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Drought and Low Flow in Europe – Observations and Multi-model simulations

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The EU-WATCH project

Objective

Bring together the hydrological, water resources and climate **communities** to:

- analyse, quantify and predict the components of the **current** and **future global water cycles** and related **water resources** and **extremes**.

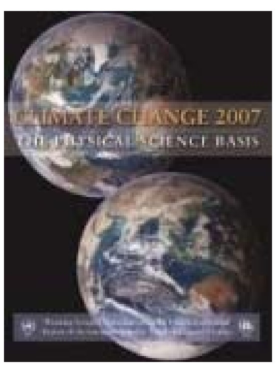
Global and **regional scale** studies (Europe).

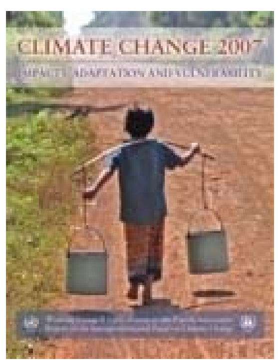
Global change

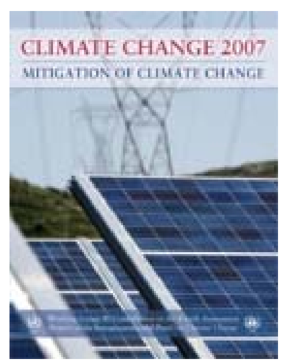
Two main approaches to assess the impact of global change (climate and other human impacts) on freshwater resources:

i) Analyse **observed data** for changes and trends

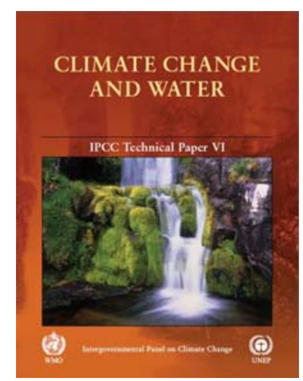
ii) Derive **future projections** using climate scenarios in combination with physically-based models (requires that the models being used have been **evaluated for the current climate**).







IPCC Fourth Assessment Report, 2007



Drought and Low Flow in Europe – Observations and Multi-model simulations

Outline

- Large-scale data
- Multi-model comparison and evaluation
  - Flow range (percentiles)
  - Flow regime (mean monthly flow)
  - Drought patterns
  - Trends (mean, regime, extremes)
- Future predictions
- Concluding remarks

photo: Henny van Lanen, 2003

Large-scale data

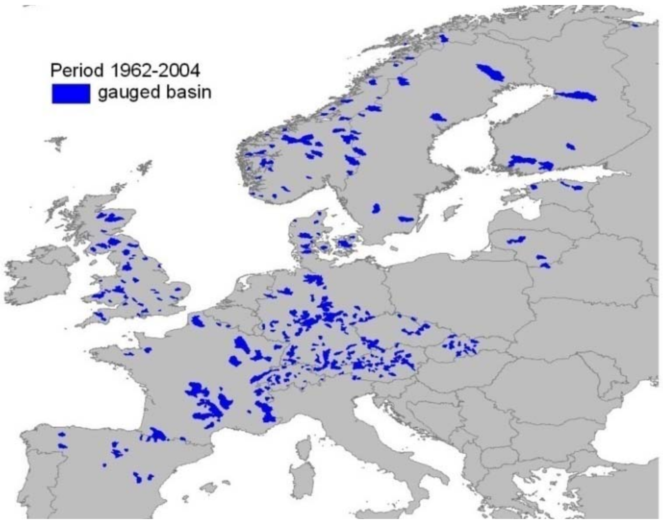
- **Observations** across larger regions and beyond national boarders are:
  - vital for a better understanding of dominating processes in the natural system (recent changes)
  - needed to provide 'ground-truth' for climate modeling and thus, improve model structures and learn the current limits of model simulations
- **Streamflow** is currently the most readily available hydrological variable across larger scales

Large-scale data – Observations

Observed streamflow data

UNESCO-FRIEND European Water Archive

- More than 400 stations
- Near-natural
- Median basin area ~ 306 km^2
- Monthly and daily time series



Stahl et al., 2010

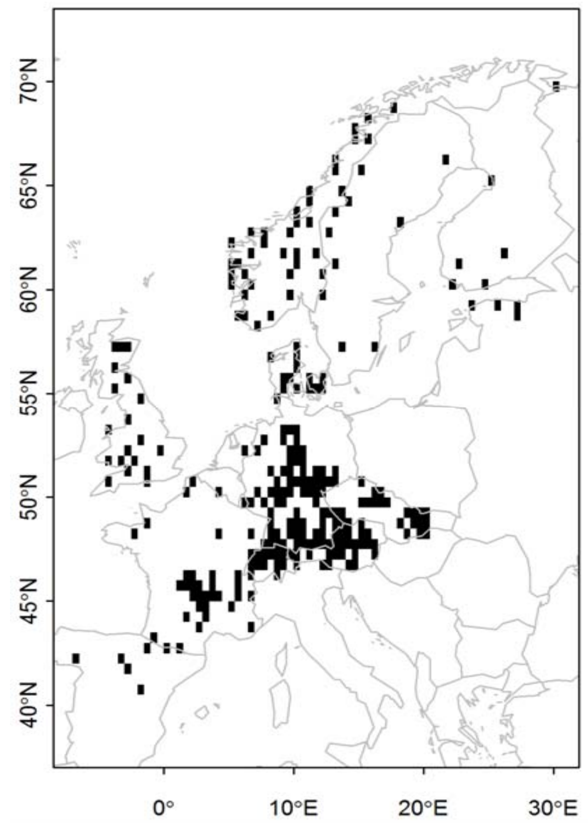
Small basins	Large basins
Near natural	Human influenced
Regional variability	Integrate across large scales
Process studies	Freshwater flux to the ocean
Cover only part of the region	Cover most of the region
Daily series	Annual series

Dai, 2011

Large-scale data – Model simulations

WATCH multi-model simulations

- Grid cells with observations: 293
- Grid cell ~ 1000 - 2 400 km^2
- Basins ~ 306 km^2
- Daily sum of subsurface and surface runoff (mm/day)
- Common period 1963-2000



