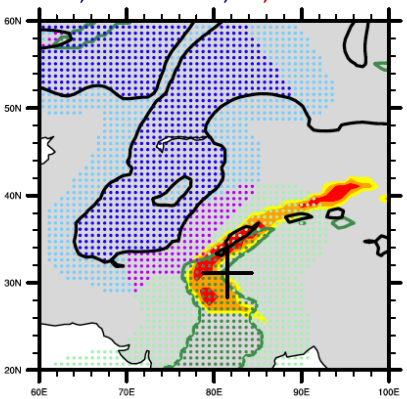
De Vries et al. 2016

Pakistan, 28 Jul 2010; >2,000 deaths



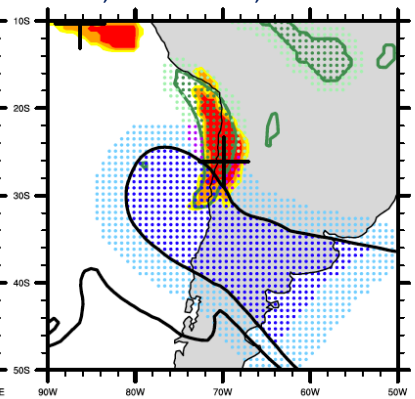
Martius et al. 2013

India, 17 Jun 2013; >6,000 deaths



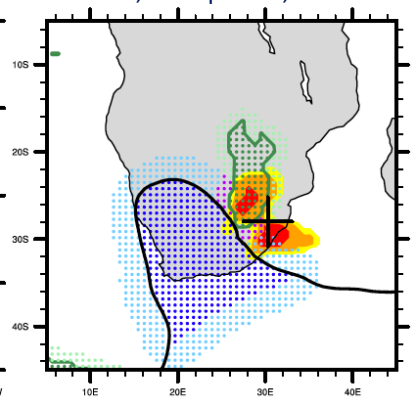
Vellore et al. 2016

Chile, 25 Mar 2015; 178 deaths



Wilcox et al. 2016

South Africa, 27 Sep 1987; 506 deaths



Van Heerden & Taljaard 1998

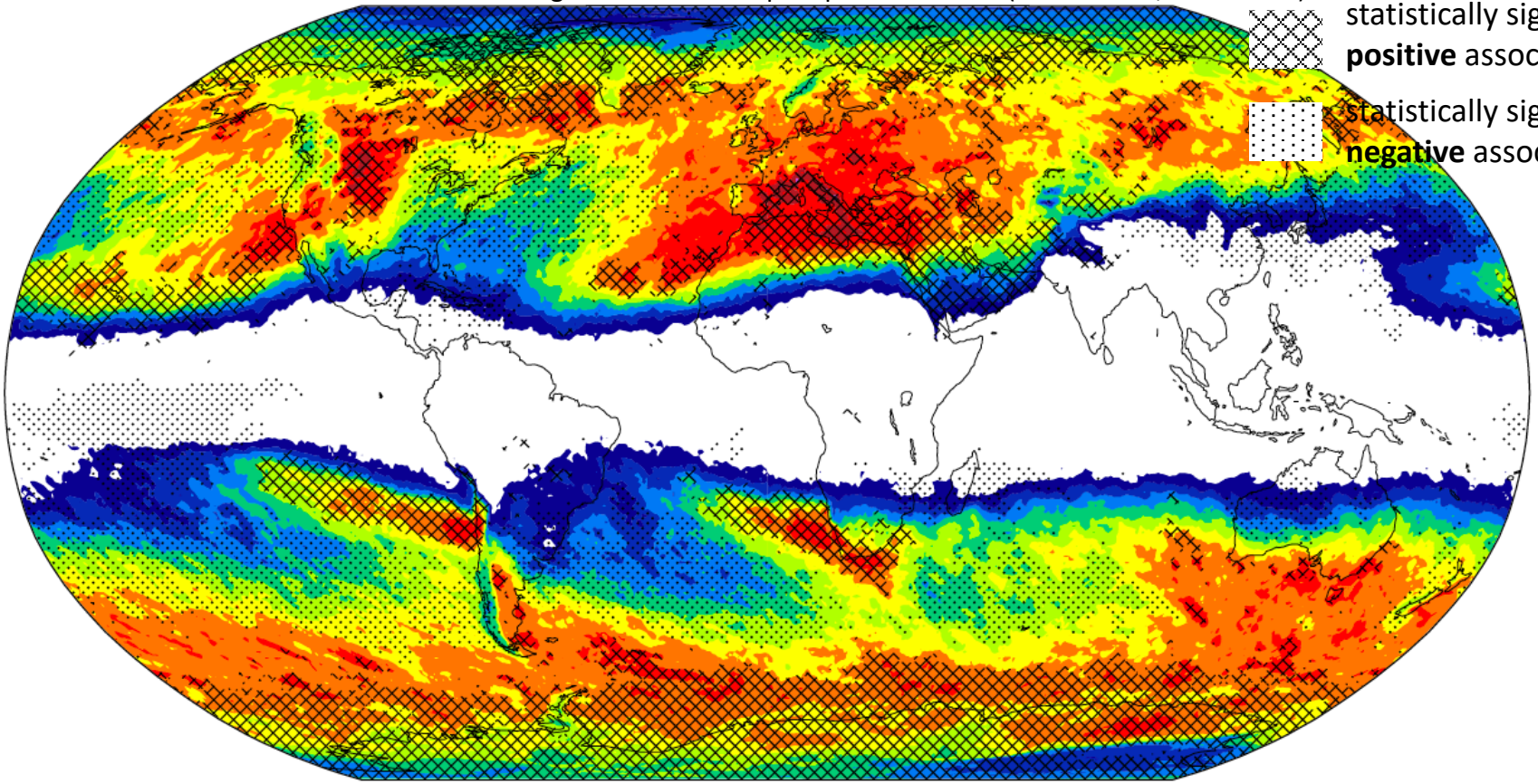
Societal impacts from the Emergency Event Database (EM-DAT)

