The European Commission's
science and knowledge service
Joint Research Centre

Climate extremes
from statistics to society

Andrea Toreti

Outline

Characterising

EVT, TX90p, SU, FD, …

Predicting

Z500, PV, AMO, …

Evaluating

CMIP5, CORDEX,…

Impacts

European Commission

Characterising

Different approaches, different data sets, different problems

EVT, index-based, others, …

observations from weather stations, satellite-ground observations, reanalysis, …

Spatio-temporal scales

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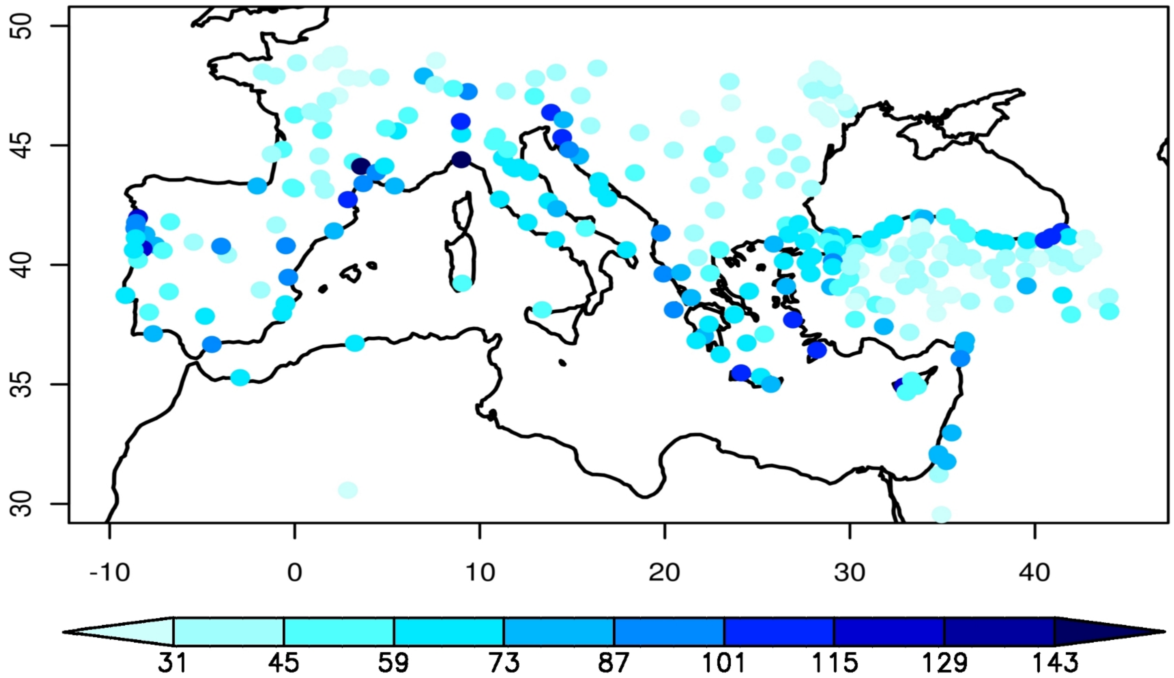
Characterising I

stationary univariate POT approach



Estimated 5-y ret levels of daily precipitation in winter. Data from the last 5 decades. Source: Toreti, 2010

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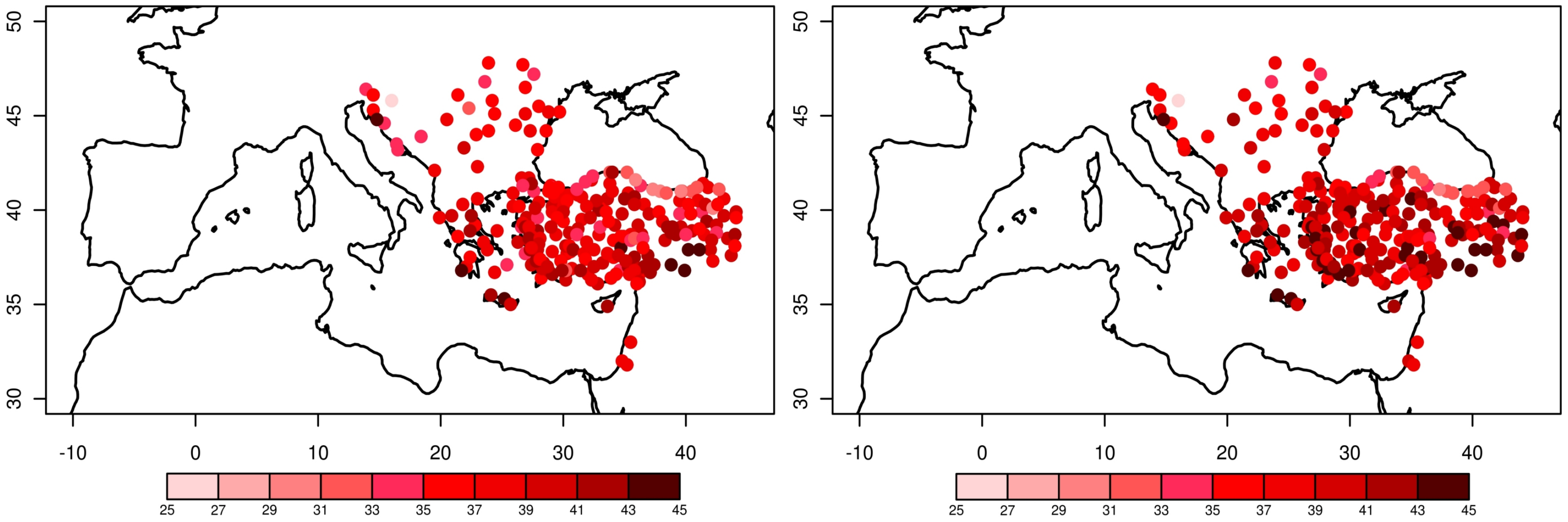
Characterising II

time-dependent location, univariate GEV approach



Estimated 5-y ret levels of daily maximum temperature in summer. Data from the last 5 decades. Source: Toreti, 2010

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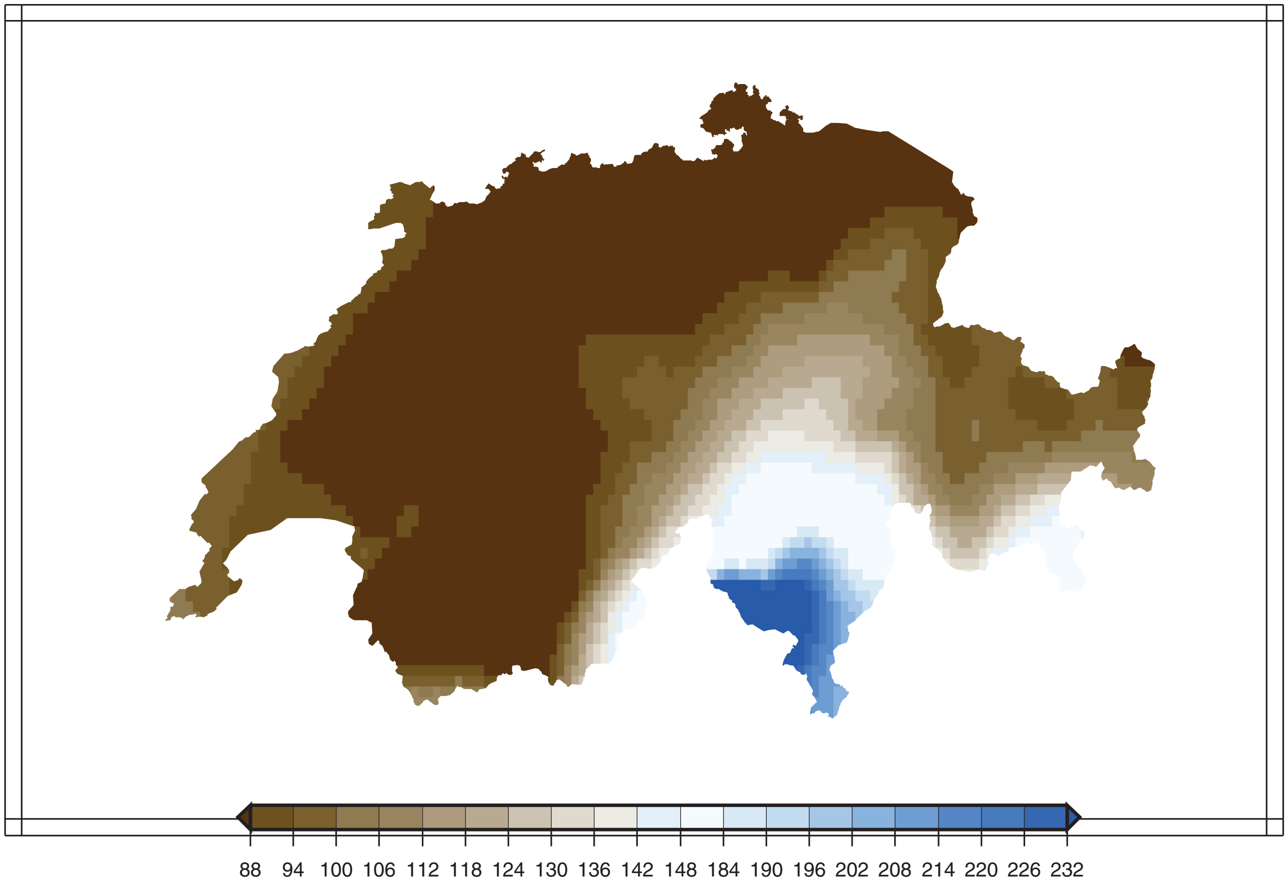
Characterising III

(partially) non-stationary approach



Estimated 50-y ret levels of daily precipitation in autumn. Data from 2001-2010.
Source: Naveau et al. 2014, WRR 50

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Characterising III

EVT - GP family

$$\overline{G}_{\sigma,\xi}(y) = 1 - G_{\sigma,\xi}(y) = \begin{cases} \left(1 + \xi \frac{y}{\sigma}\right)^{-1/\xi} & \text{if } \xi \neq 0, \\ \exp\left(-\frac{y}{\sigma}\right) & \text{if } \xi = 0. \end{cases}$$

$\sigma(\mathbf{X})$ and assuming ξ constant

Probability weighted moments

$$\mu_r(\boldsymbol{X}) = \mathbb{E}[Y(\boldsymbol{X})\overline{G}^{r}_{\sigma(\boldsymbol{X}),\xi}(Y(\boldsymbol{X}))] \qquad \text{where } Y(\mathbf{X}) \text{ follows } GP(\sigma(\mathbf{X}), \xi)$$

$$\mu_r(\mathbf{X}) = \sigma(\mathbf{X}) \frac{1}{(1+r)(1+r-\xi)}$$

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Characterising III

$$\mu_r(\boldsymbol{X}) = \sigma(\boldsymbol{X})\mathbb{E}[Z\overline{G}^r_{1,\xi}(Z)] \quad Z \sim GP(1,\xi)$$

by using $\mu_0(\boldsymbol{X})$, $\mu_r(\boldsymbol{X})$ and $\mu_s(\boldsymbol{X})$

$$\xi = \frac{(1+s)^2 - (1+r)^2\alpha_{rs}}{(1+s) - (1+r)\alpha_{rs}} \text{ and } \sigma(\boldsymbol{X}) = \mu_0(\boldsymbol{X})(1-\xi)$$

$$\alpha_{rs} = \frac{\mathbb{E}[Z\overline{G}^r_{1,\xi}(Z)]}{\mathbb{E}[Z\overline{G}^s_{1,\xi}(Z)]}$$

ξ becomes function of only $\alpha_{r,s}$

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Characterising III

Let $\hat{\mu}_0(\mathbf{X})$ and $\hat{\alpha}_{rs}$ be the estimators of $\mu_0(\mathbf{X})$ and α_{rs}

by selecting $r = 1$ and $s = 2$

$$\widehat{\xi} = \frac{9 - 4\hat{\alpha}}{3 - 2\hat{\alpha}} \quad \text{and} \quad \hat{\sigma}(\boldsymbol{X}) = \hat{\mu}_0(\boldsymbol{X})(1 - \hat{\xi})$$

$$\widehat{\mu}_0(\boldsymbol{X}) = \frac{1}{\sum_i K(\boldsymbol{X} - \boldsymbol{X}_i)} \sum_{i=1}^{n} Y(\boldsymbol{X}_i)\, K(\boldsymbol{X} - \boldsymbol{X}_i)$$

