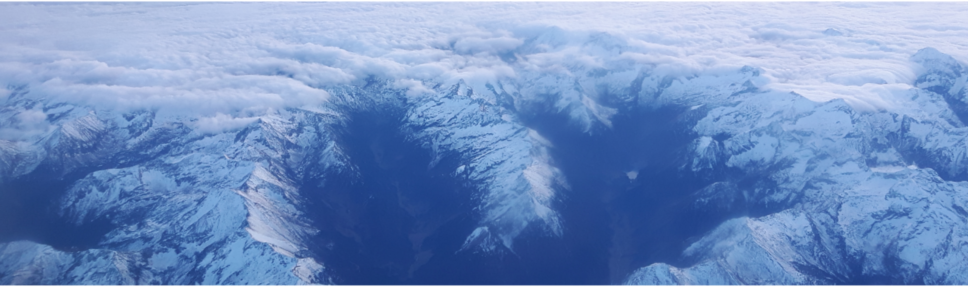


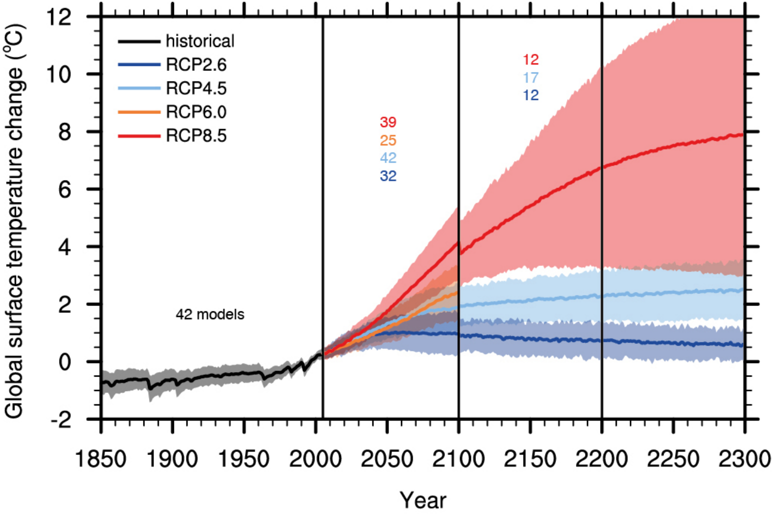
# Evaluation of Regional Climate Projections

Douglas Maraun
Wegener Center for Climate and Global Change, University of Graz

# Outline

- Uncertainties
- Evaluation Framework
- Dynamical Model Performance
- Statistical Downscaling Performance
- Practical Guidelines

# Projected global mean temperature




*Collins et al., IPCC, 2013*

# Sources of Uncertainty

**Forcing Uncertainty**

- greenhouse gas emissions
- other anthropogenic forcings
- natural forcings

**Model Imperfections**

- model inadequacies (processes misrepresented or missing)
- model uncertainty (choice of parameters, parameterisations)

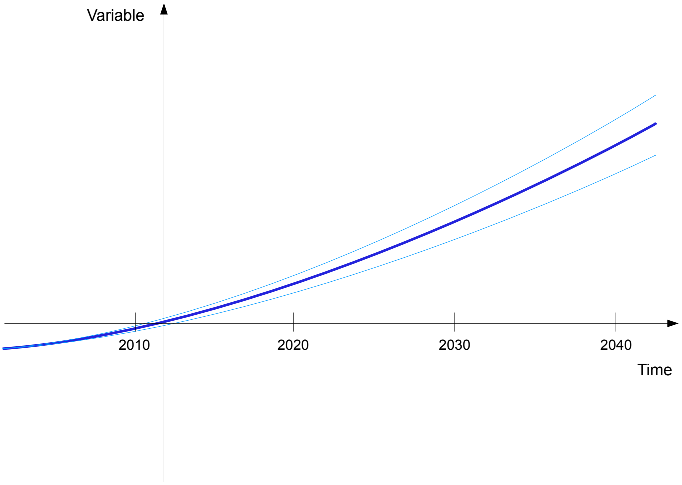
**Internal Climate Variability**

- Random fluctuations on scales from days to centuries

Model ensembles are required to sample uncertainties!