PV streamer
PV streamer extended
IVT structure
IVT structure extended
>99th >99.5th >99.9th daily extreme precipitation

De Vries, 2021 (WCD)

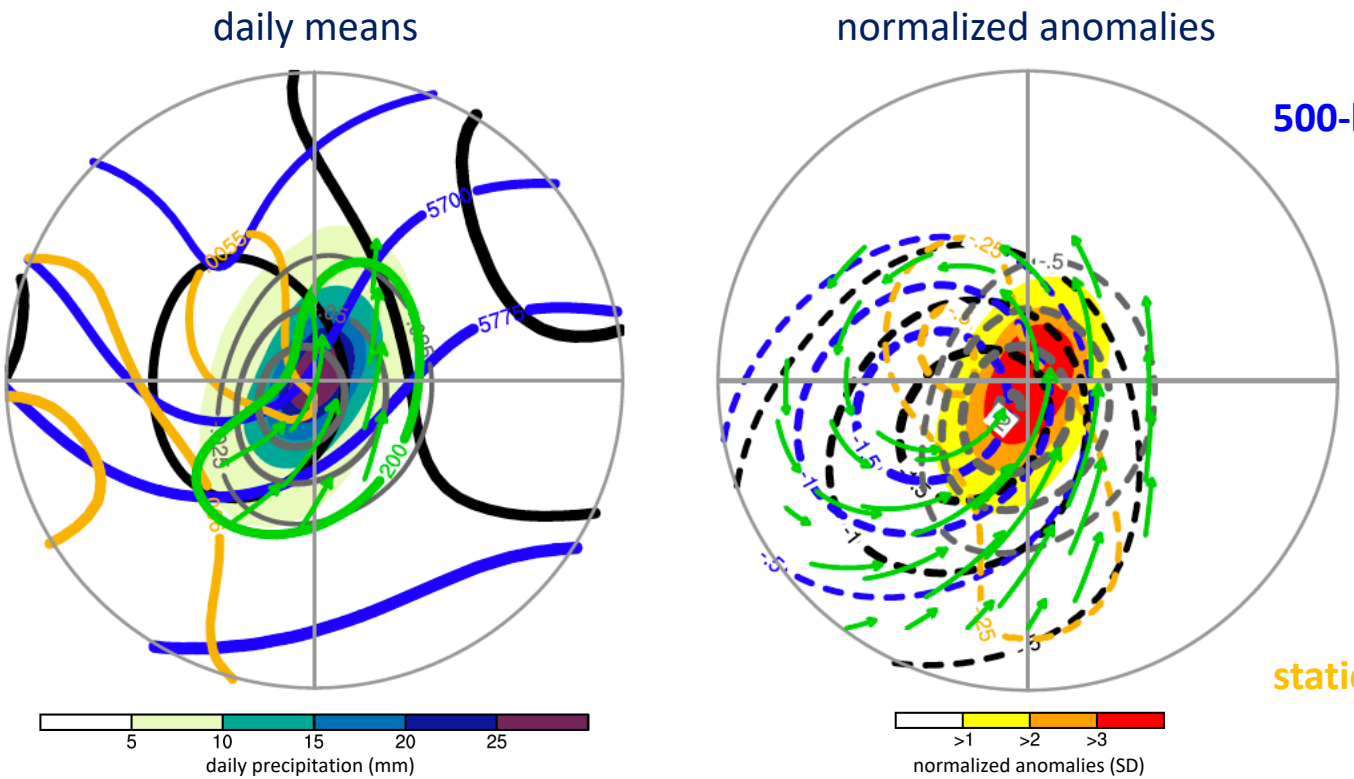
Climatology

Contribution of RWB to larger-scale extreme precipitation events (ERA-Interim, 1979-2018)



De Vries, 2021 (WCD)

How does RWB lead to (extreme) precipitation?



500-hPa geopotential height

sea level pressure