where K is a Kernel

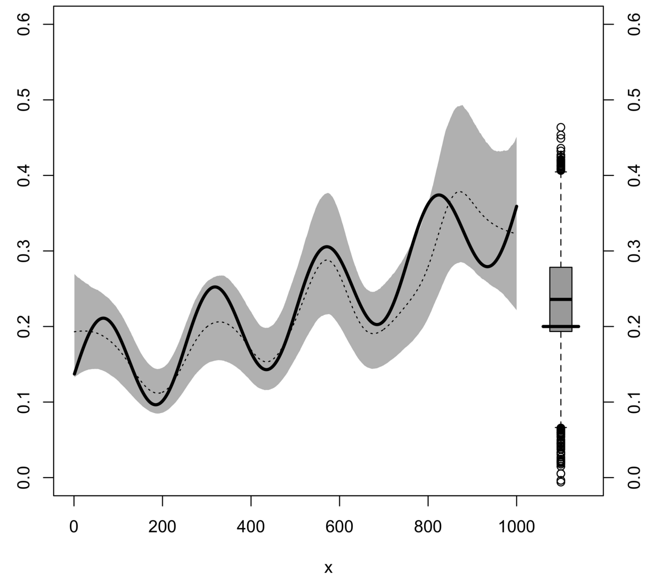
Characterising III

To estimate α_{rs}

$$Z_i' = Y(\boldsymbol{X}_i)/\hat{\mu}_0(\boldsymbol{X}_i)$$

use your favourite method (e.g. U-statistic approach) to estimate

$\mathbb{E}[Z'\overline{G'}^{r}_{1,\xi}(Z')]$ for $r = 1, 2$



Source: Naveau et al., 2014. WRR 50

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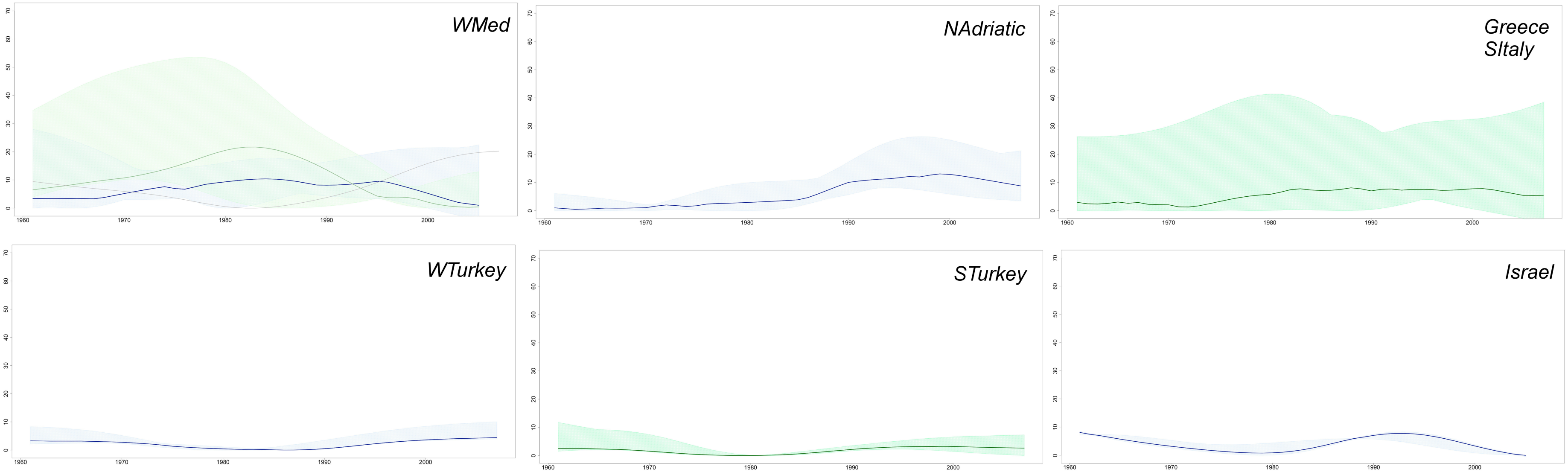
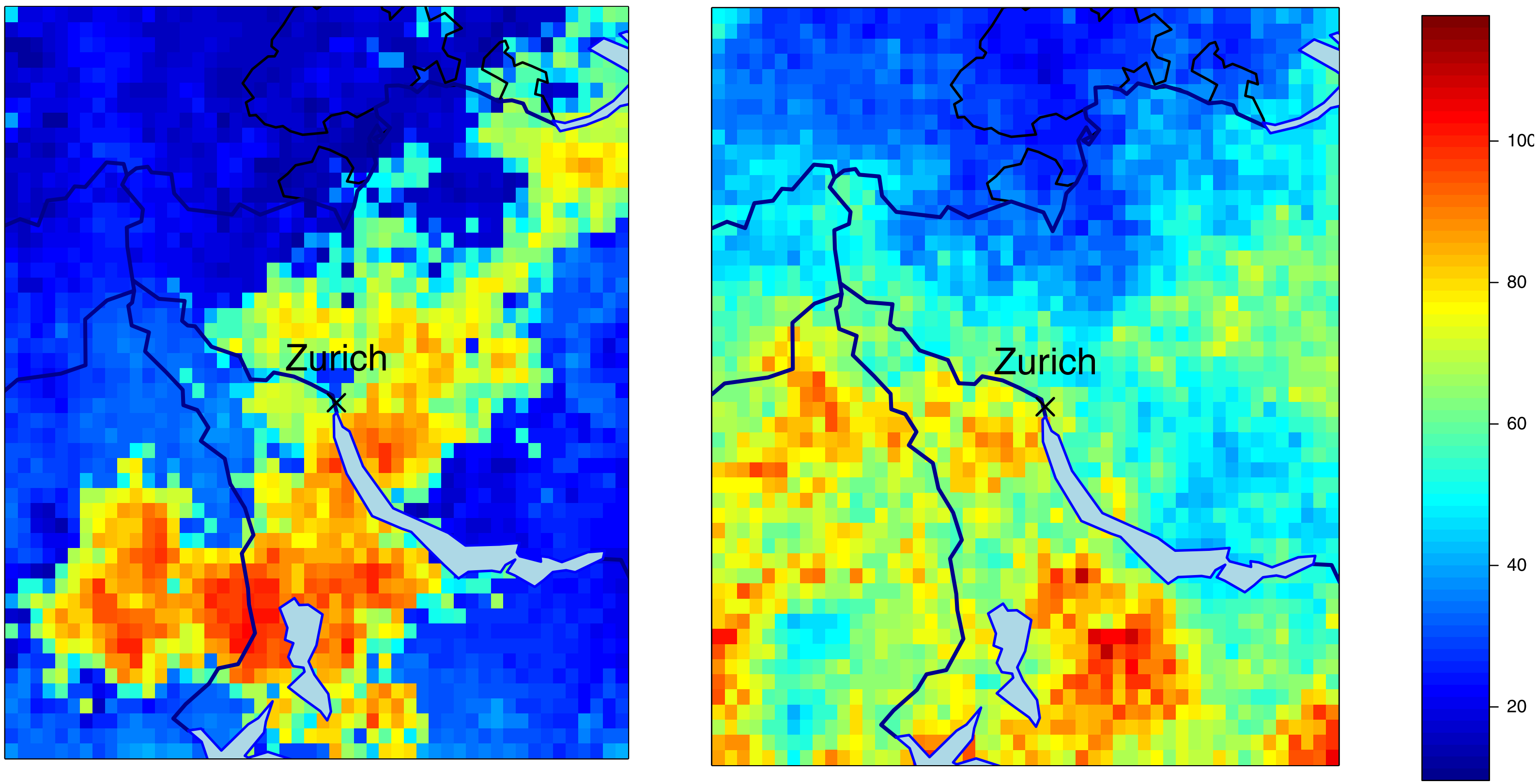
Characterising III

an attempt to model and understand the temporal evolution of precipitation extremes



Characterising IV

Max-stable models



One realisation from the Schlather and Brown Resnick models applied to daily summer precipitation from 1962 to 2008. Source: Davison et al., 2012. Statistical Science 27

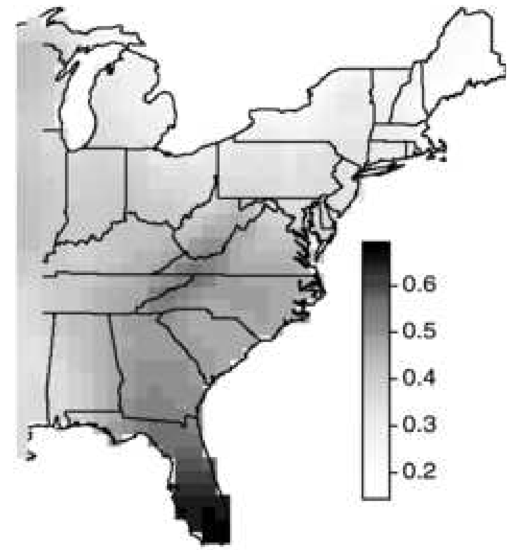
Characterising V

$$Y(\mathbf{s}) \sim GEV(\mu(\mathbf{s}), \sigma(\mathbf{s}), \xi(\mathbf{s}))$$

$$Y(\mathbf{s}) = \mu(\mathbf{s}) + \frac{\sigma(\mathbf{s})}{\xi(\mathbf{s})}[X(\mathbf{s})^{\xi(\mathbf{s})} - 1]$$

$$X(\mathbf{s}) = U(\mathbf{s})\theta(\mathbf{s}) \text{ with } U(\mathbf{s}) \sim GEV(1, \alpha, \alpha)$$

$$\theta(\mathbf{s}) = \left[\sum_{l=1}^{L} A_l w_l(\mathbf{s})^{1/\alpha}\right]^{\alpha} \text{ with } A_l \sim PS(\alpha)$$



(c) GEV shape, posterior mean

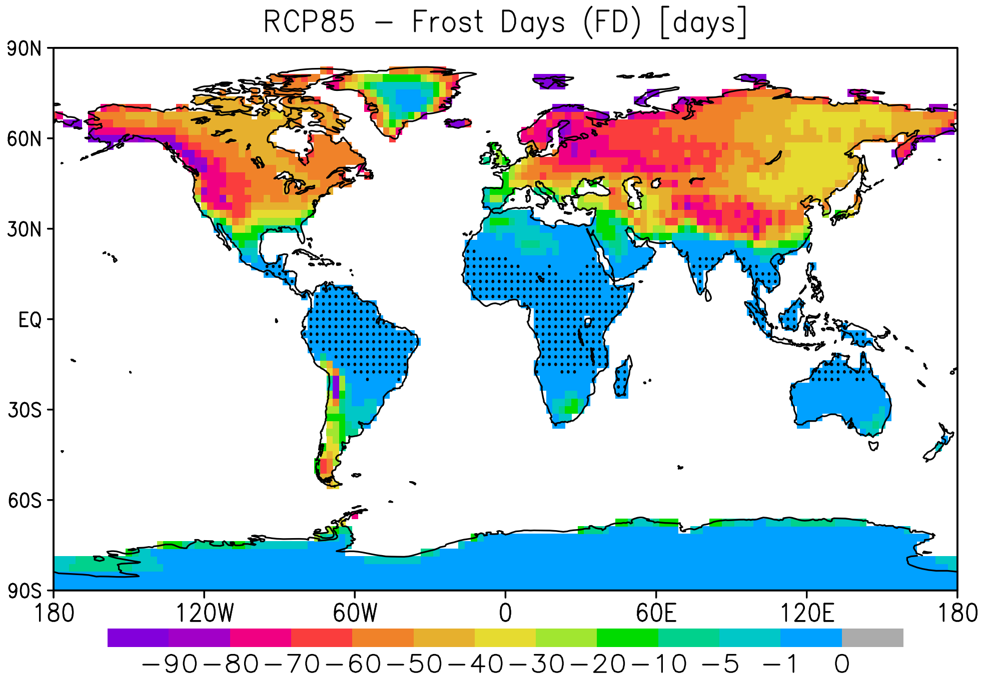
$$Y(\mathbf{s}_i)|A_1, \ldots, A_2, \ldots, A_L \sim_{indep} GEV[\mu^\star(\mathbf{s}_i), \sigma^\star(\mathbf{s}_i), \xi^\star(\mathbf{s}_i)]$$

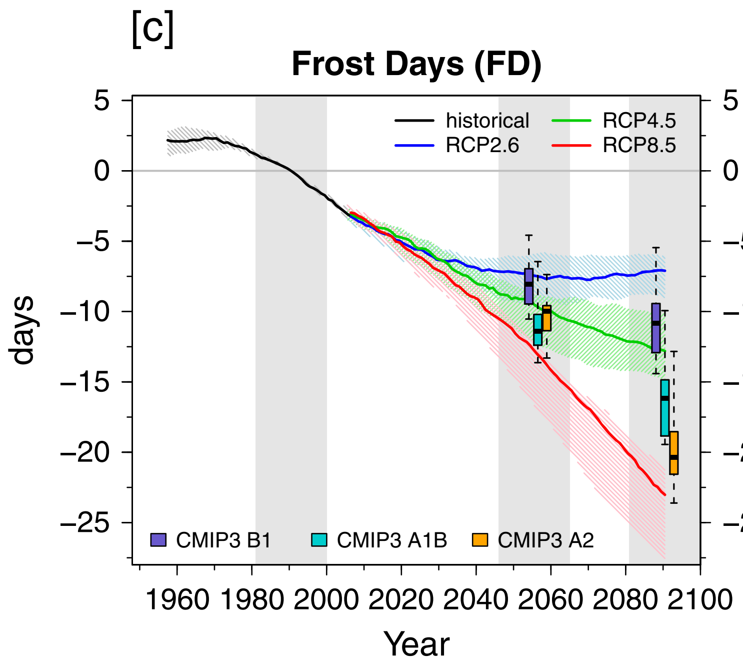
Hierarchical spatial model for precipitation extremes

Source: Reich and Shalby 2012. Ann. Appl. Stat. 6

Characterising VI

Index-based approach





2081-2100 Changes w.r.t. 1981-2000. Source: Sillmann et al. 2013, JGR 118

Characterising

- Erroneous data
- Inhomogeneities
- Missing data
- inhomogeneous spatial coverage
- Complexity of the events is often not captured
- Computational and statistical issues when dealing with large data sets
- Constraints and assumptions for large regions

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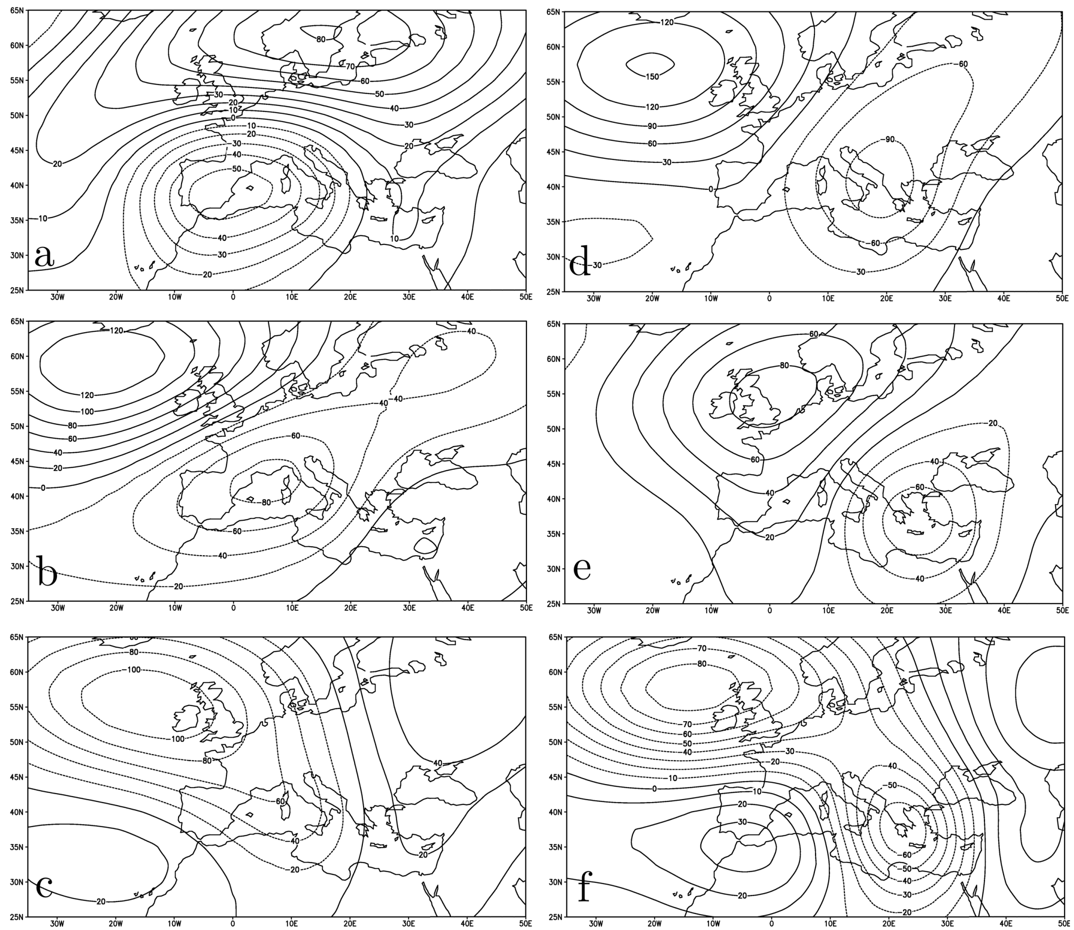
Predicting I

Synoptic patterns associated with extreme preci



Z500 anomalies associated with precipitation extremes. Source: Toreti et al., 2010. NHESS 10

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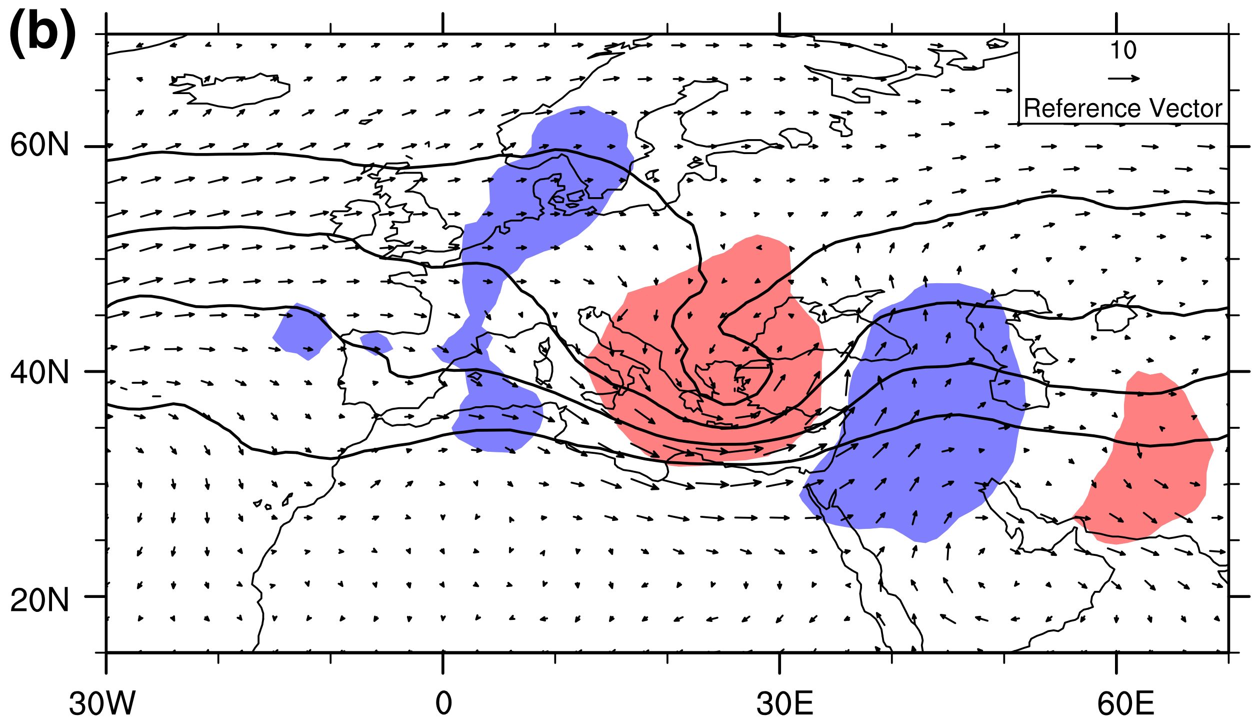
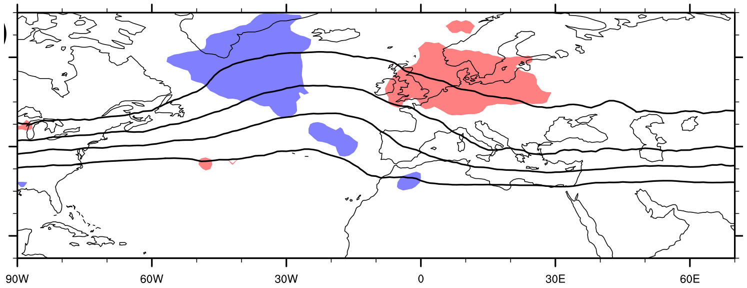
Predicting I





PV anomalies and wind at 850 hPa DJF associated with preci extremes in Western Turkey. Source: Toreti et al. 2016, Climate Dynamics in press