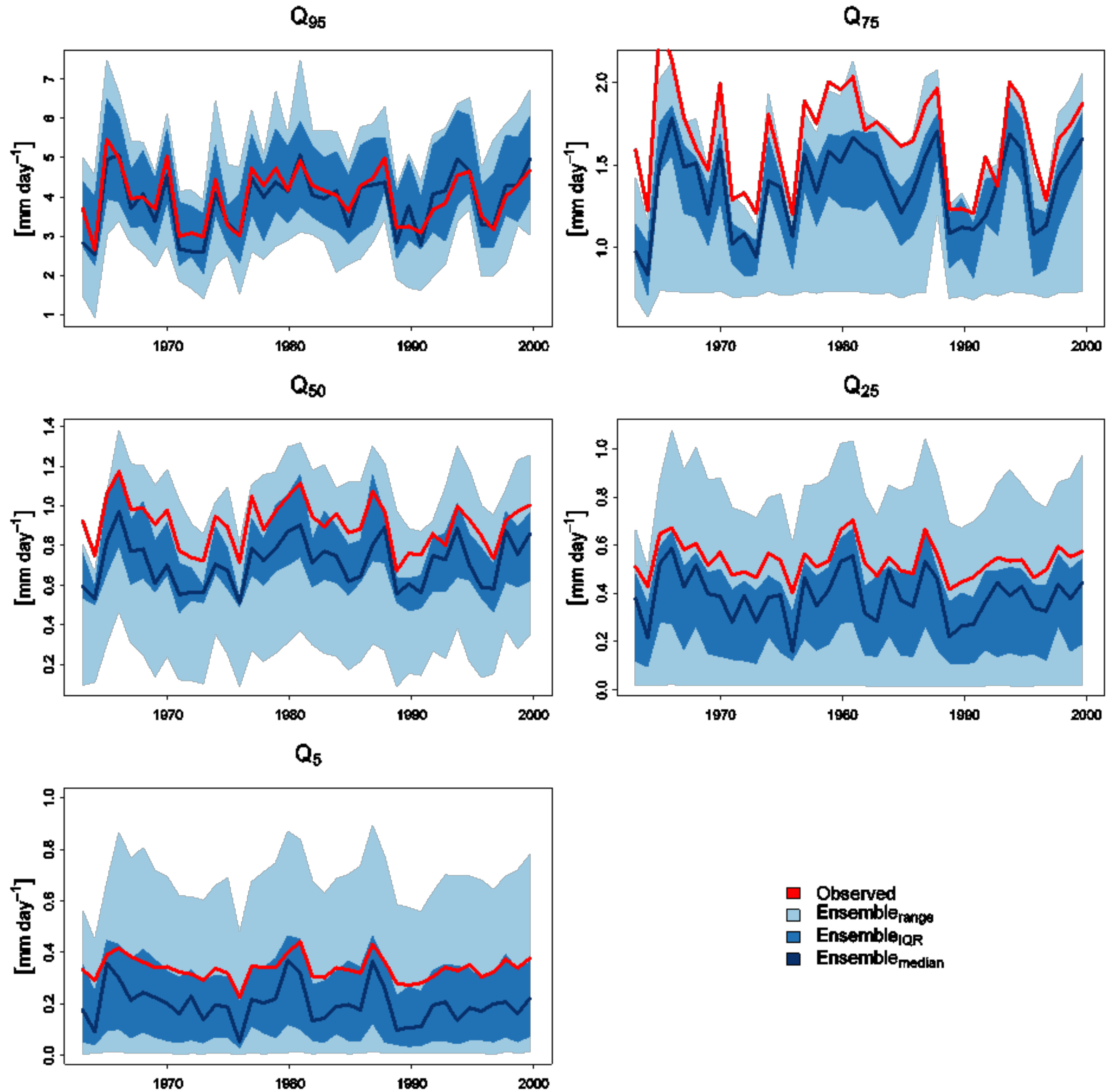
Paired grid-cell comparison of observed and modeled runoff for a series of benchmarks.

Large-scale models

Model-name	Evapo-transpiration	Snow	Runoff scheme	Reference(s)
GWAWA	Pennman-Monteith	Degree Day	Q_s : PDM $Q_{sb} = f(S_{gw})$	*Meigh et al.* [1999]
H08	Bulk approach	Energy Balance	Q_s : Saturation excess $Q_{sb} = Q_d = f(S_{soil})$	*Hanasaki et al.* [2008]
HTESSEL	Pennman-Monteith	Energy Balance	Q_s : ARNO $Q_{sb} = Q_d = f(S_{soil})$, Richards	*Balsamo et al.* [2009]
JULES	Pennman-Monteith	Energy Balance	Q_s : Infiltration excess $Q_{sb} = Q_d = f(S_{soil})$, Richards	*Essery et al.* [2003] *Cox et al.* [1999]
LPJmL	Priestley-Taylor	Degree Day	Q_s : Saturation Excess $Q_{sb} = Q_d = f(S_{soil})$	*Bondeau et al.* [2007] *Rost et al.* [2008]
MATSIRO	Bulk-approach	Energy Balance	Q_s : TOPMODEL $Q_{sb} = f(S_{gw})$	*Takata et al.* [2003] *Koirala* [2010]
MPI-HM	Thornmwaite	Degree Day	Q_s : improved ARNO $Q_{sb} = Q_d = f(S_{soil})$	*Hagemann and Dümenil Gates* [1998] *Hagemann and Dümenil Gates* [2003]
ORCHIDEE	Bulk-approach	Energy Balance	Q_s : ARNO $Q_{sb} = Q_d = f(S_{soil})$	*de Rosnay and Polcher* [1998]
WATERGAP	Priestley-Taylor	Degree Day	Q_s : Saturation excess $Q_{sb} = f(S_{gw})$	*Alcamo et al.* [2003]

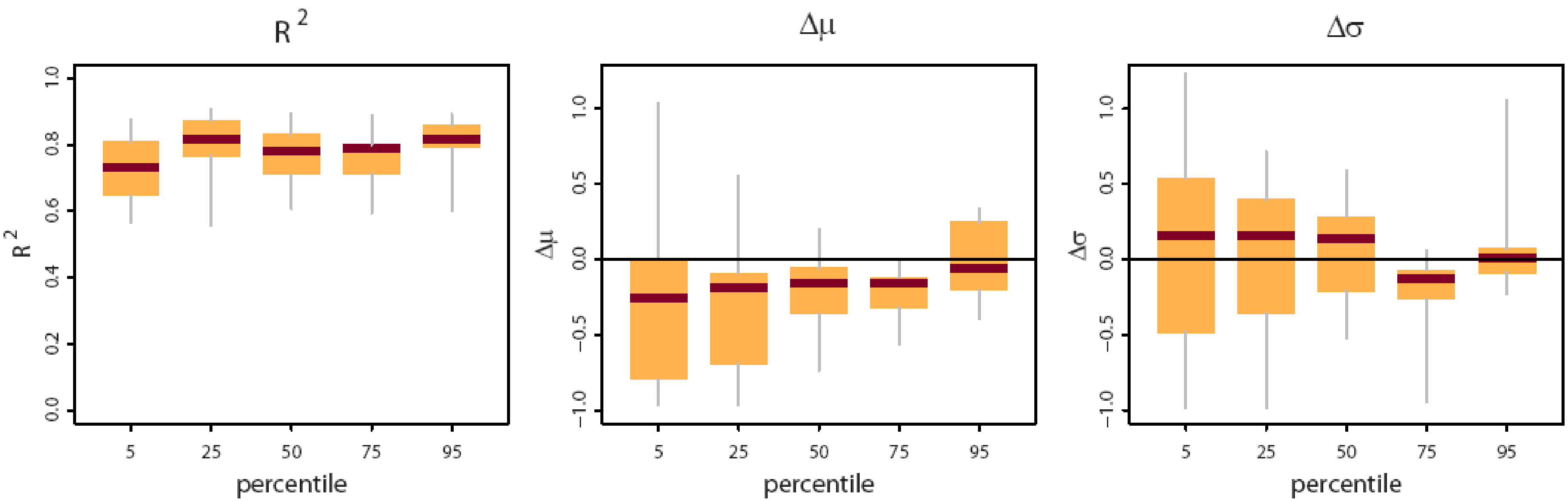
Modified from Haddeland et al. (2011) JHM