IVT vectors

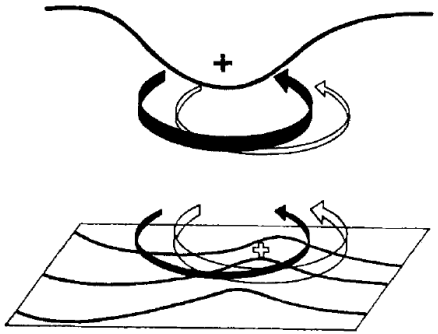
500-hPa QG ascent

static stability (850-500 hPa)

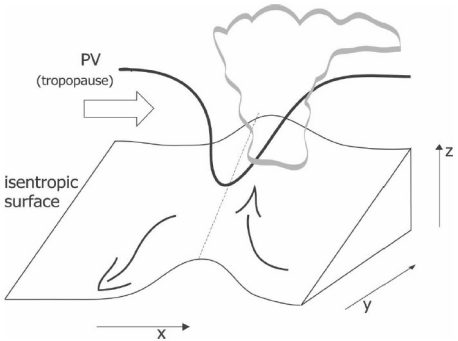
Composites centered on subtropical (20-40N) extreme precipitation events over water linked to PV streamers and intense moisture transport

De Vries, 2021 (WCD)

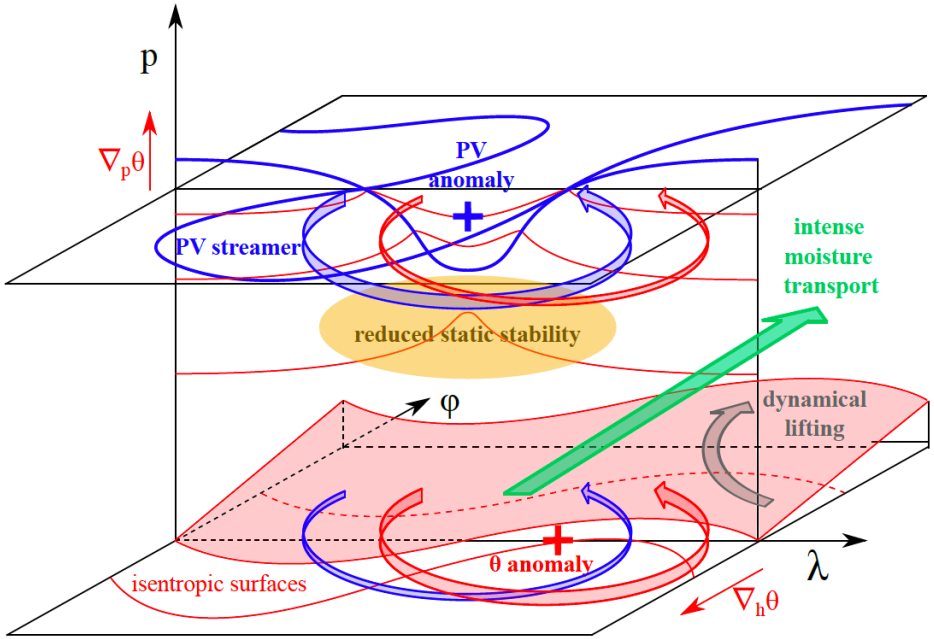
Synthesis



Hoskins et al. 1985 (QJRMS)