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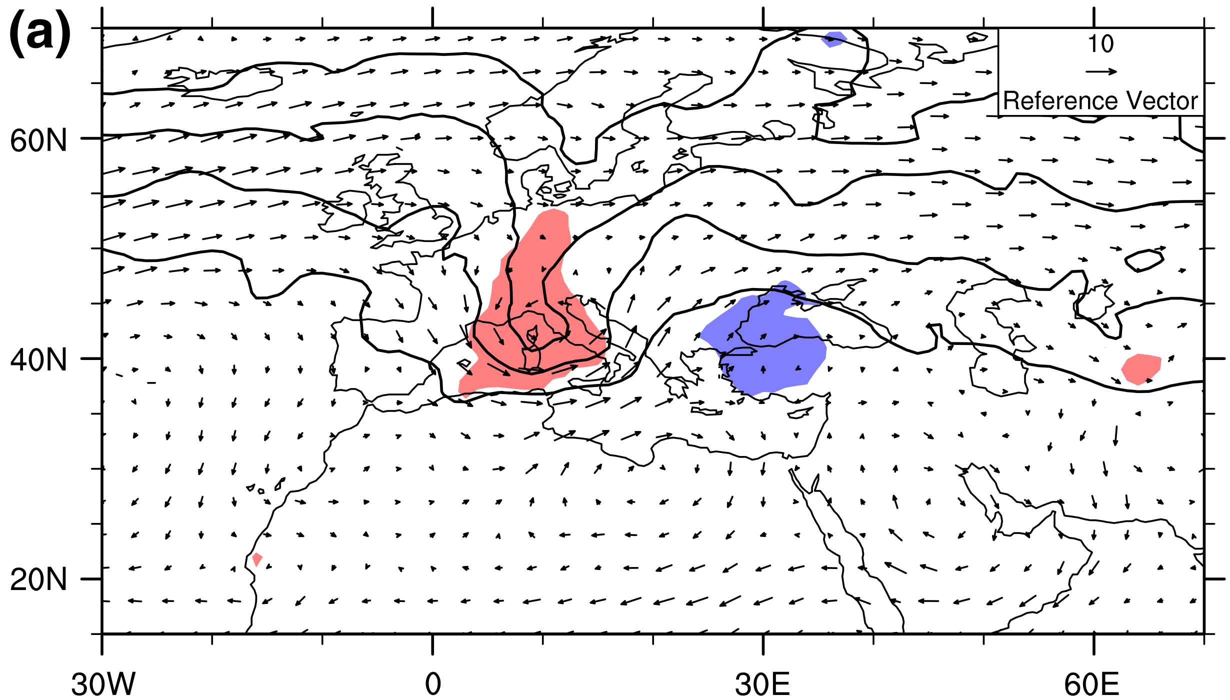
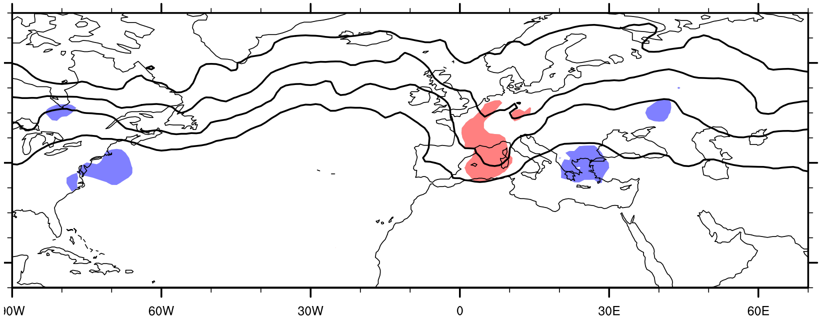
Predicting I





PV anomalies and wind at 850 hPa DJF associated with preci extremes in Po Valley. Source: Toreti et al. 2016, Climate Dynamics in press

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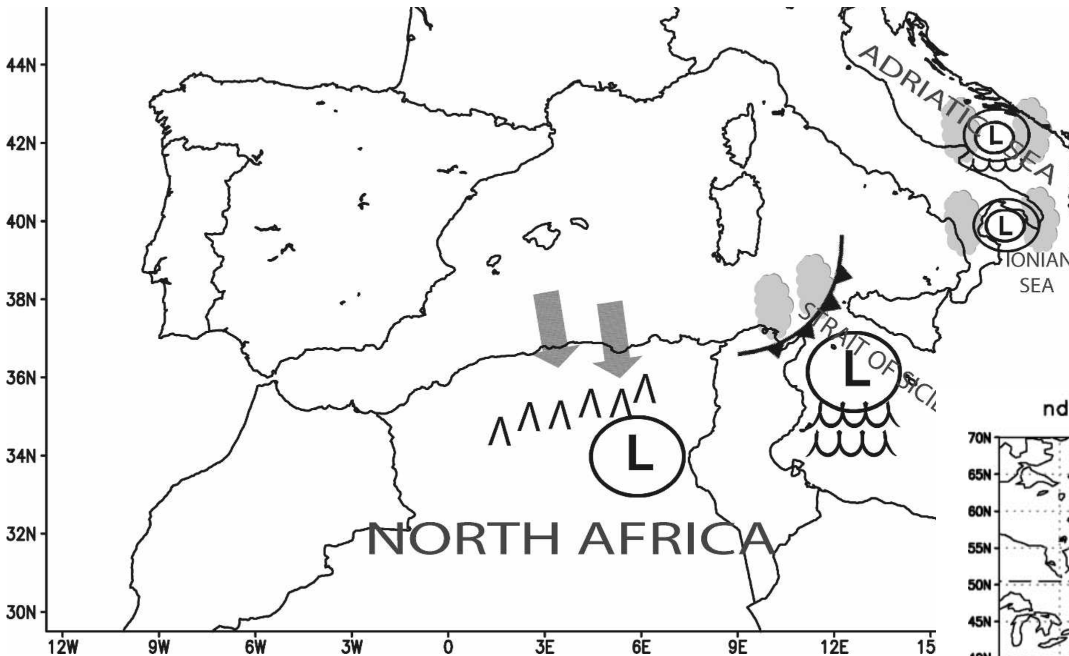
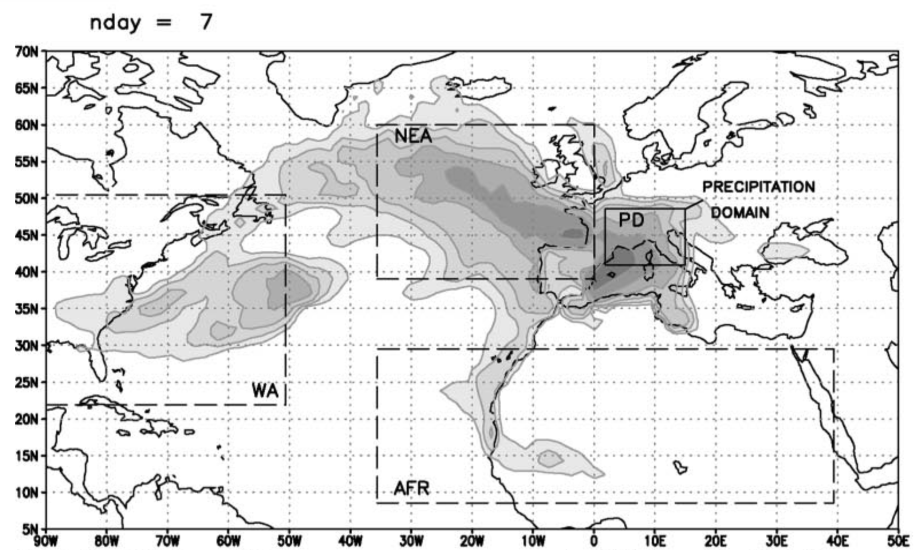
Predicting I

Other factors contributing to precipitation extremes

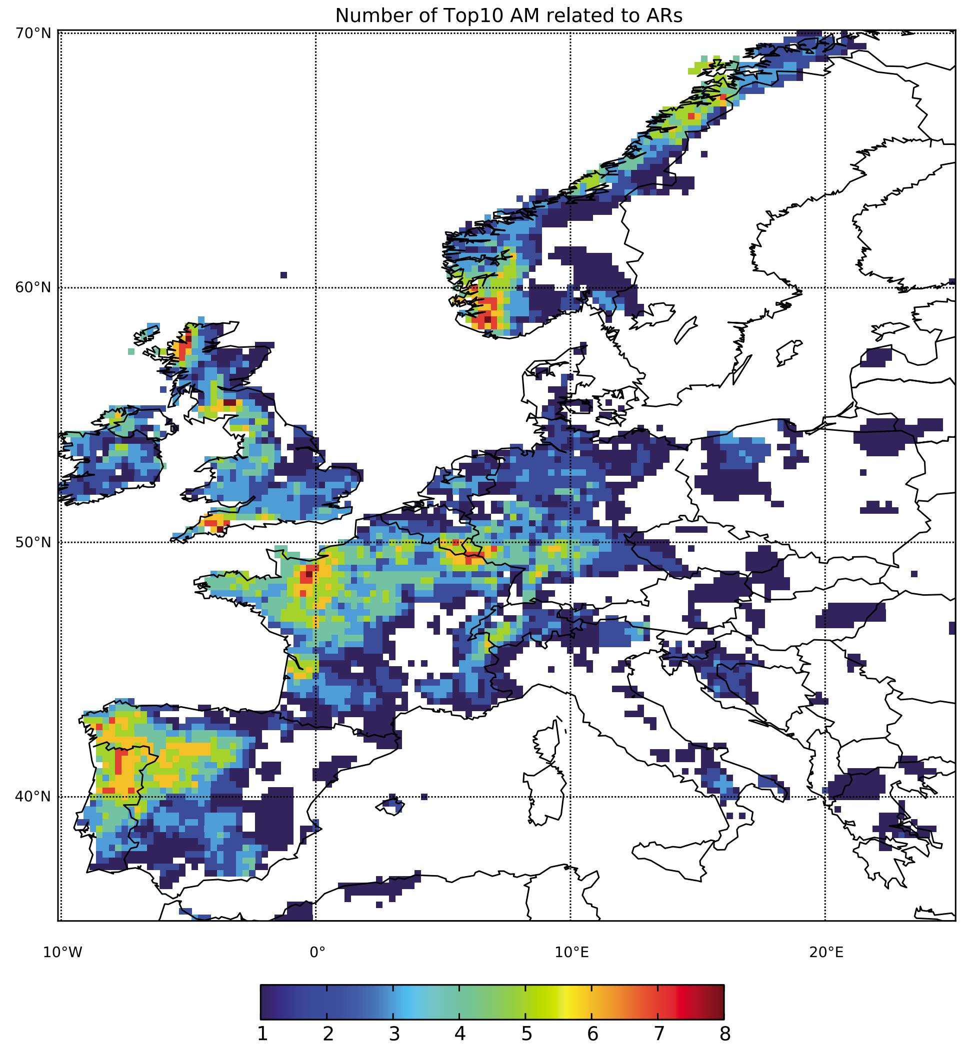


Source: Moscatello et al., 2008. MWR 136



Source: Turato et al., 2004. J Hydromet 5

Predicting I



Number of top 10 annual maxima preci events associated with atm rivers. Source: Lavers and Villarini 2013, GRL 40.

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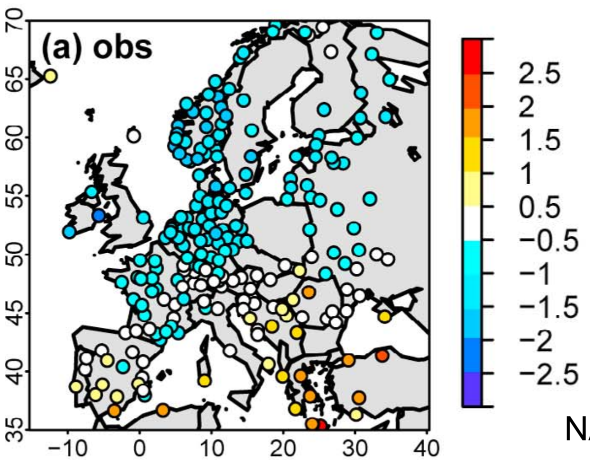
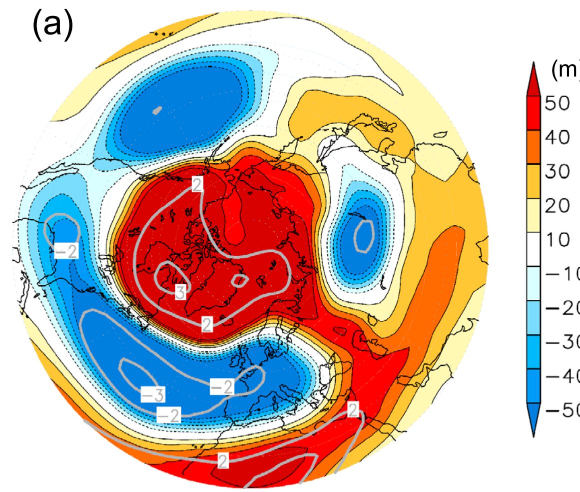
Predicting II

Cold Spell winter 2009-10

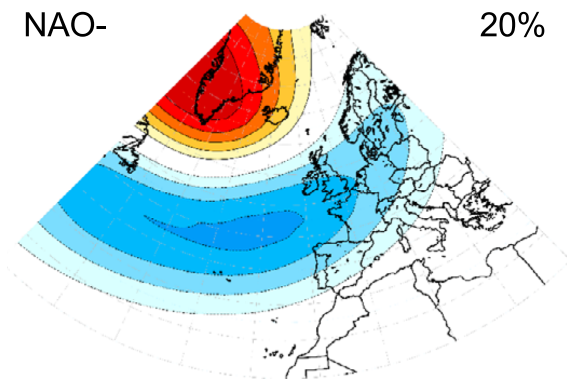


Normalised winter temperature anomalies

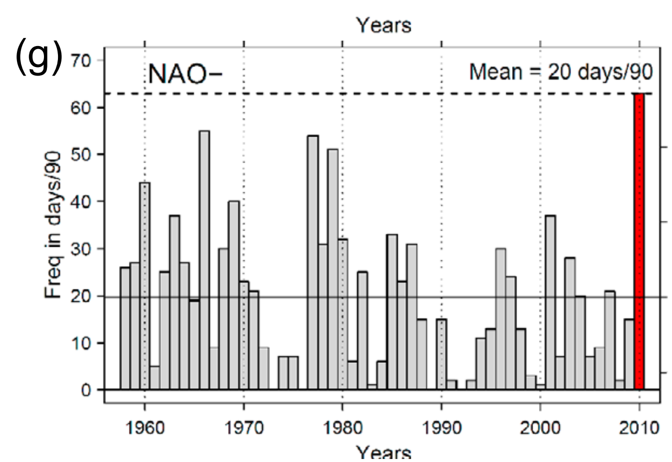


Anomalies of Z500

NAO-



20%

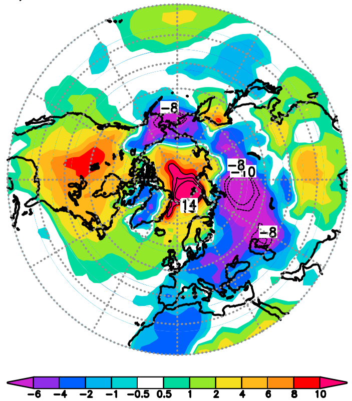


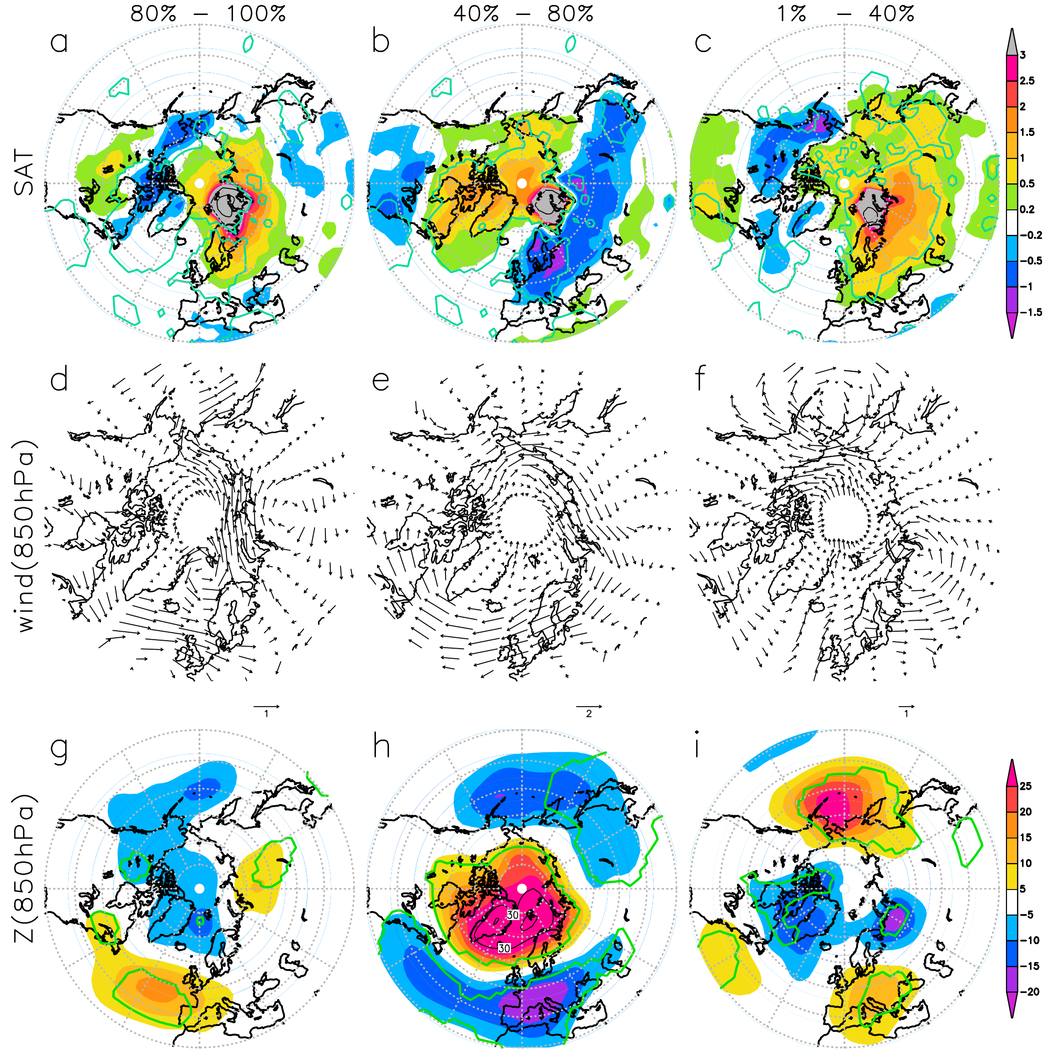
Negative NAO

Source: Cattiaux et al. 2010, GRL 37

Predicting II

a) Jan 2006 SAT anom.