Flow range - from wet to dry percentiles



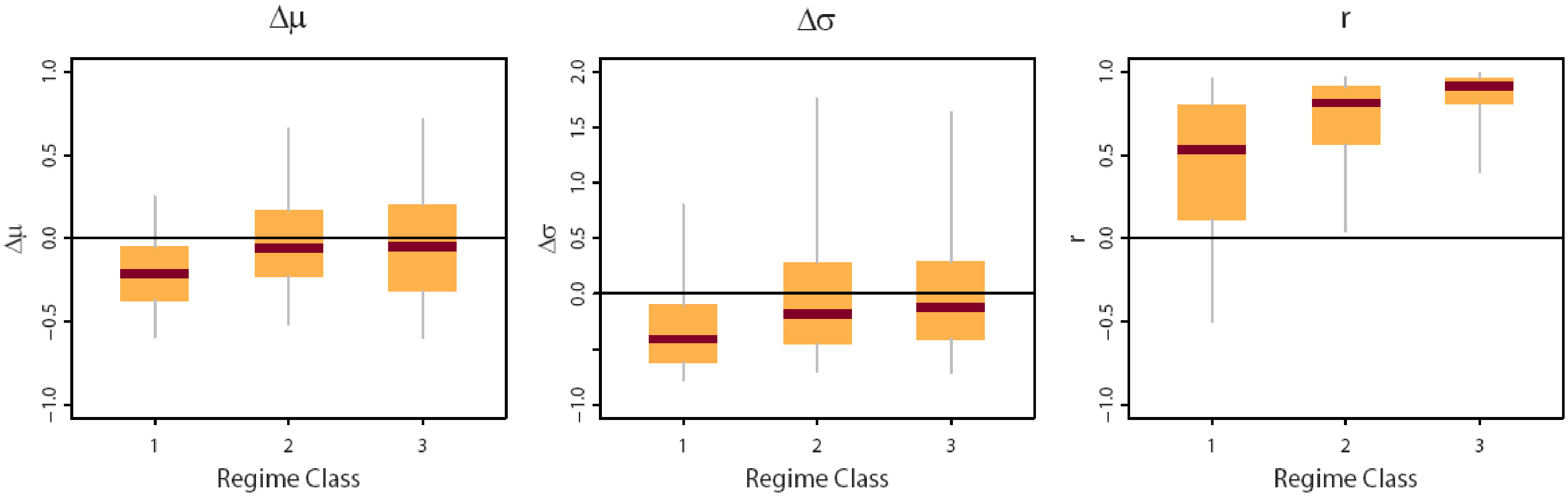
Gudmundsson et al., (2011) JHM

Flow range - from wet to dry percentiles



Gudmundsson et al. (2011) JHM

Flow regime - Mean monthly flow



Gudmundsson et al. (2012) WRR (in review)

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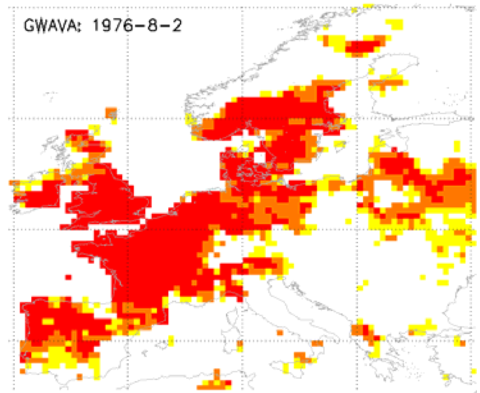
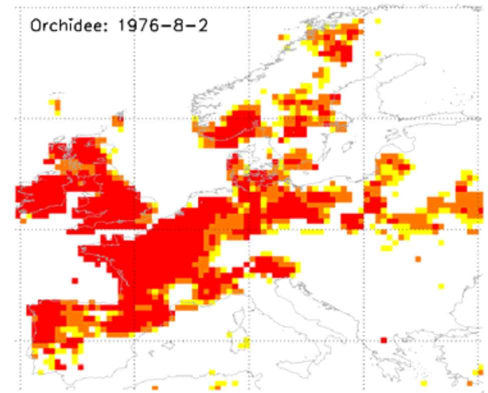
Drought patterns