Funatsu & Waugh 2008 (JAS)



PV perspective on formation of EPEs & forcing mechanism of upward motion
(*Hoskins et al.* 1985; *Funatsu & Waugh* 2008;
Schlemmer et al. 2010; *Martius et al.* 2013)

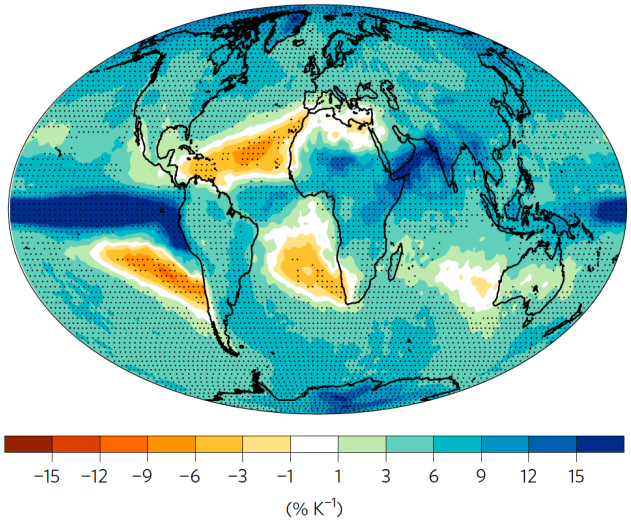
De Vries, 2021 (WCD)

Enhanced moisture transport, dynamical lifting and reduced static stability

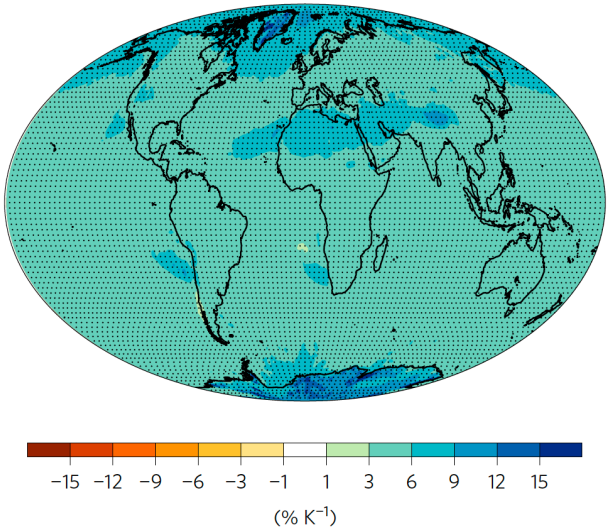
Climatic Changes

Future changes in extreme precipitation

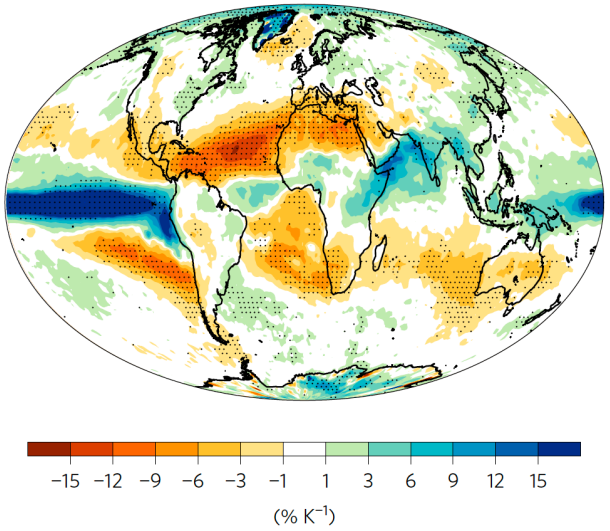
Change in annual maximum precipitation (Rx1day)