Nonlinear response to decrease in the Barents-Kara sea ice concentration.

Source: Petoukhov and Semenov 2010, JGR 115

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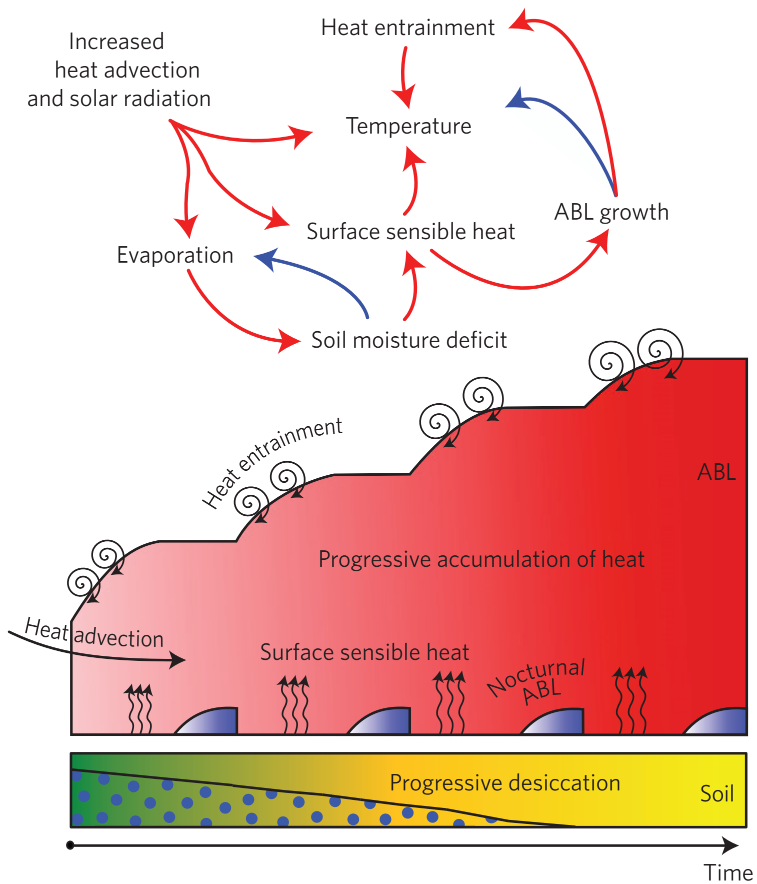
Predicting III



Soil moisture - air temperature interaction in the development of mega heat waves. Source: Miralles et al. 2014, Nature Geoscience 7.

	Anticyclonic summer weather regimes (BL/AL)	Cyclonic summer weather regimes (AR/NAO-)
Dry winter/spring	Feedback amplification Many hot days	Feedback inhibited Few hot days
Wet winter/spring	No feedback possible Few hot days	

Sensitivity of hot days to summer atm circulation and soil moisture conditions. Source: Quesada et al. 2012, NCC 2.

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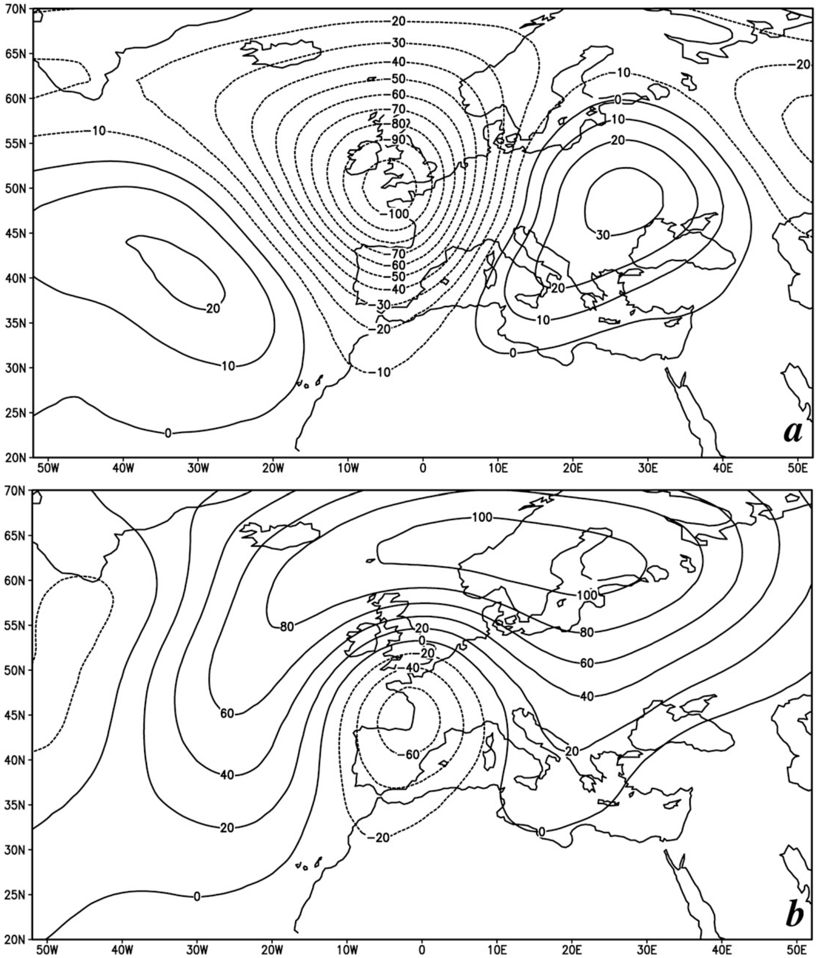
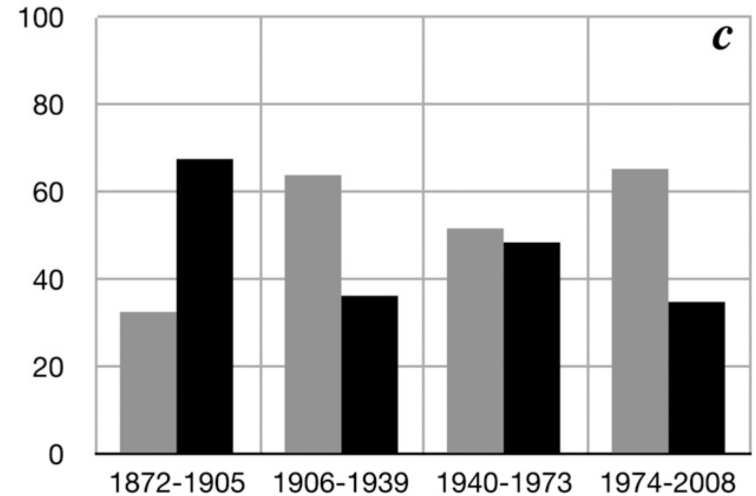
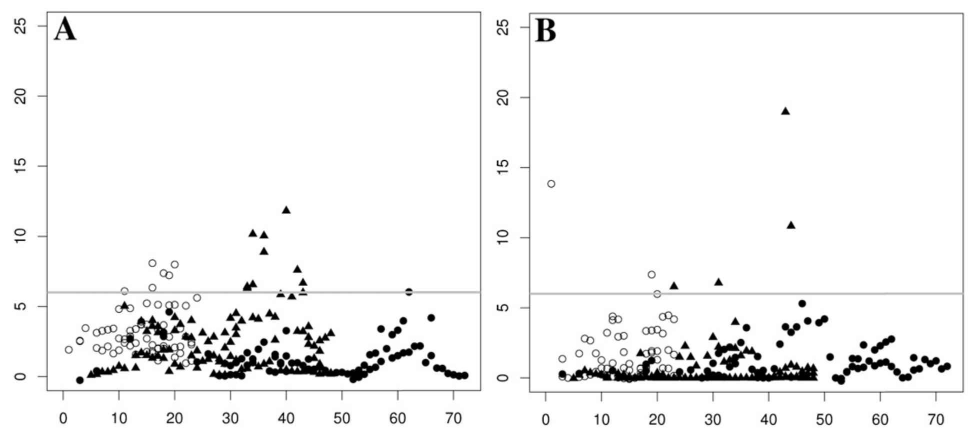
Predicting IV







Z500 anomalies associated with Debris Flows in the souther Swiss Alps and convective time scales. Source: Toreti et al. 2013, JAMC 52

Predicting

- Interactions of different phenomena acting at different spatio-temporal scales
- coarse resolution of available reanalyses
- nonlinear processes

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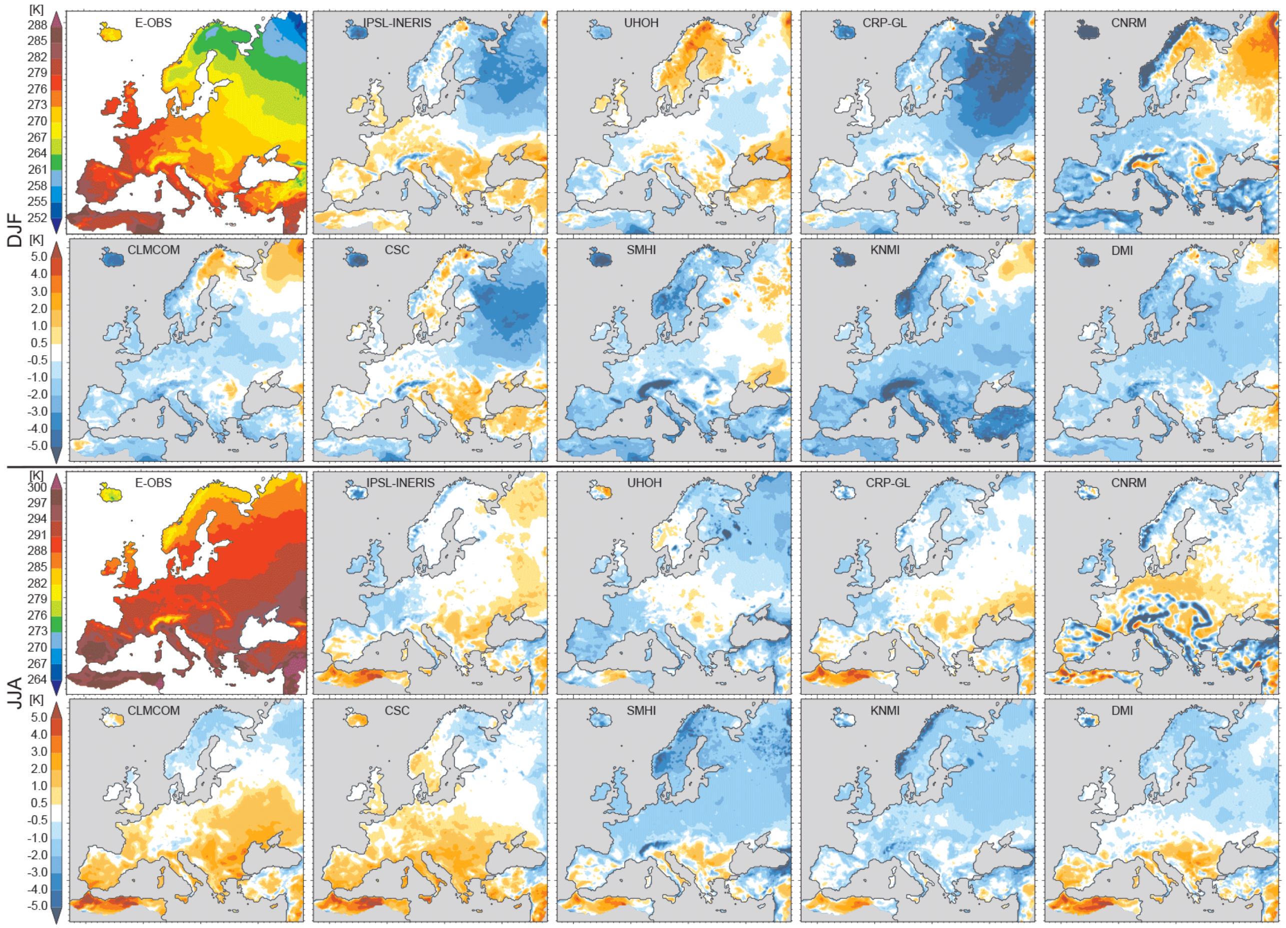
Evaluating I



Bias in mean seasonal temperature of EUR-11 cordex runs 1989-2008.
Source: Kotlarski et al. 2014, Geosci. Model Dev., 7