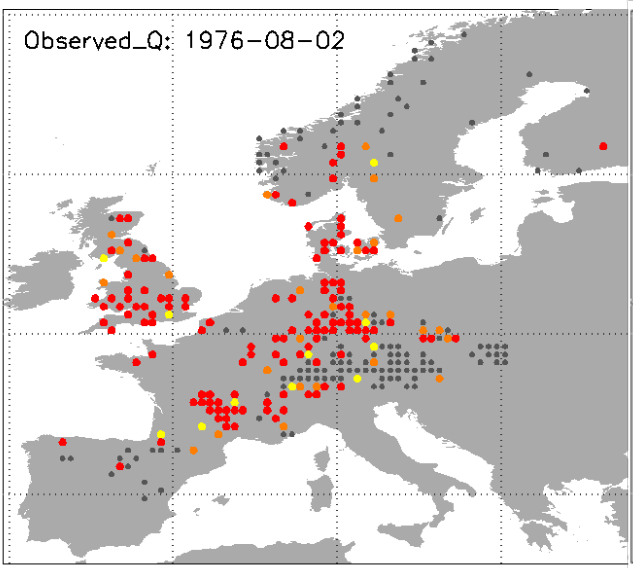
→ compare models

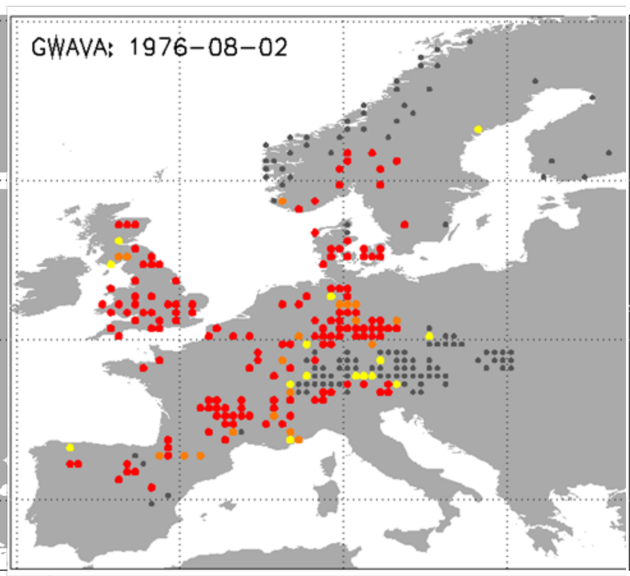


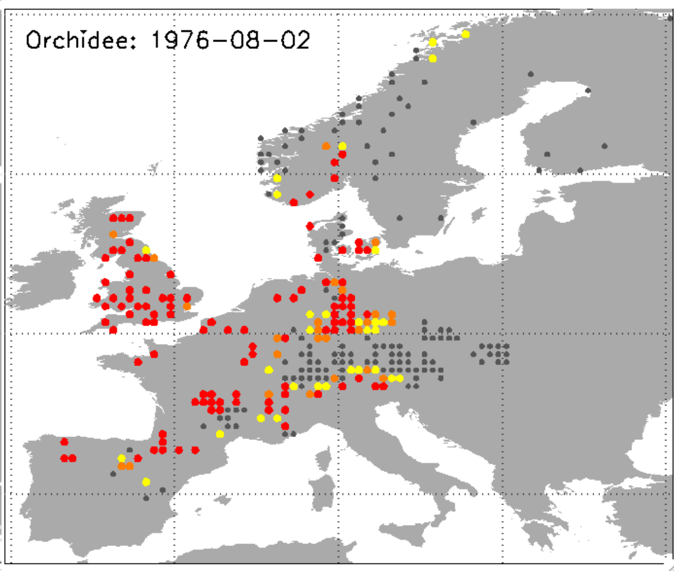


<Q10 <Q20 <Q30

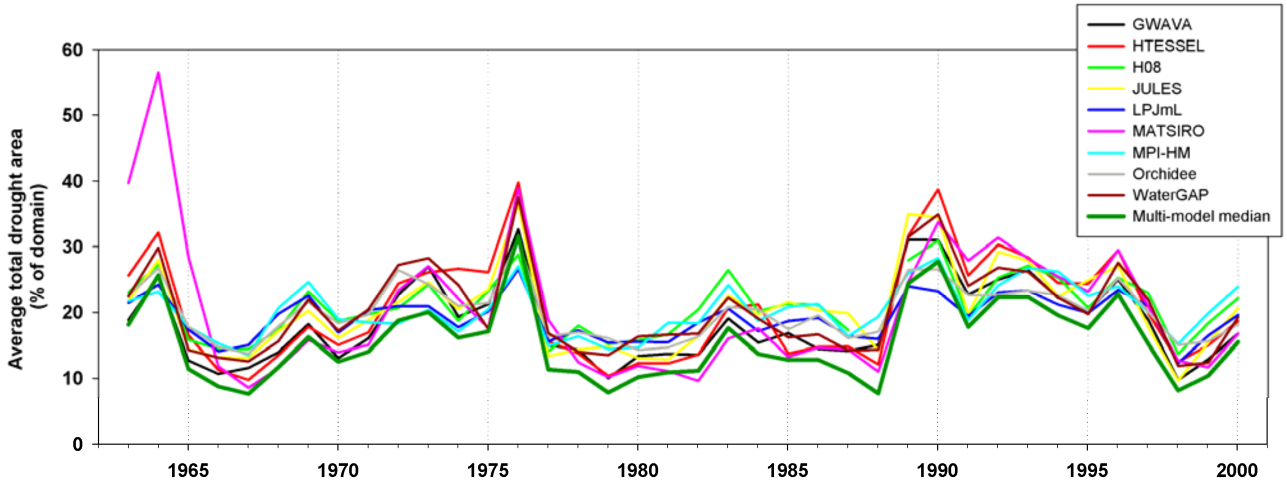
→ compare grid cells with observation(s)