Thermodynamic contribution



Dynamic contribution



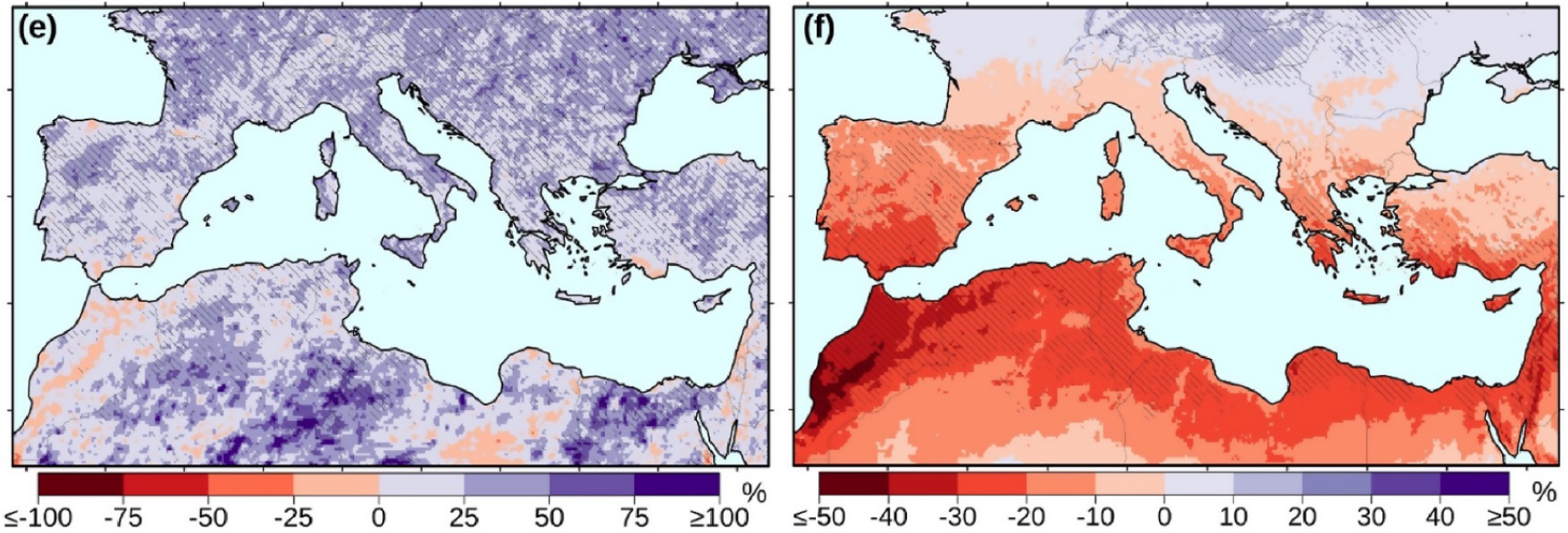
22 CMIP5 models (1950-2100)
Stippling shows where at least 80% of the models agree on the sign of change

Pfahl et al. 2017 (Nat. Clim. Change)

Intensified precipitation extremes, reduced total annual amounts

50-year maximum daily precipitation

total annual precipitation

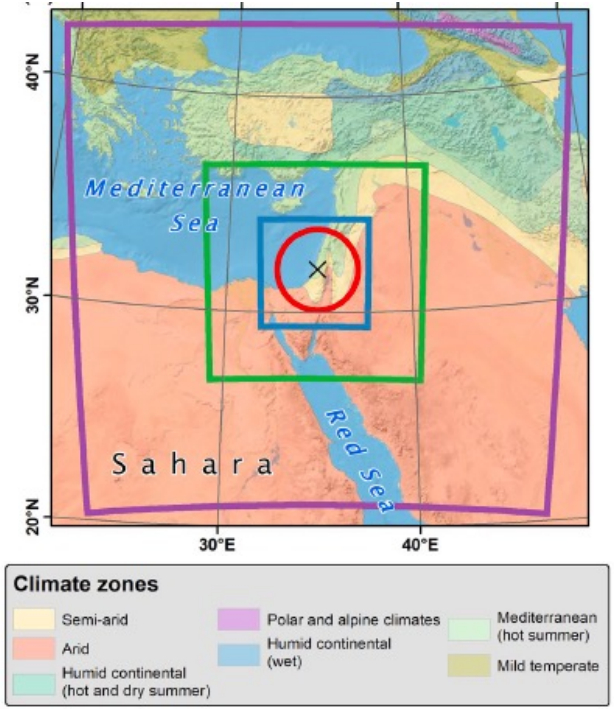


Projected changes in 33 EURO-CORDEX simulations for the future (2051-2100) compared to the reference period (1951-2000)