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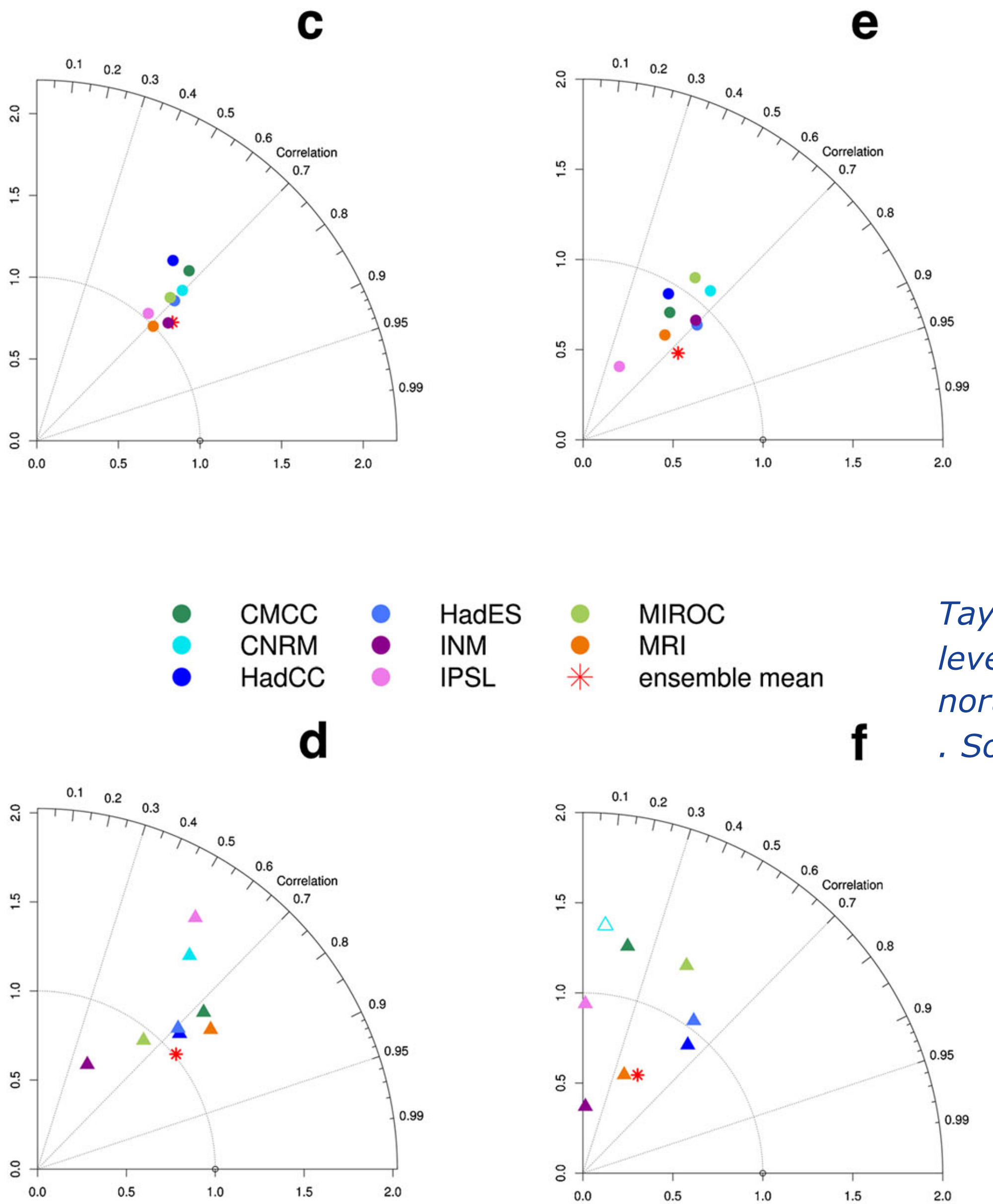
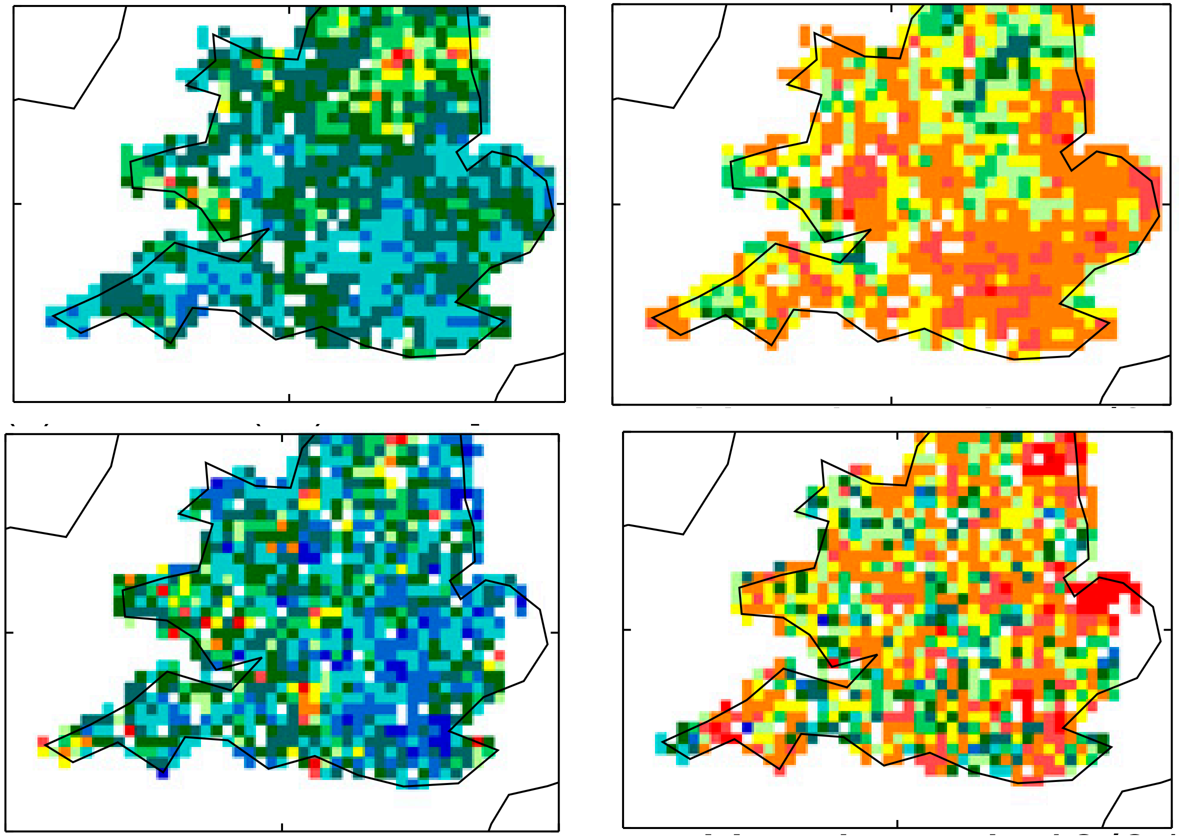
Evaluating II



Taylor diagrams for estimated 50 year return levels in winter and summer over (c, d) northern Eurasia and (e, f) North America . Source: Toreti et al. 2013, GRL 40.

Evaluating III



Estimated GPD parameters for winter (DJF) precipitation extremes. Model w.r.t. observations
Source: Chan et al. 2014, J Clim 27

Evaluating IV

non-parametric approach

$$A = \frac{mn}{N} \int_{-\infty}^{\infty} \frac{(\bar{G}_m - \bar{F}_n)^2}{(\bar{H}_N)} dH_N$$

$$\bar{H}_N = \frac{n\bar{F}_n + m\bar{G}_m}{N}; \quad N = n + m$$

$$T = (A - \mathbb{E}(A))\sigma_A^{-1}$$

$$I(f_e; g_e) = \mathbb{E}_{f_e} \left\{ log \left(\frac{f_e(X_e/\mu_0^{X_e})}{g_e(X_e/\mu_0^{X_e})} \right) \right\}$$

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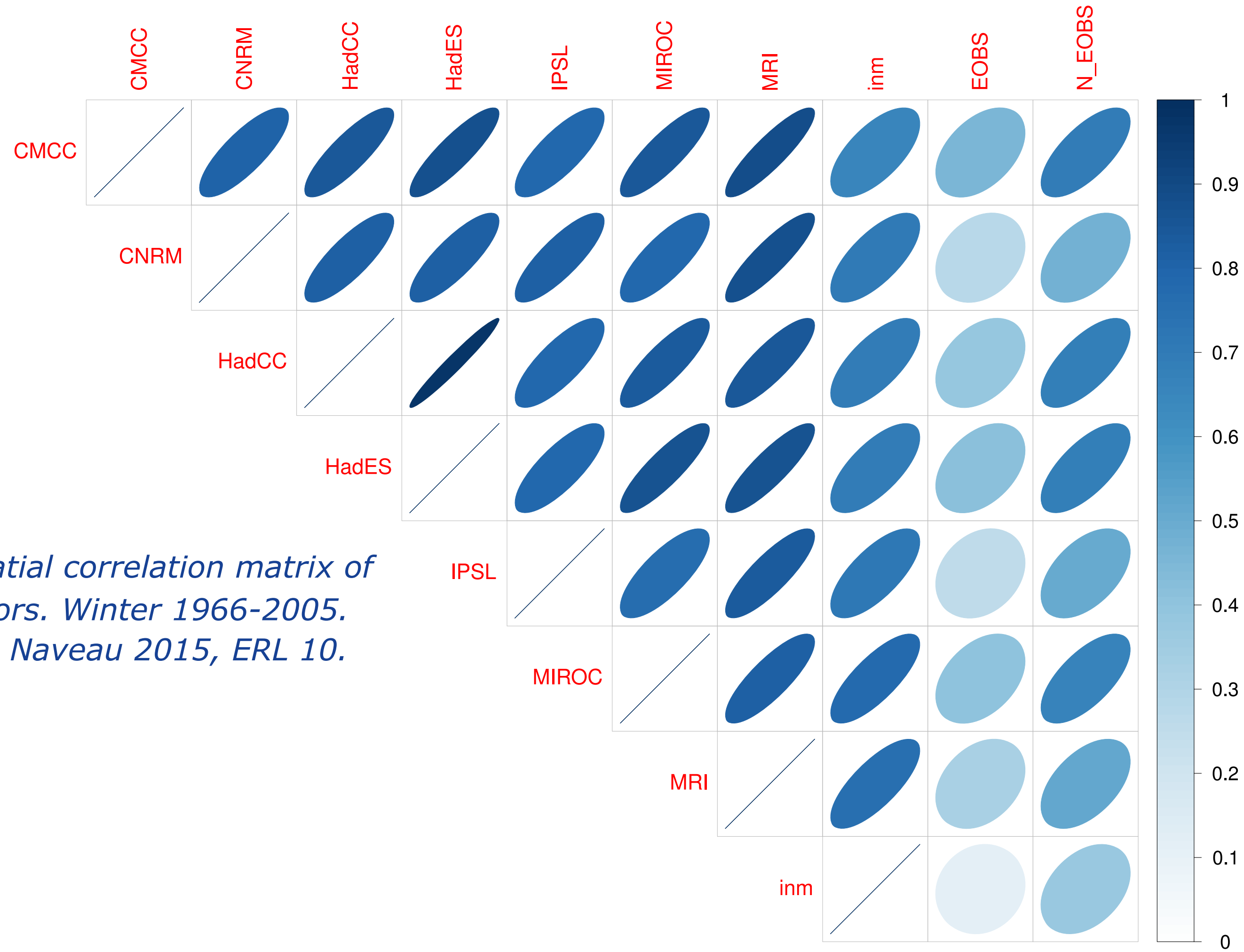
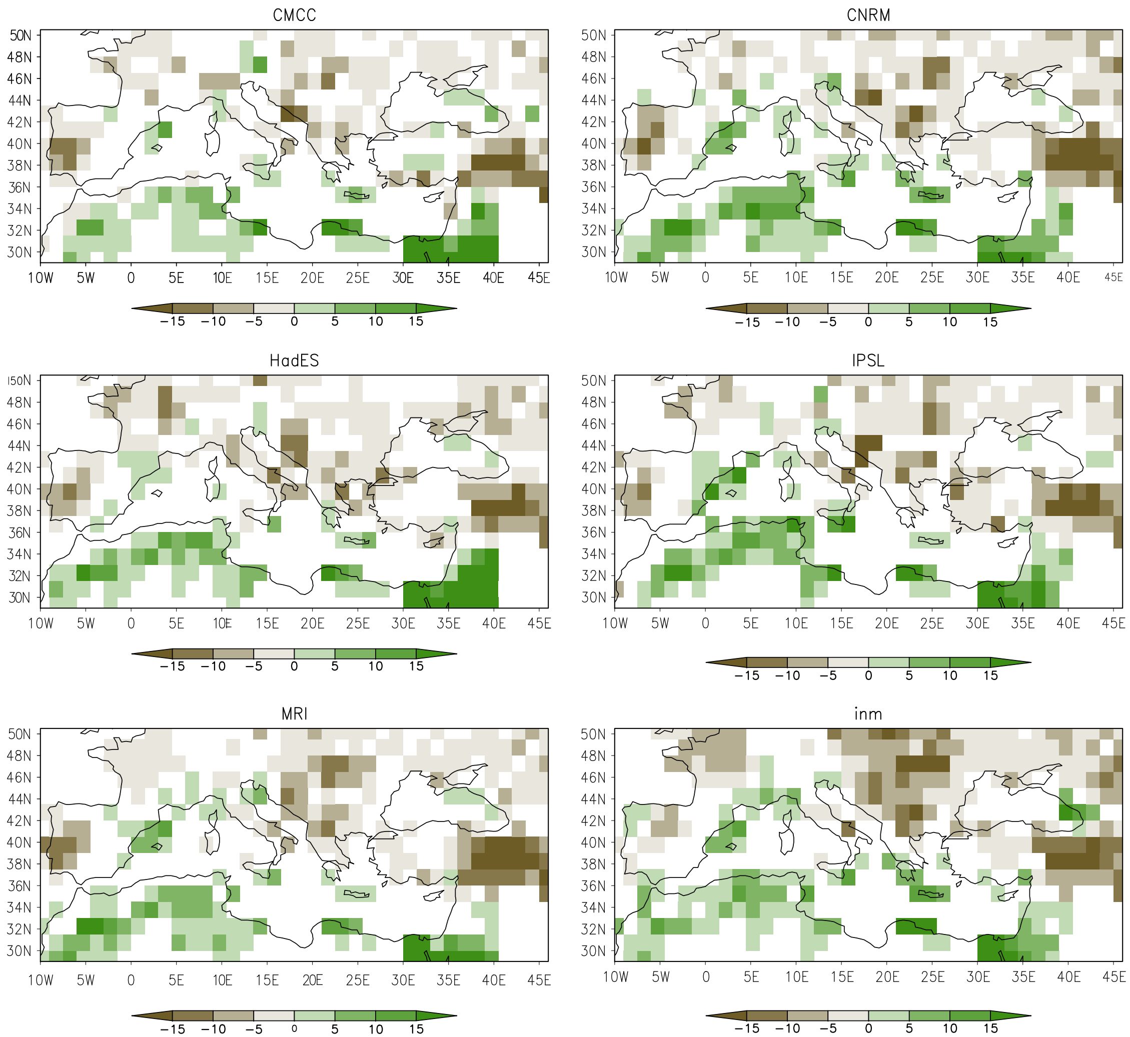
Evaluating IV



Spearman-based spatial correlation matrix of the tail scaling factors. Winter 1966-2005. Source: Toreti and Naveau 2015, ERL 10.

Evaluating IV



Rescaled-tail comparison of model simulations and E-OBS.
Winter 1966-2005
Source: Toreti and Naveau 2015, ERL 10.

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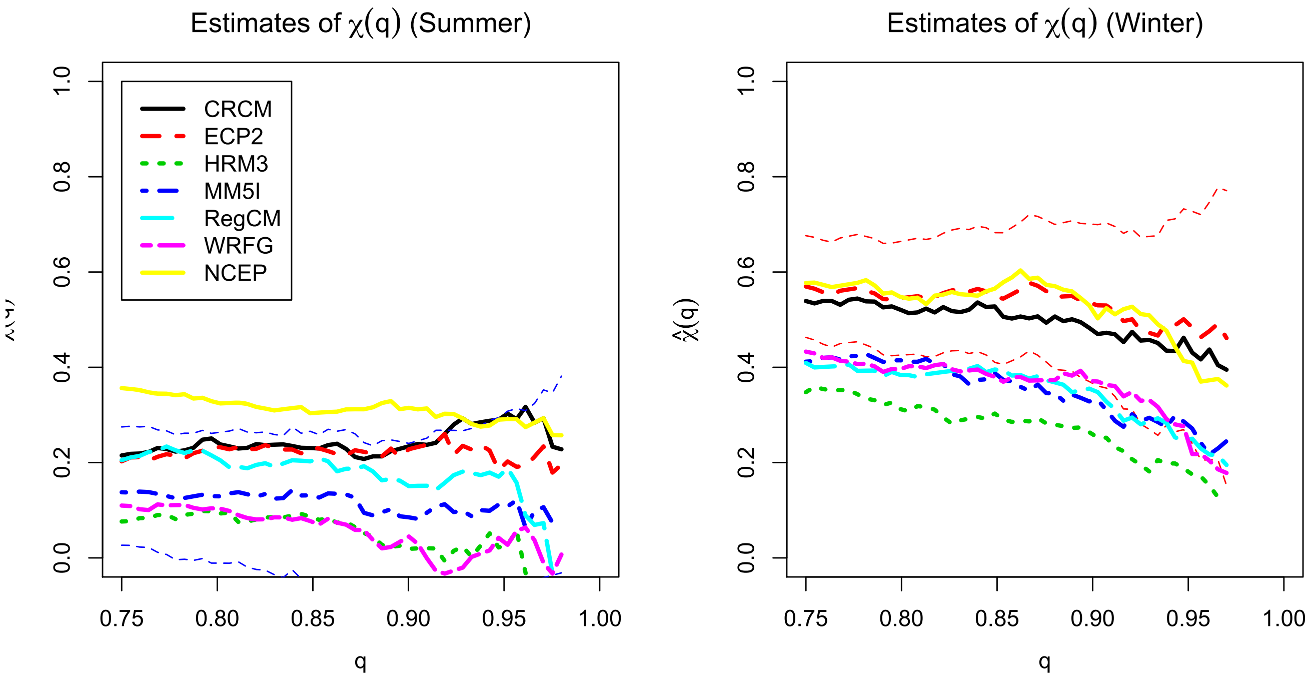
Evaluating V

$$\chi(q) = 2 - \frac{log\mathbb{P}(Z_2 < z_q, Z_1 < z_q)}{log\mathbb{P}(Z_2 < z_q)}$$



Tail dependence of NARCCAP RCMs w.r.t NCEP reanalysis over Pacific region.
Source: Weller et al. 2013, JGR 118.