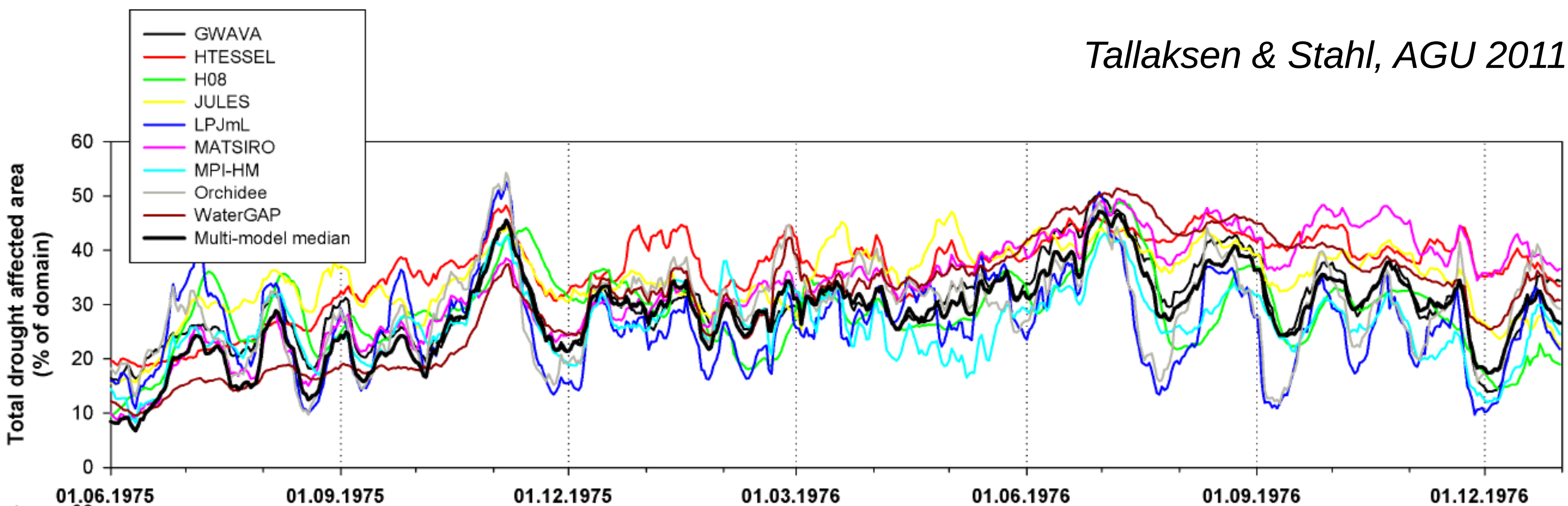




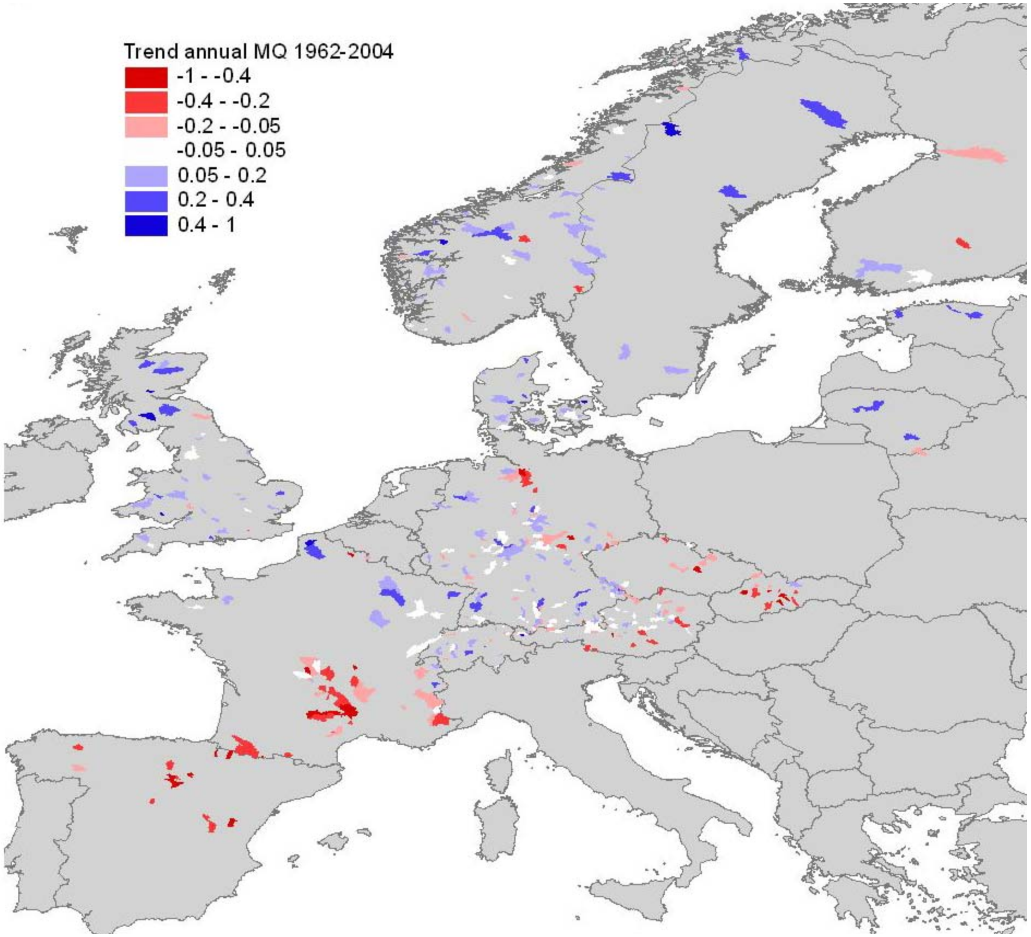
Drought patterns – temporal



Tallaksen & Stahl, AGU 2011



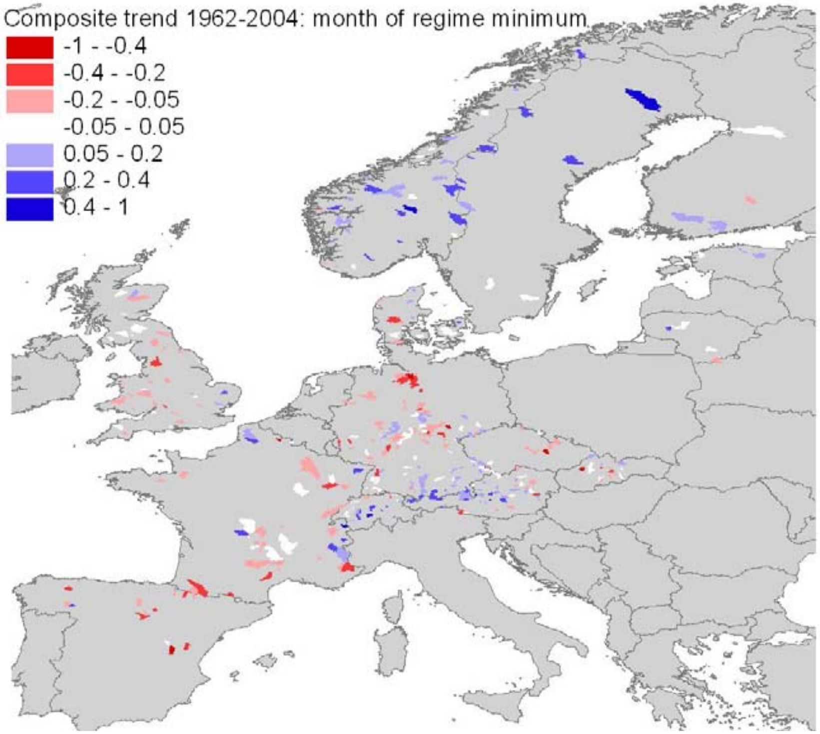
Trends in mean annual streamflow



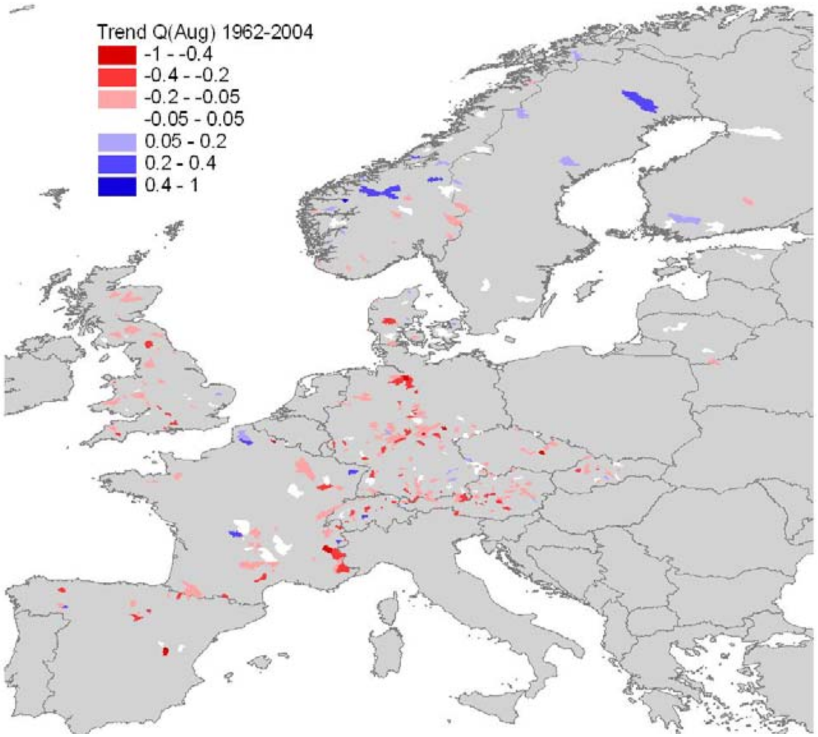
Stahl et al. (2010) HESS,14