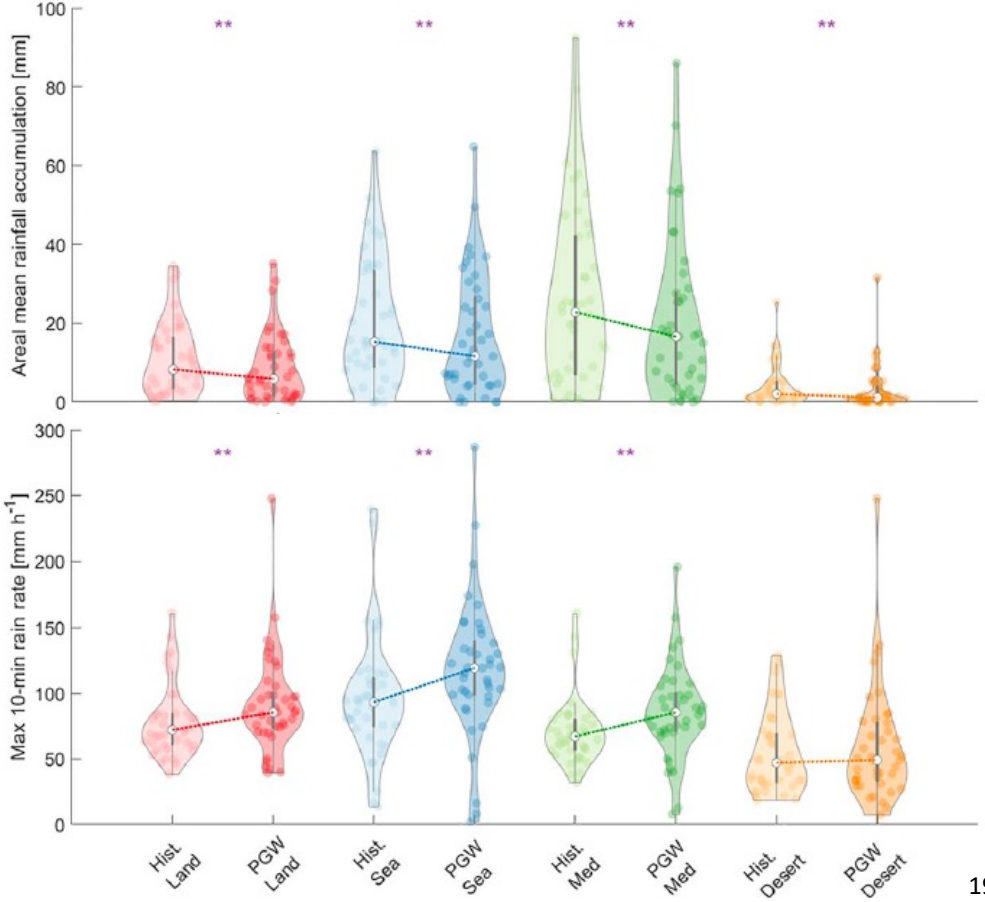
Zittis et al. 2021 (Weather and Clim. Extremes)

41 HPE in a pseudo global warming (PGW) experiment

41 heavy precipitation events simulated by WRF in convection-permitting setup for the historic and future (PGW) climate