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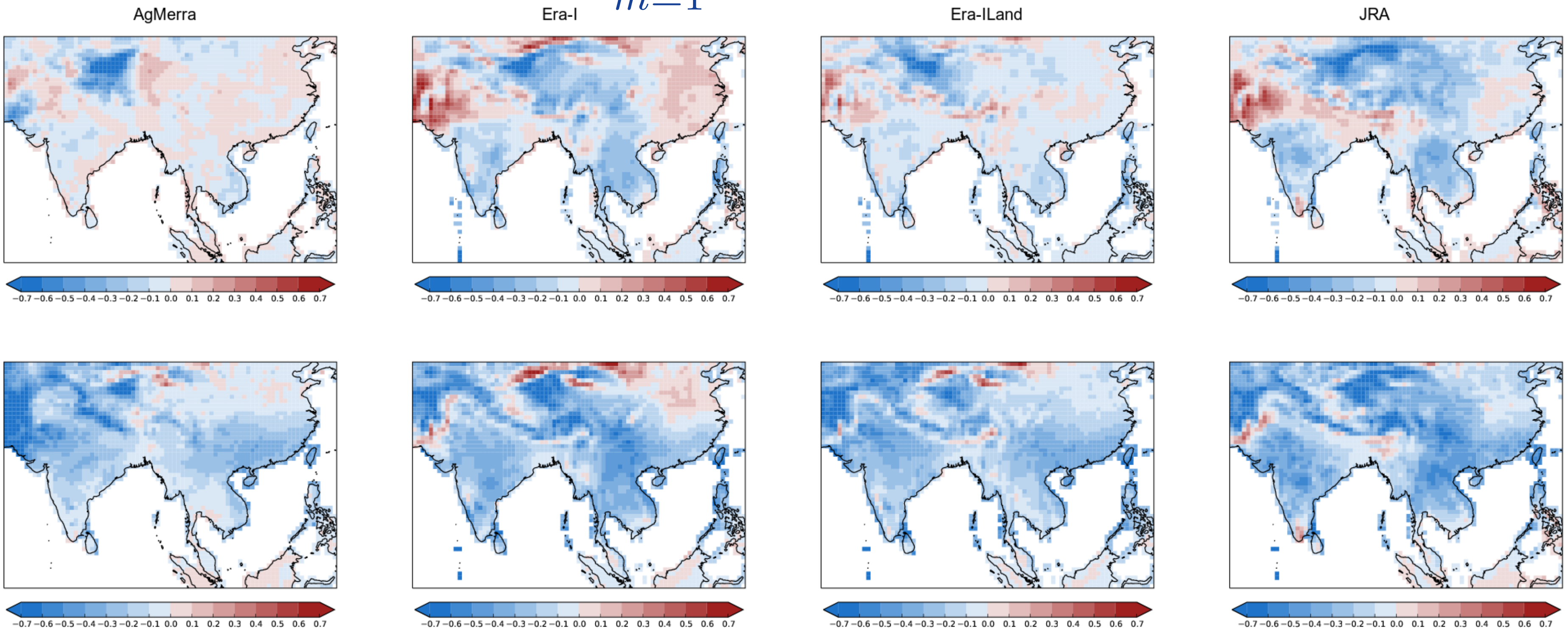
Evaluating VI

$$D(x) = \sum_{m=1}^{12} p_m(x) \log_2 \left(12\, p_m(x)\right)$$



Comparison of estimated precipitation seasonality of reanalyses with Aphrodite and Chirps. Source: Ceglar et al. 2016, submitted.

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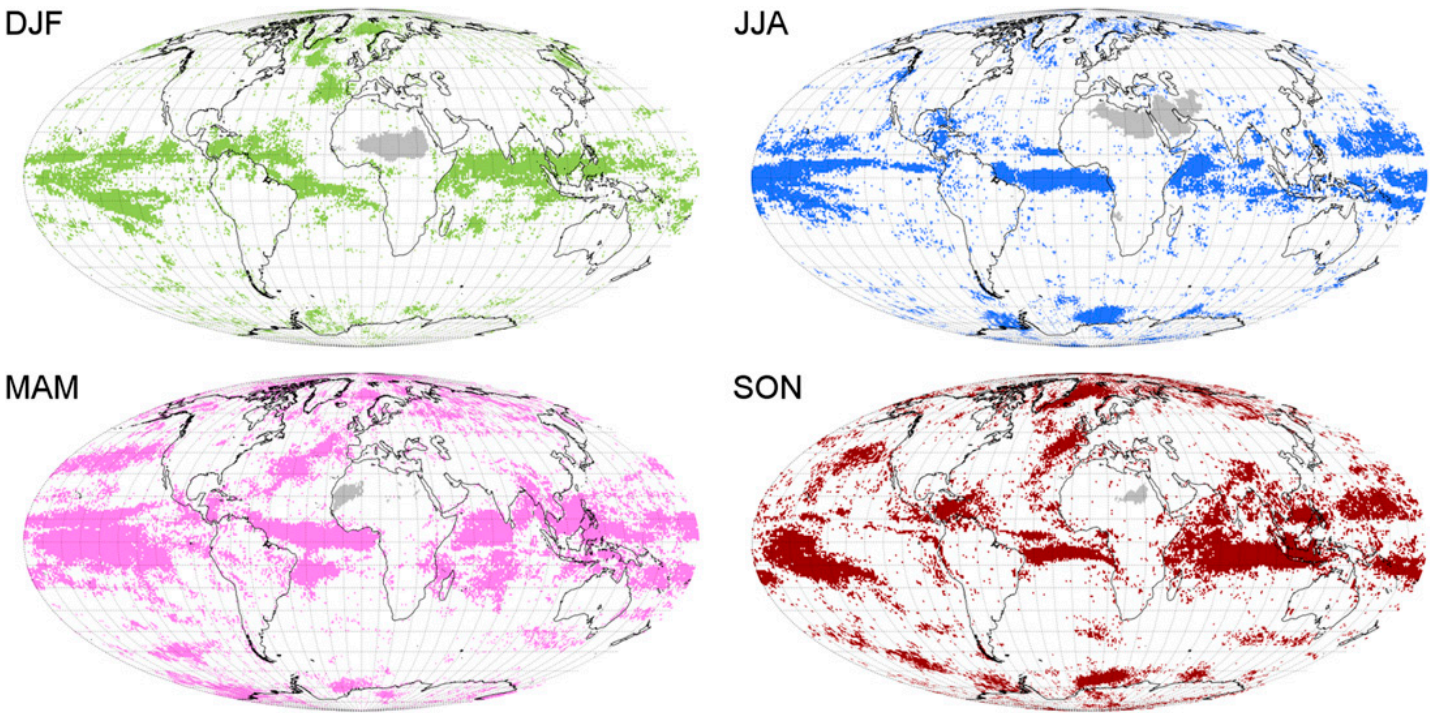
Evaluating VII



Seasonal maps of points having a minimal length to estimate internal variability longer than 30 years. Source: Schindler et al. 2015, J Climate 28

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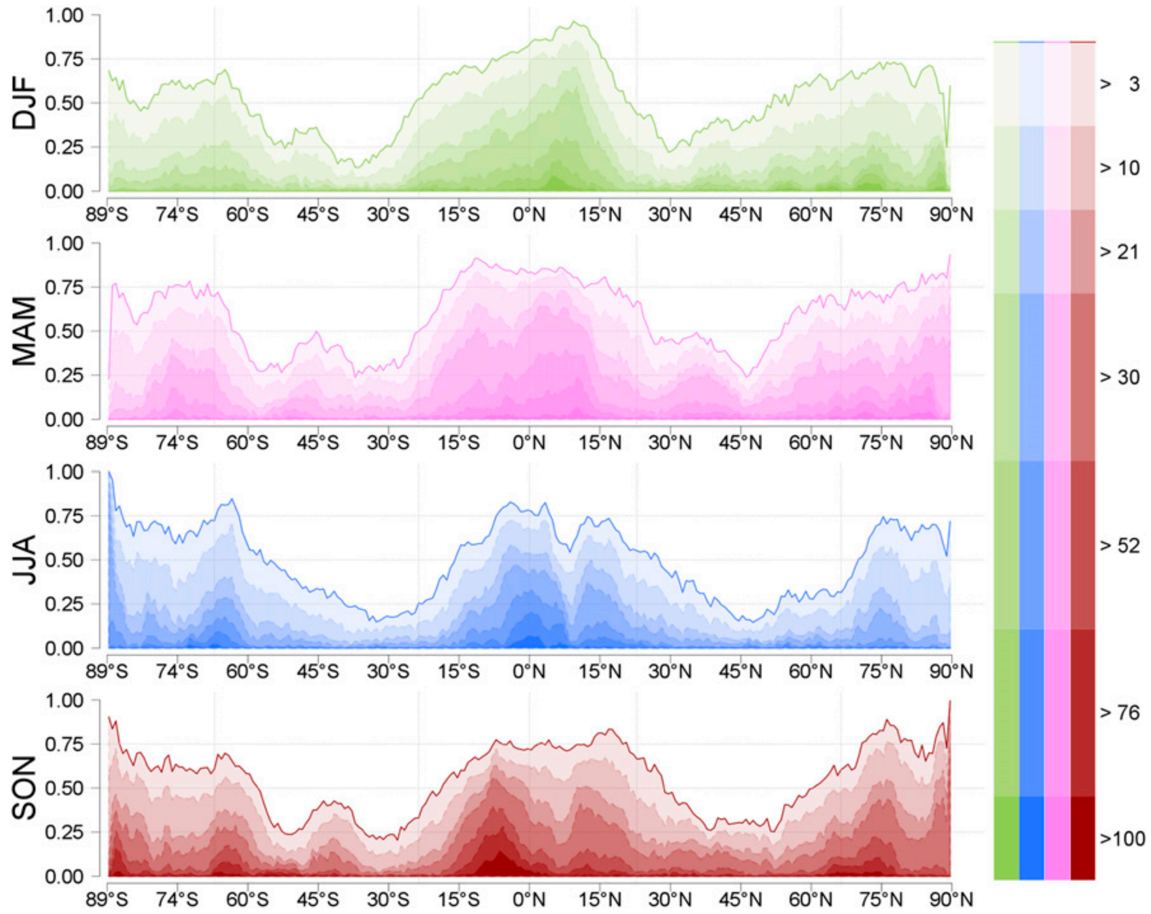
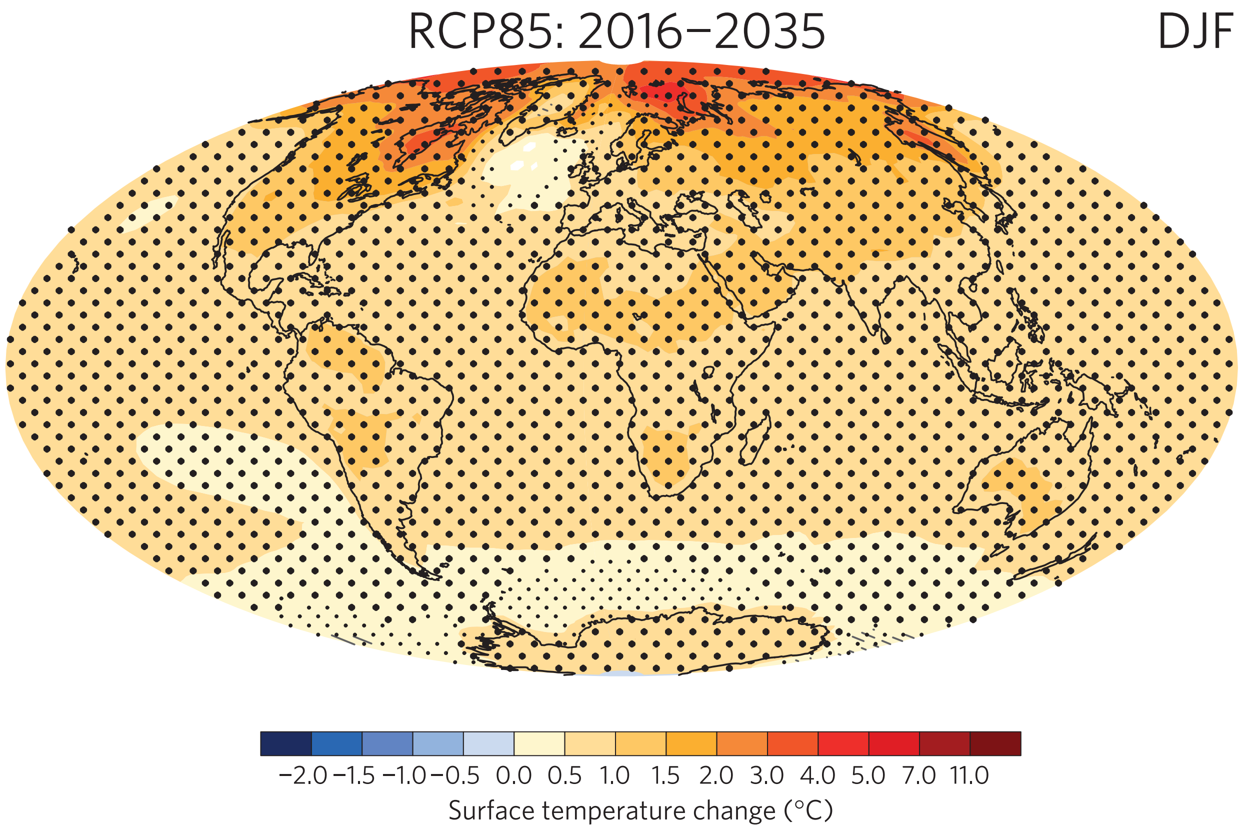
Evaluating VII



Zonal plots of % of points having minimum length longer than some fixed thresholds. Source: Schindler et al. 2015, J Climate 28

Evaluating VIII



Temperature changes w.r.t. 1986-2005. Source: Knutti and Sedlacek 2013, NCC1716

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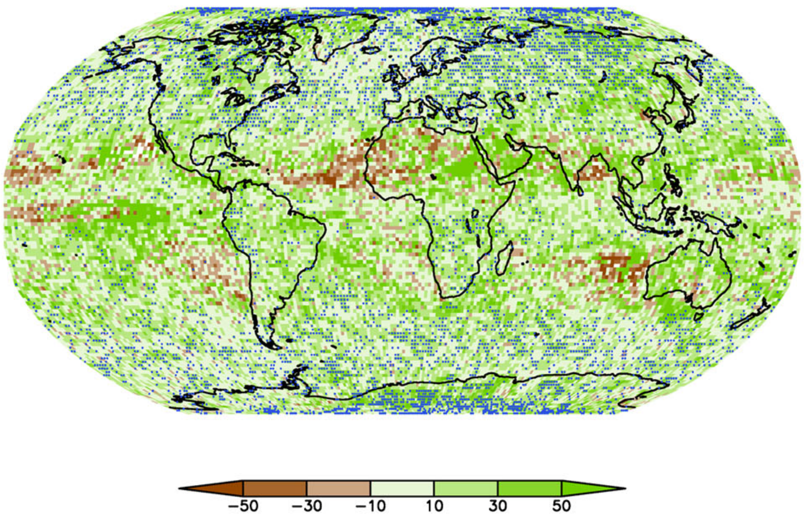
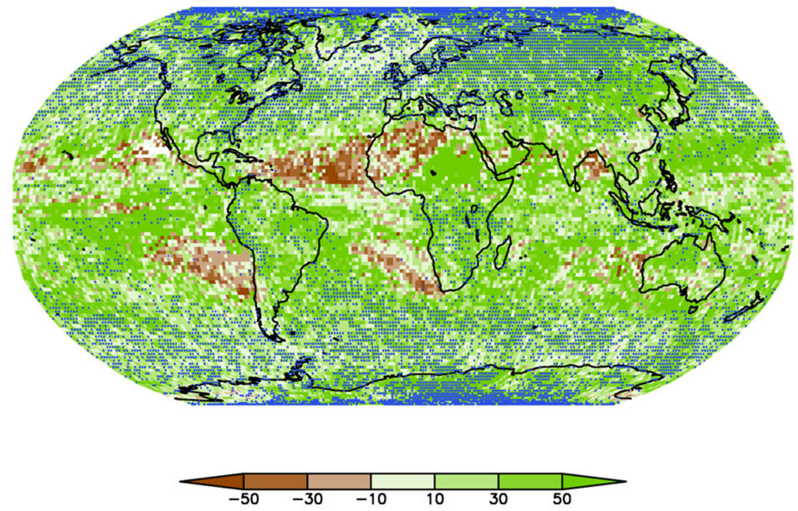
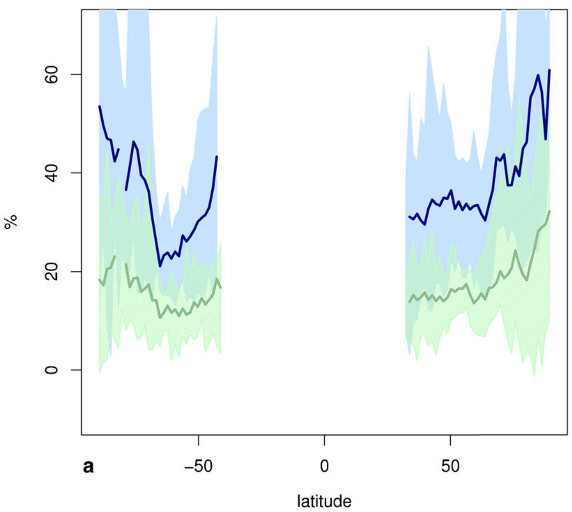
Evaluating IX