Trends in mean monthly streamflow

Months of the minimum flow



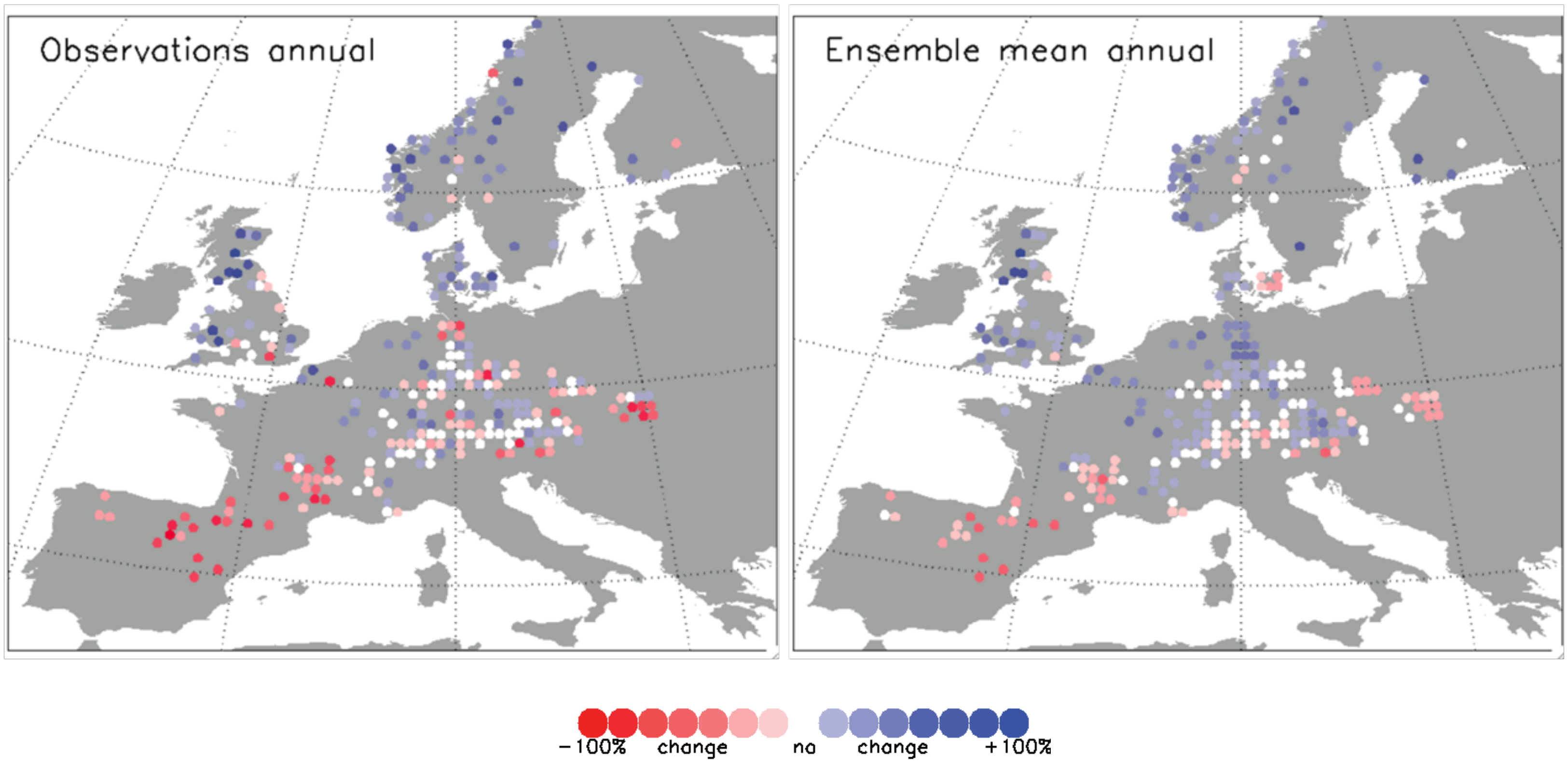
August flow



Stahl et al. (2010) HESS, 14

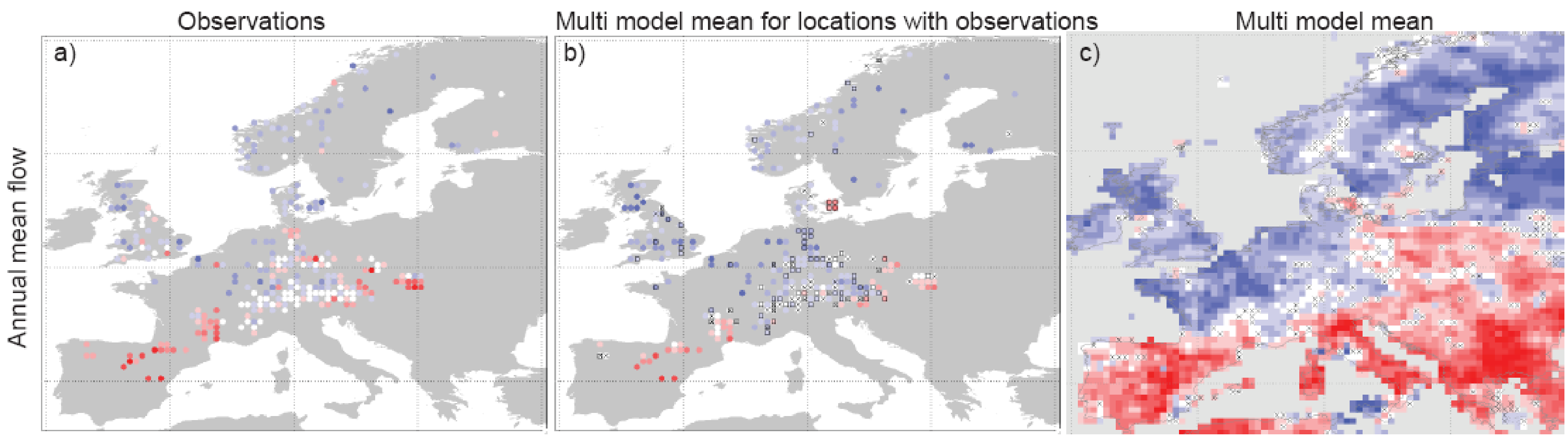
Trends in mean annual runoff

Observed **Ensemble**



Stahl et al. (2012) HESSD

Trends – Filling the white space