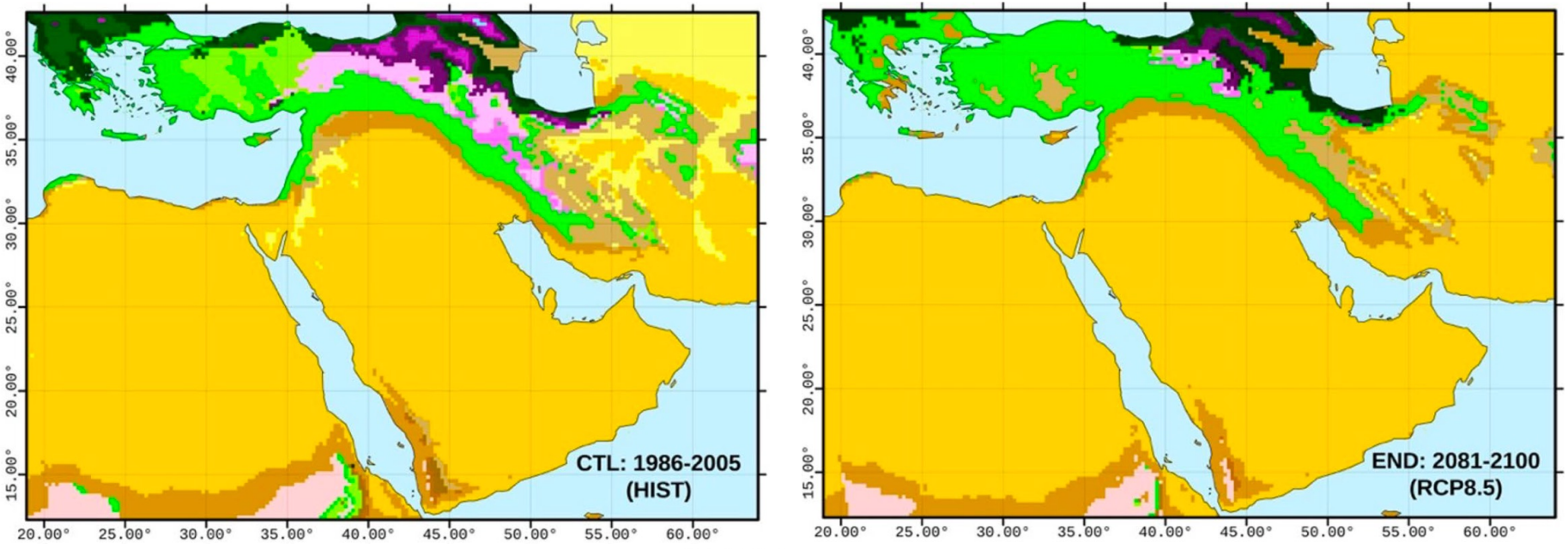


Changes in (top) areal mean rainfall accumulations and (bottom) 10-min rain rate



Armon et al. 2022 (Earth's Future)

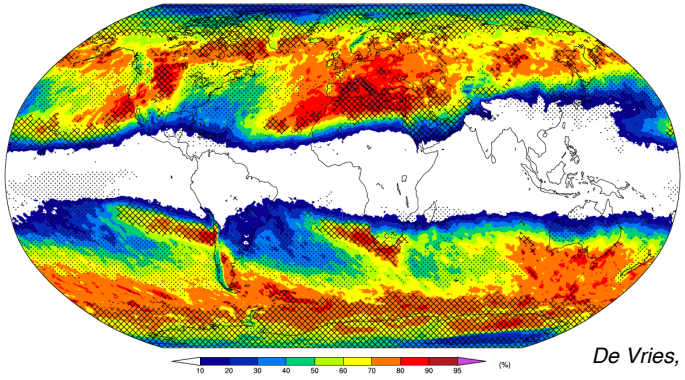
Aridification



Zittis et al. 2022 (Rev. Geophys.)

Summary

(extreme) precipitation in the subtropics: Floods and freshwater resources

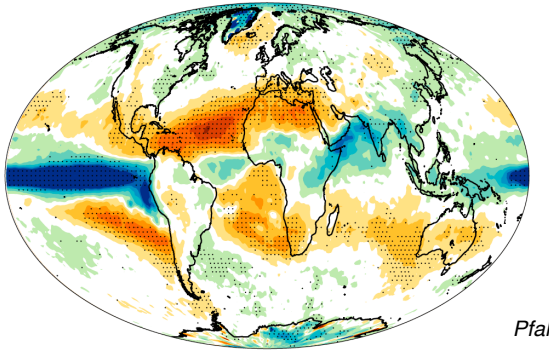


De Vries, 2021 (WCD)

(Credit: Terri Cook via Imaggeo)

(Credit: Andrea Carri via Imaggeo)

Weather systems
- a range of phenomena
- tropical-extratropical interactions
- Rossby wave breaking



Pfahl et al. 2017 (NCC)

Climatic changes
- largest model uncertainties
- importance dynamics
- intensified extremes, reduced annual totals

1) Seasonality and changes of precipitation and extreme precipitation in the subtropics
2) Weather systems; extratropical and tropical influence