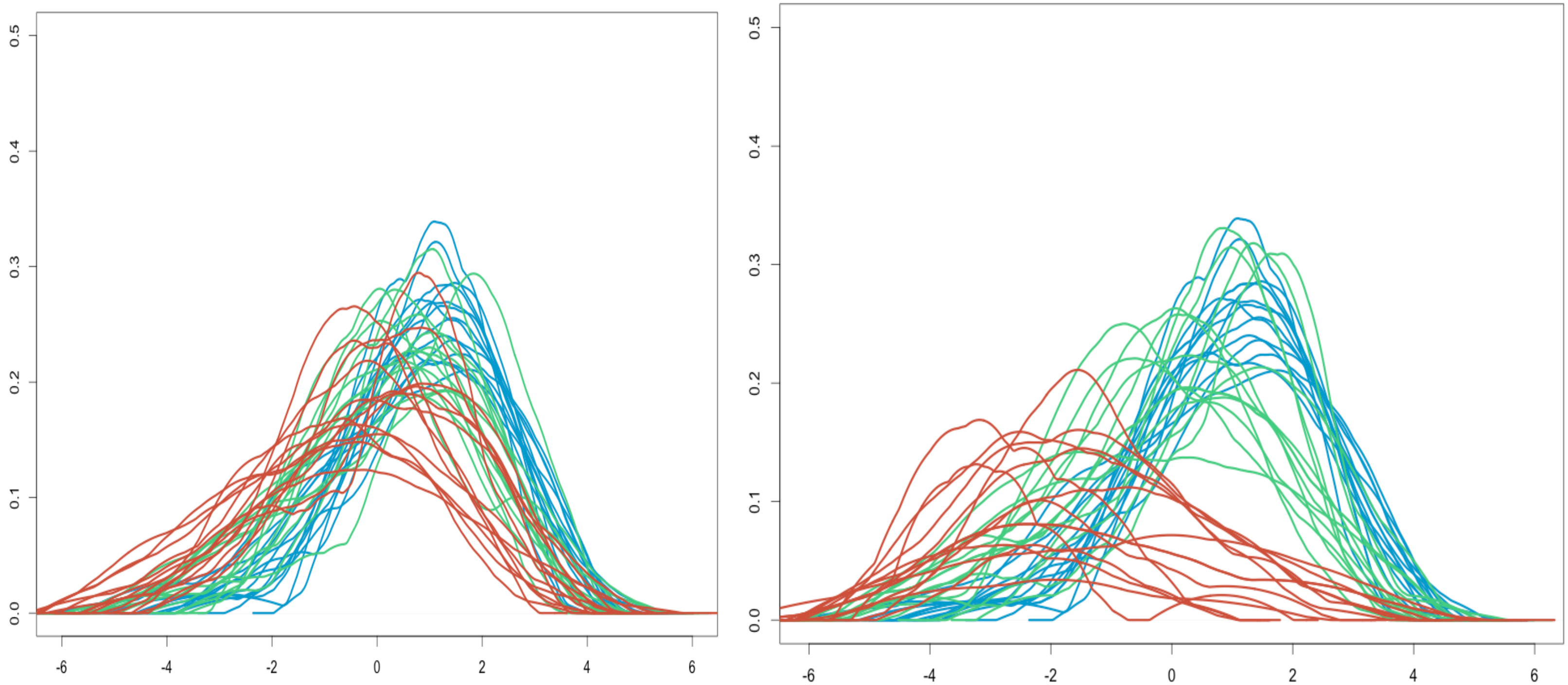
Ensemble mean changes under RCP8.5. 2020-2059 and 2060-2099 w.r.t. 1986-2005 during winter. Source: Toreti et al., 2013



Zonal mean changes under RCP8.5. 2020-2059 (green) and 2060-2099 (blue) w.r.t. 1986-2005 during winter. Source: Toreti et al. 2013, GRL 40

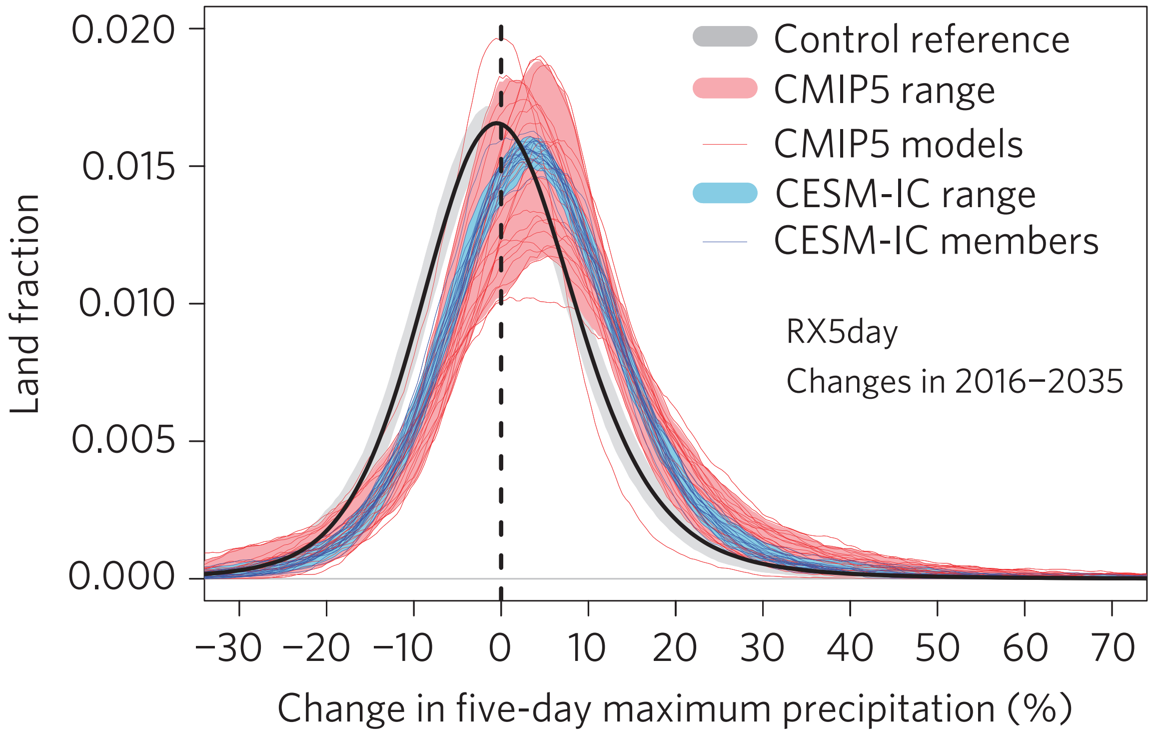
Changes in 50-y ret. levels of extreme precipitation

Evaluating X



Estimated PDFs of the (transformed) spatial extension of early cold spells over Europe. Blue lines are associated with the historical simulation (1976-2005), green lines with the mid-century (2020-2049) and red lines with the end of the century (2070-2099). Left Panel: RCP4.5. Right Panel: RCP8.5.
Source: Toreti et al., in preparation

Evaluating XI



Spatial pdfs of changes in land points 66° N - 66° S
Source: Fischer et al. 2013, NCC 3

Evaluating

- Grid based evaluations
- complexity of extreme events not really captured
- Gridded observations not anymore available at the current resolution of regional climate models

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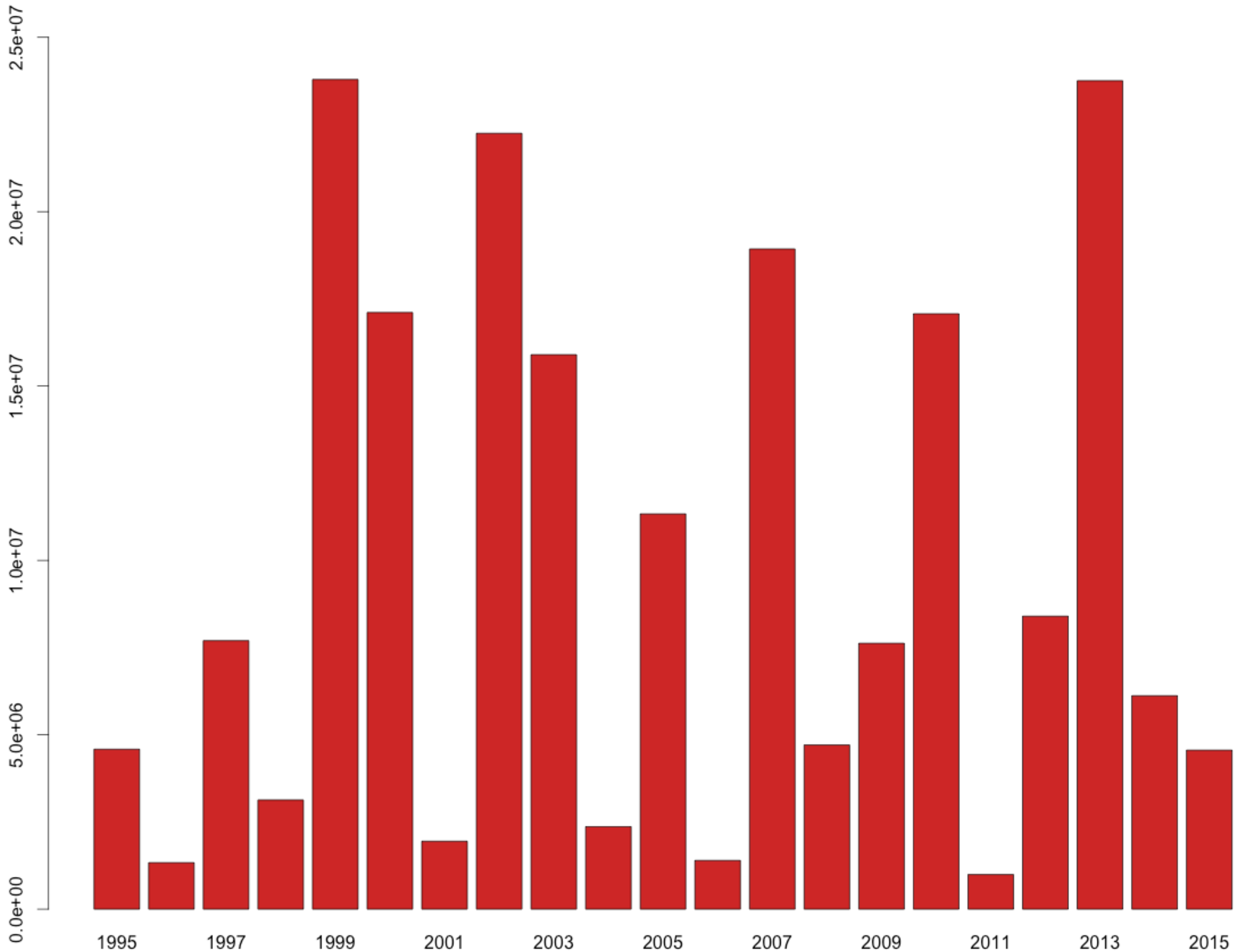
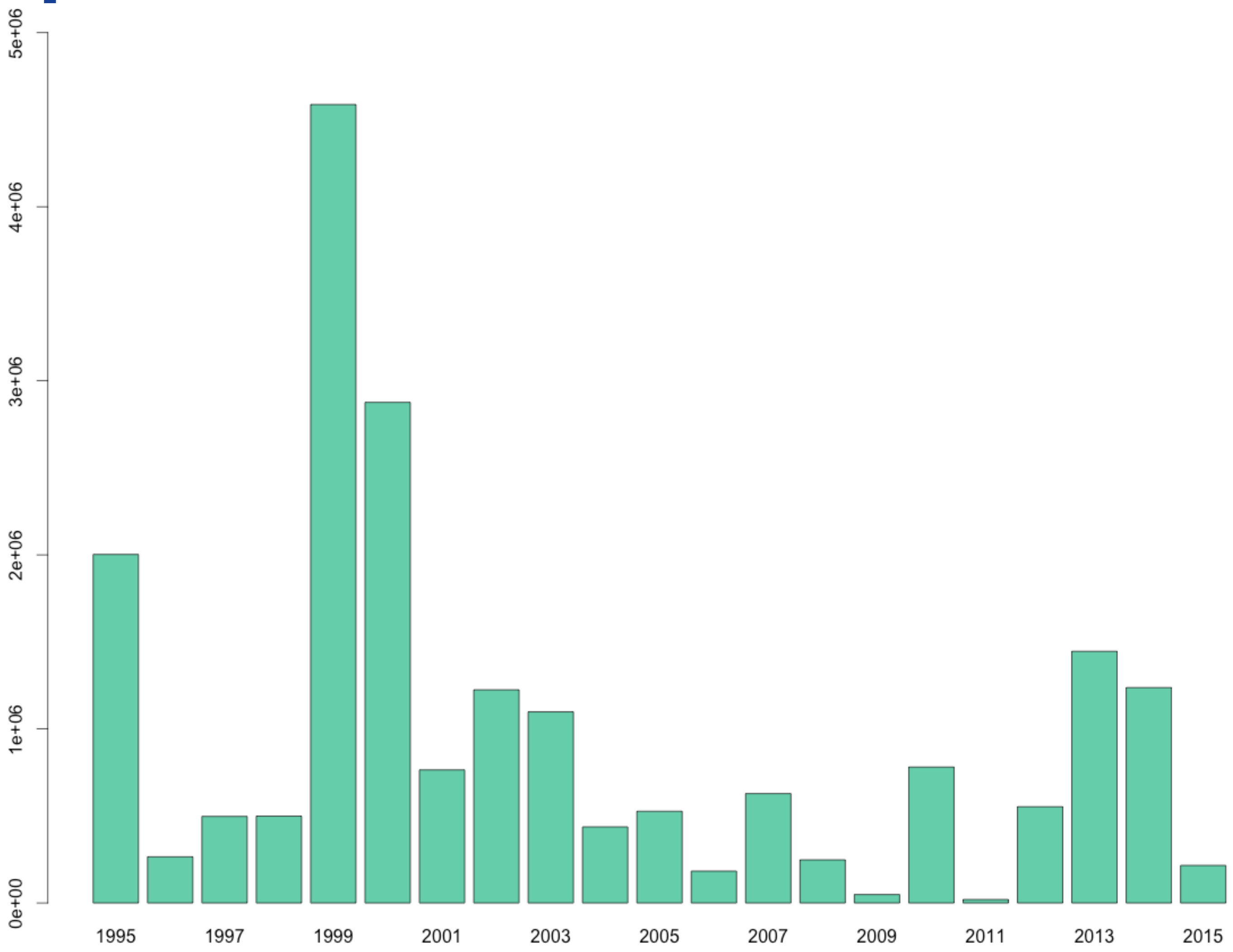
Impacts I



Total damages (10^3 \$) caused by extremes events (floods, drought, extreme temp, storms) in Europe. Data from: EM-DAT, The CRED/OFDA International Disaster Database 2016.