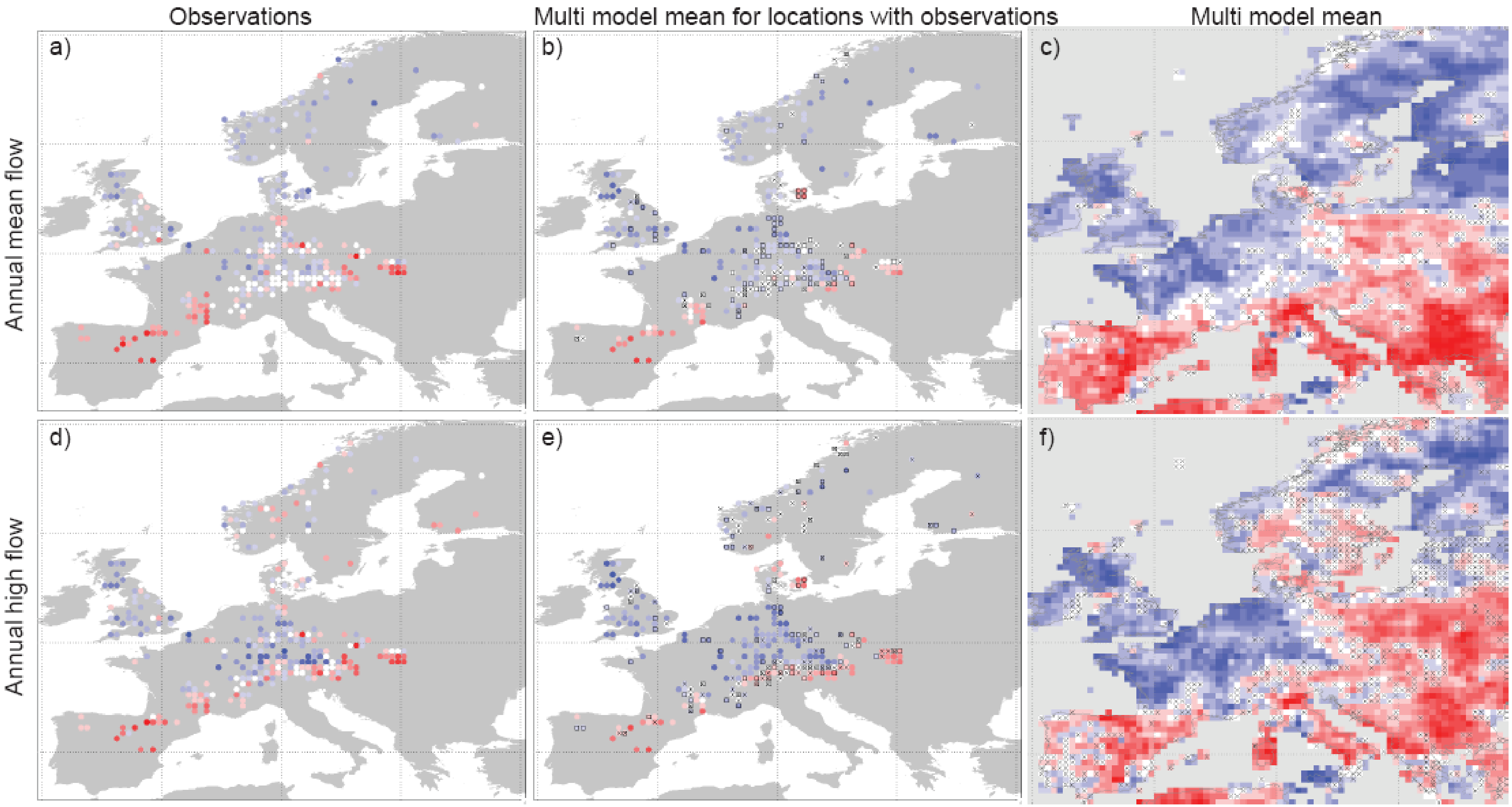


Paired grid-cell comparison

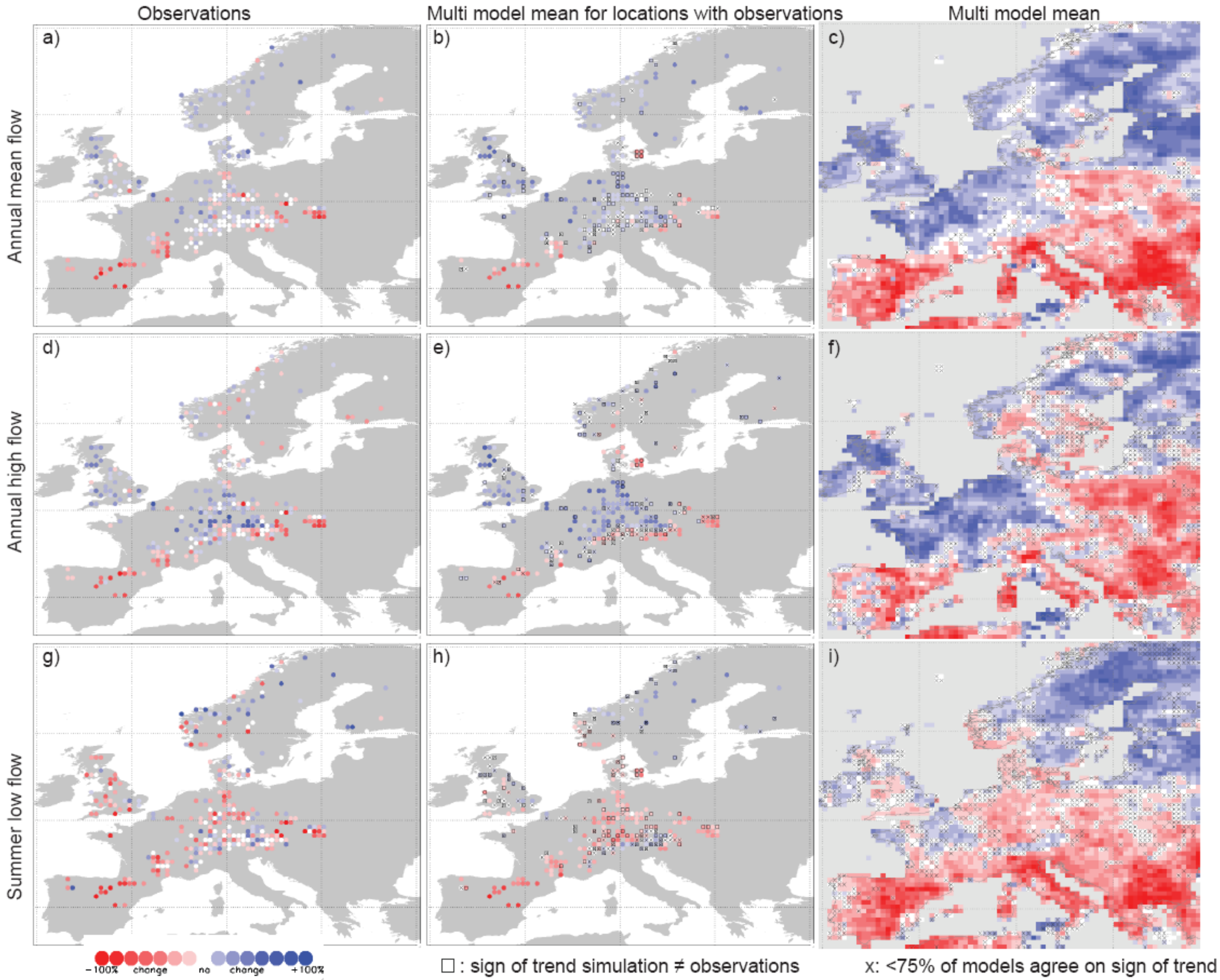
- Highlight if the ensemble trend direction is opposite to the observed trends
- Highlight if less than six out of eight (<75%) of the models agree on the direction of the ensemble mean.

Stahl et al. (2012) HESSD

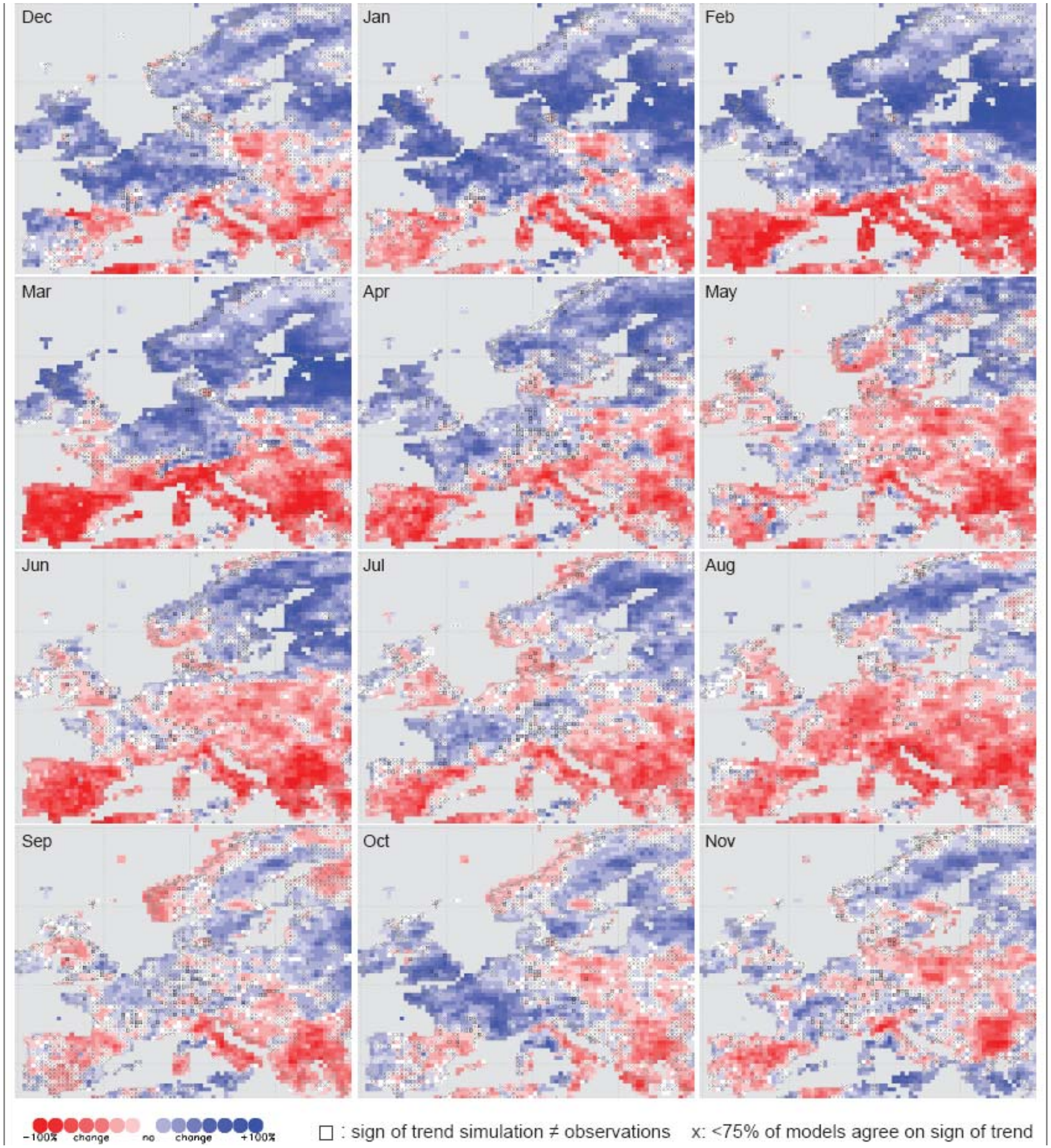
Trends – Filling the white space



Stahl et al. (2012) HESSD



Stahl et al. (2012) HESSD



Stahl et al. (2012) HESSD

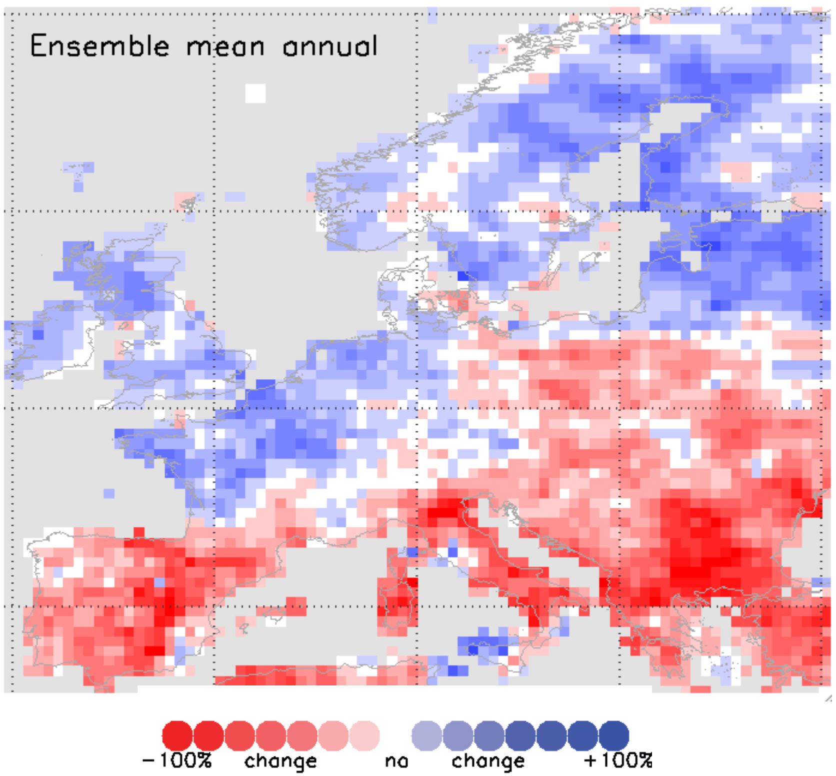
Model performance

- Overestimation of the number and magnitude of increasing (wetter) trends and underestimation of the decreasing drying trends
- Considerable higher local (spatial) variability in trends in observations

Lower agreement are found in	Likely cause
Transition regions	Model resolution or spatial offset
Regions with weak trends	High uncertainty in both observations and simulations
High altitude regions	Small-scale variability in terrain, geology and climate
Snow dominating regimes	Model structure and forcing data (elevation dependence)
Drier regions, summer low flows and early autumn	Model representation of storage and release processes

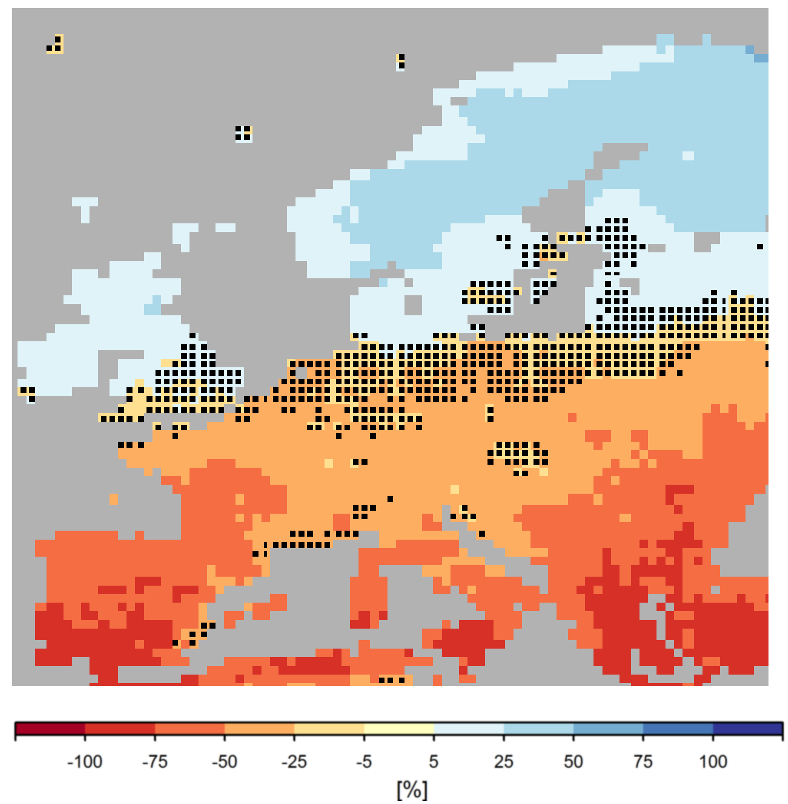
Modelled changes for current climate – Future projections (3 GCMs, A2 scenario)

Trends 1963 – 2000



Stahl et al., HESSD (2012)

1971-2000 versus 2071-2100



Gudmundsson et al. (2011)

Concluding Remarks

- **Streamflow observations**
  - are critical for assessing recent changes and improve future projections
  - confirm an overall drying in southern Europe and decreasing low flows in regimes with a summer minimum
- **Large-scale models** are able to satisfactory reproduce
  - flow dynamics and high flows, but less so the lower percentiles
  - trends in annual flows, winter runoff and high flow, but less so the monthly flows and low extremes
  - Timing, location and area of large-scale droughts, but less so the internal variability and number of events
- The **ensemble mean** performs overall best
  - Large differences are found among models and the use of ensemble techniques is one way to cope with model uncertainty.
  - Care when extrapolating results to regions where the model behaviour can not be assessed due to lack of observations.

Open research Questions

1. Generally, a higher confidence in model simulations should be sought through validation.
   - What is the best approach to validate large-scale models?
   - And what sort of data are preferable?
2. How to improve model representation of low flow and drought situations?
3. How to encourage data sharing and long-term international collaboration within the climate and hydrology community?

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