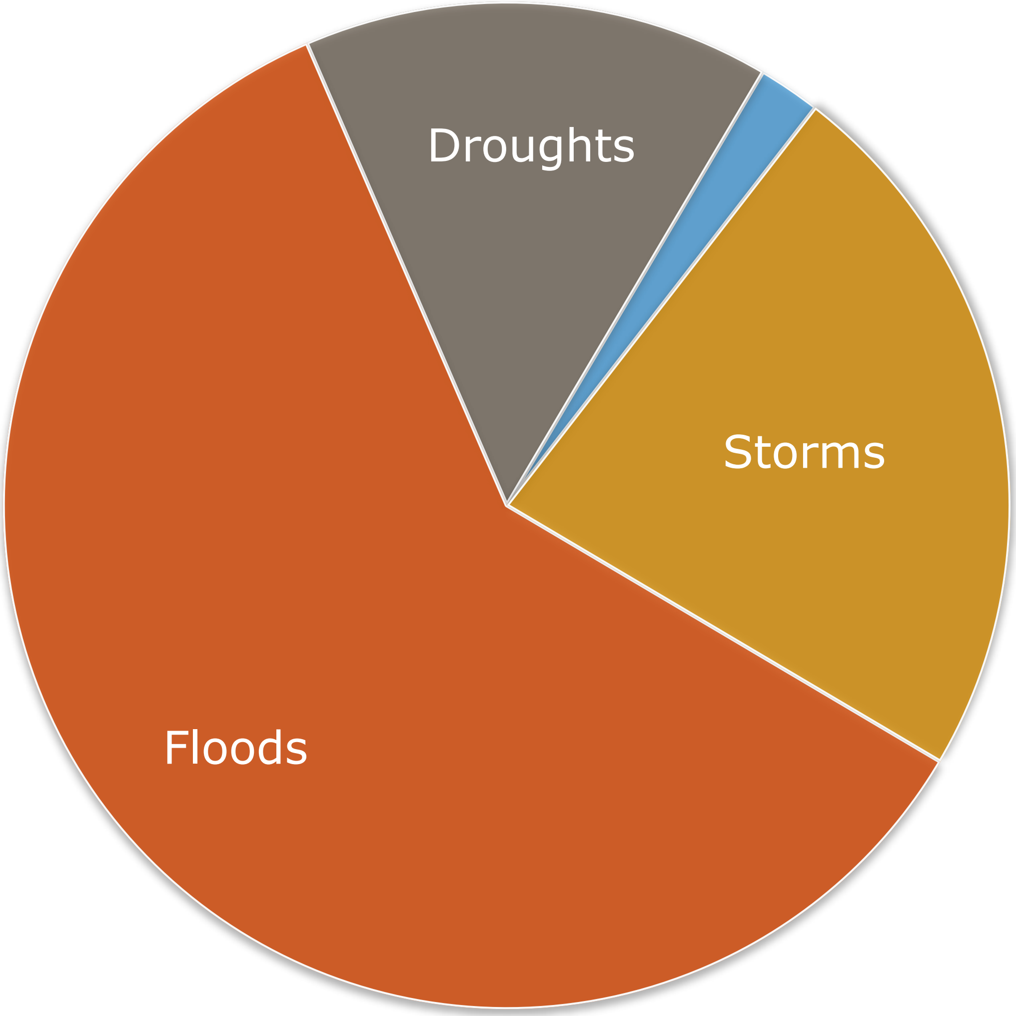
Impacts I



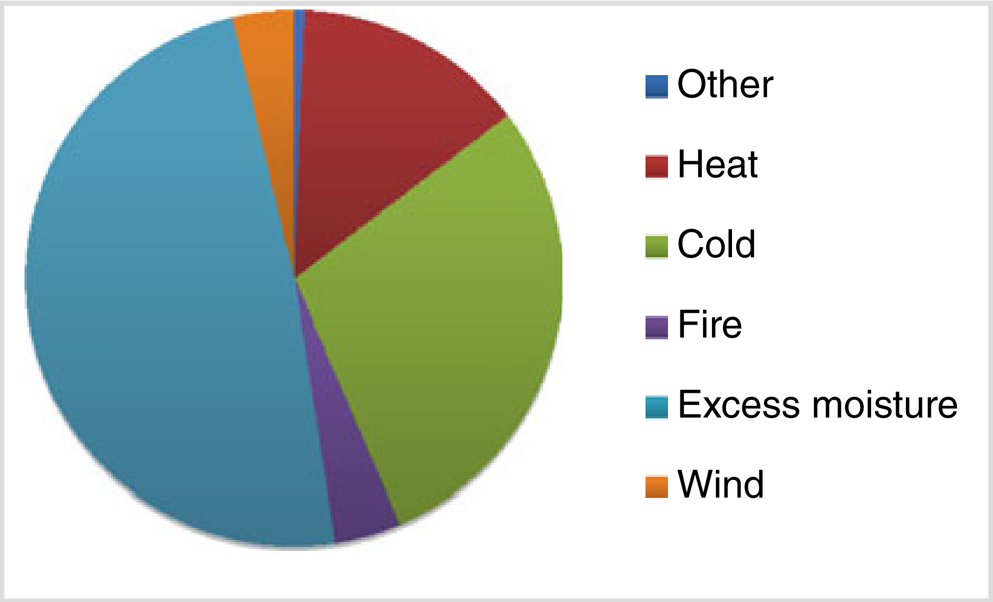
Total number of people affected by extremes events (floods, drought, extreme temp, storms) in Europe. Data from: EM-DAT, The CRED/OFDA International Disaster Database 2016.

Impacts II

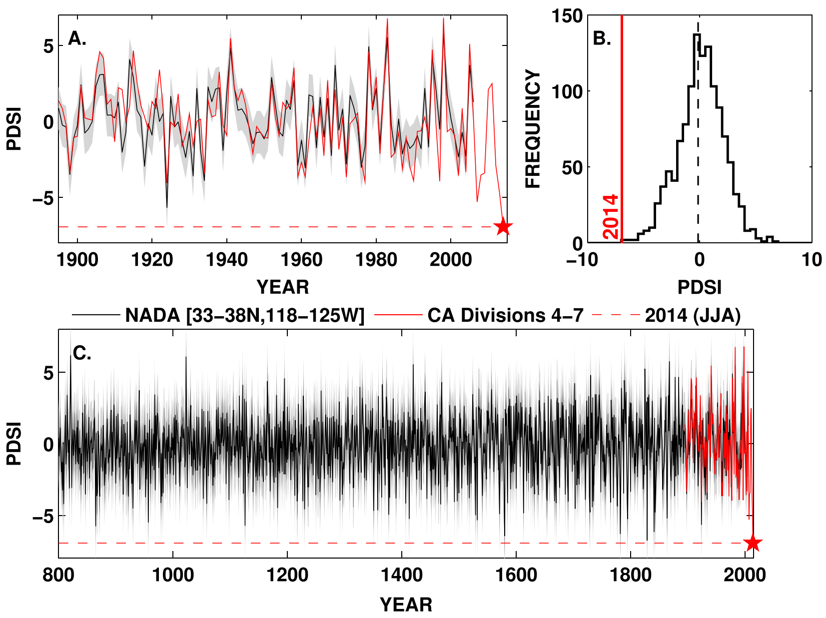
2003-2013, Developing Countries. Average percentage share of damage and loss to crops by type of hazard. Adapted from FAO, 2015.



Impacts II



Estimated total losses from disasters attributable to different extremes (1993-2007) - California agriculture. Source: Lobell et al., 2011



The 2012-2015 California drought. 2014 PDSI value w.r.t. the historical and reconstructed values. Source: Griffin and Anchukaitis, 2014.

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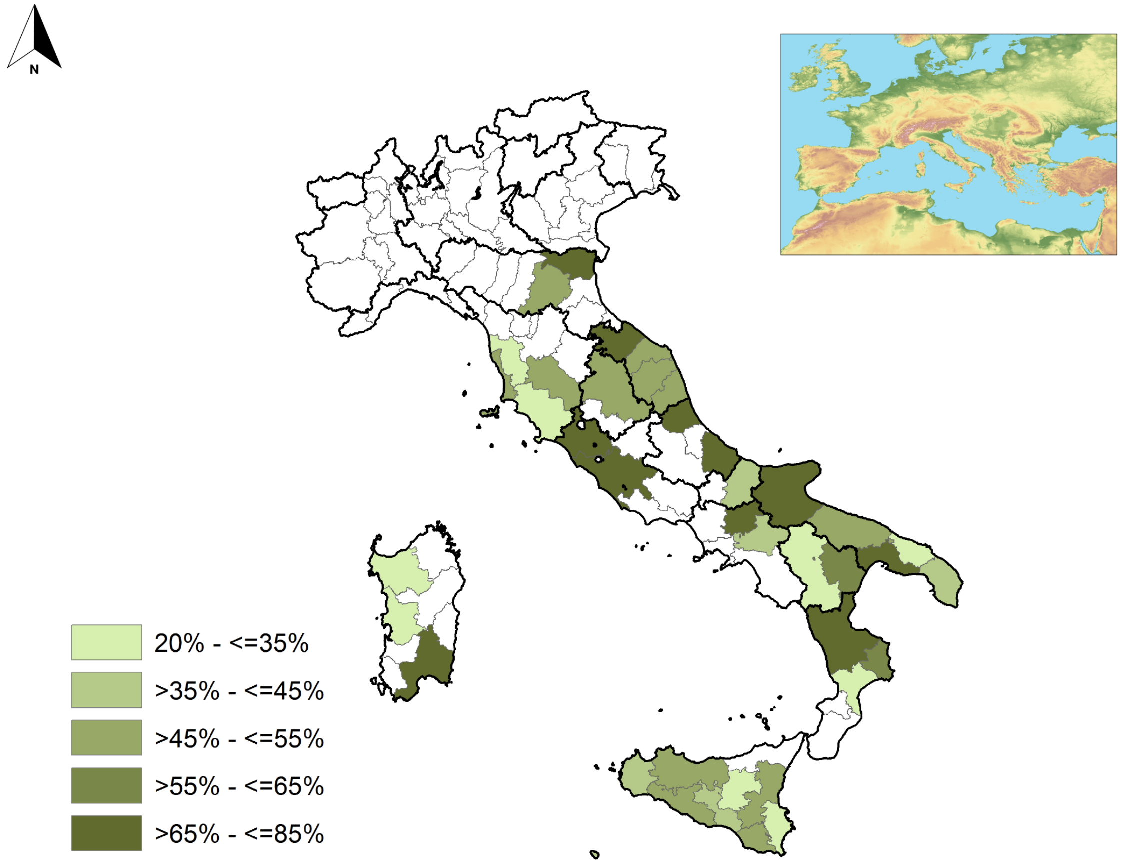
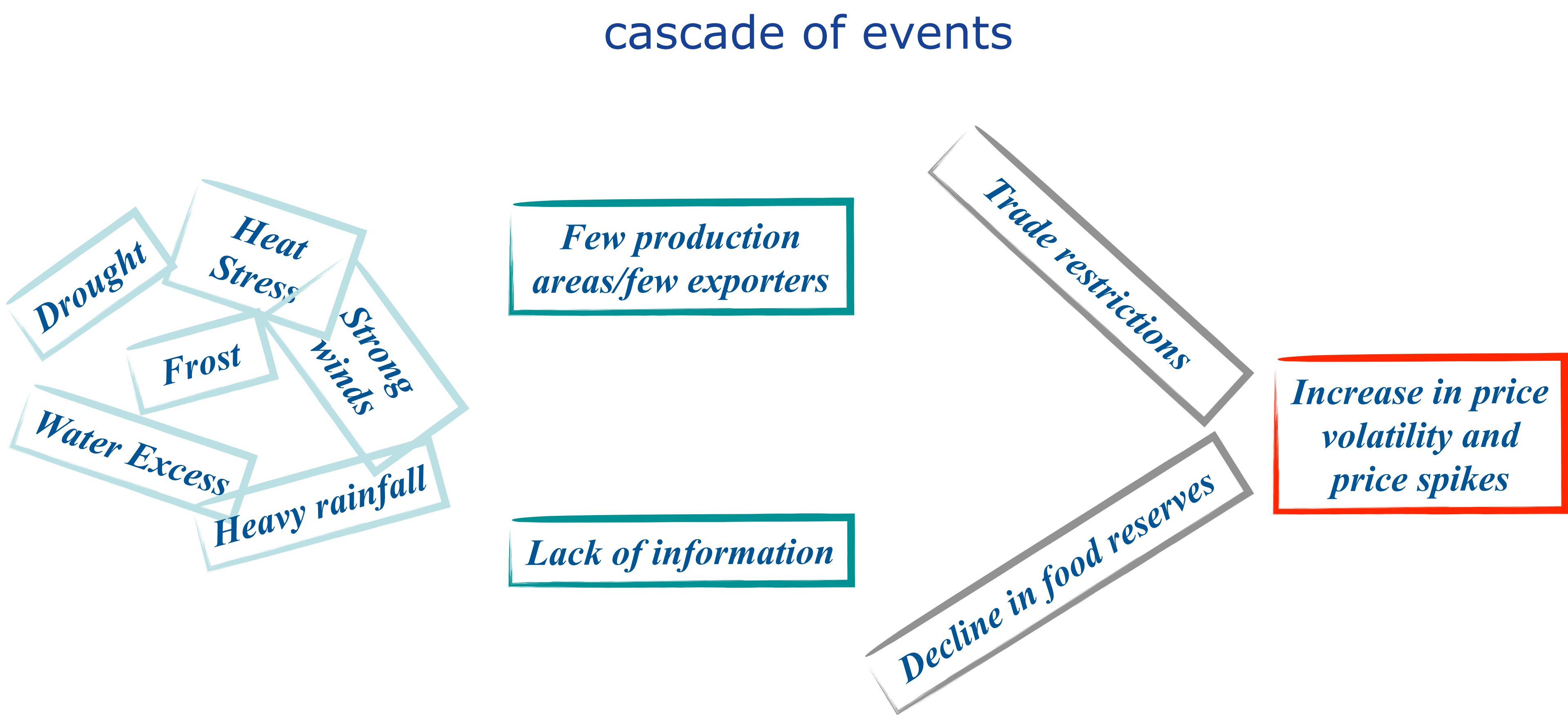
Impacts II



Number of concurrent early heat waves and significant negative yield anomalies of durum wheat in the period 1995–2013 (% w.r.t. the total number of year with significant negative yield anomalies). Source: Fontana et al. 2015, NHESS 15

Impacts II



Adapted from von Braun and Tadesse, 2012

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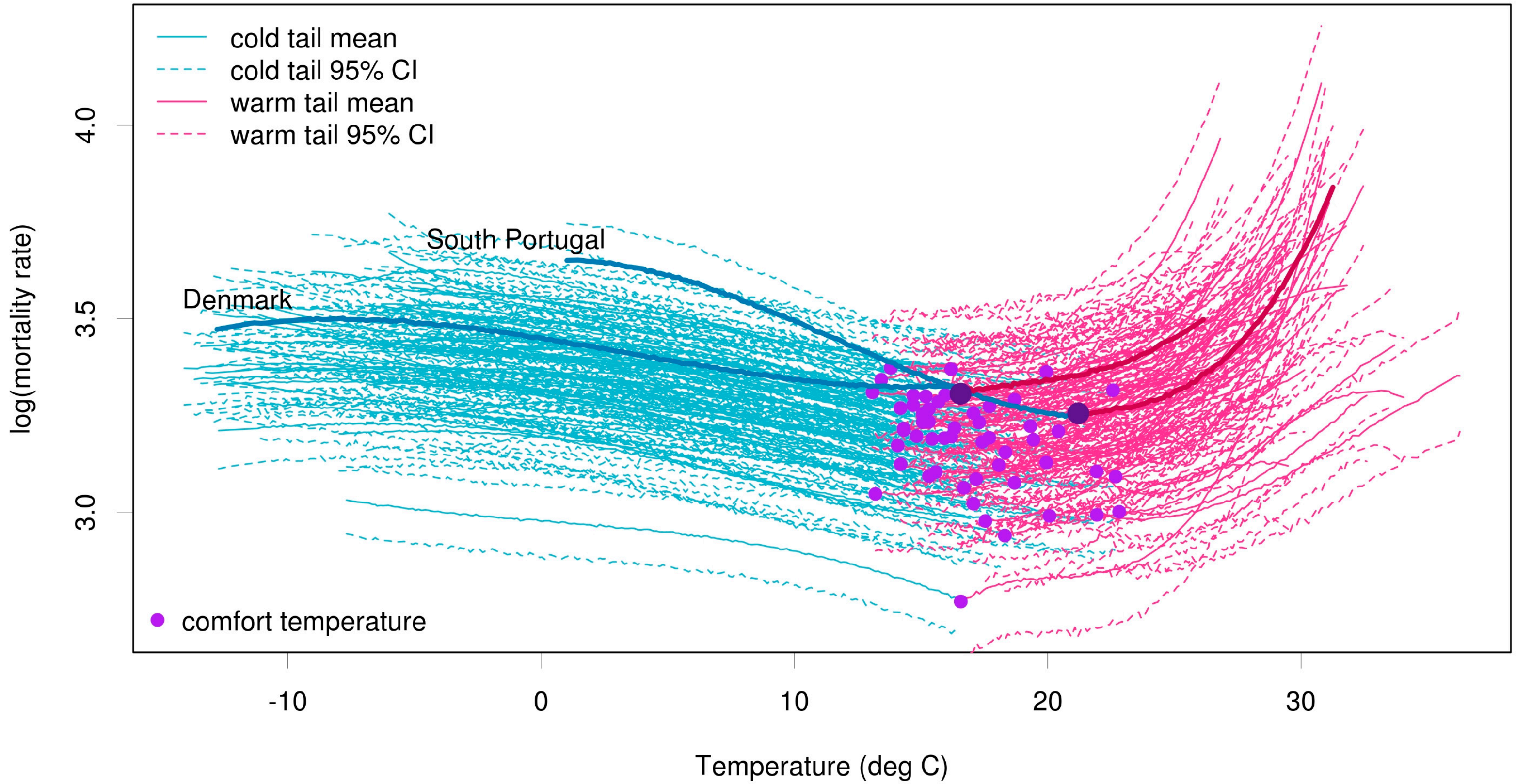
Impacts III



Estimated mortality and comfort zone in 54 European regions, 1998-2003. Source: Lowe, 2015

Impacts

- Interaction of different extremes as well as occurrence of favourable/triggering conditions
- non-climatic factors
- many variables are needed
- Bias in model outputs

Open issues, new challenges,…

- Modelling multivariate extremes having different spatio-temporal scales
- Understanding of past and current changes in extremes still limited
- Process/event oriented evaluation of models
- lack of high resolution gridded observations
- Gap between impact community and climate community

Thank you!

The views here expressed are purely those of the author and may not in any circumstances be regarded as stating an official position of the European Commission.

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