# The Role of Internal Climate Variability

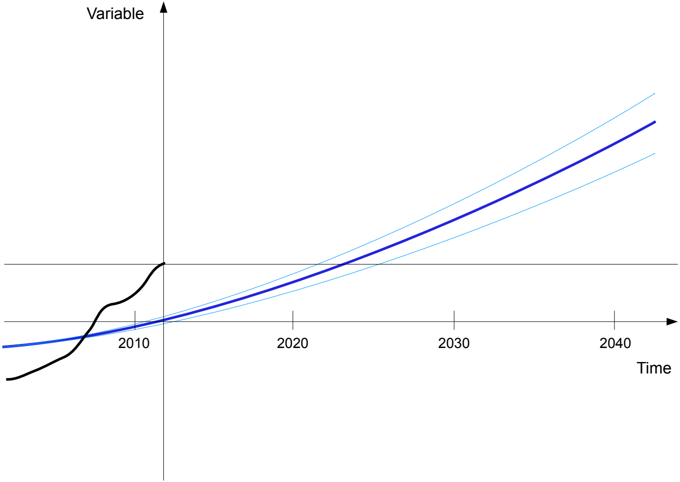
forced signal



# The Role of Internal Climate Variability

forced signal

observed series,
decadal scale

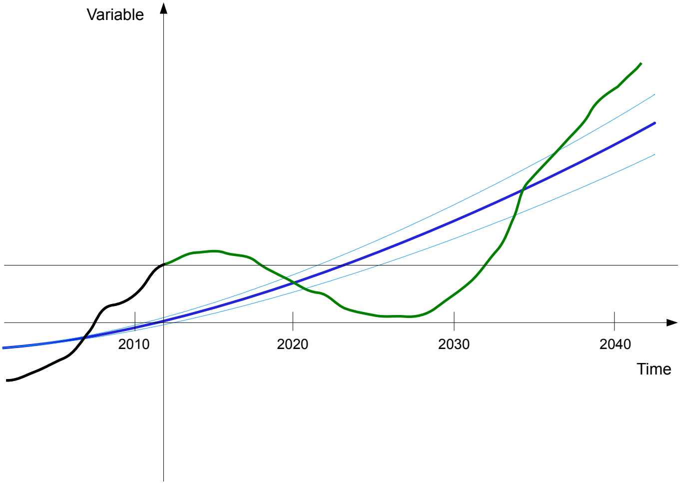


# The Role of Internal Climate Variability

forced signal

observed series,
decadal scale

possible future



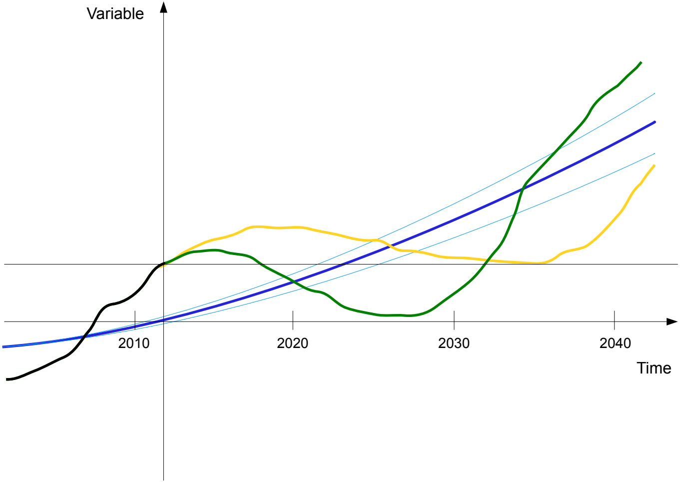
# The Role of Internal Climate Variability

forced signal

observed series,
decadal scale

possible future

possible future



# The Role of Internal Climate Variability

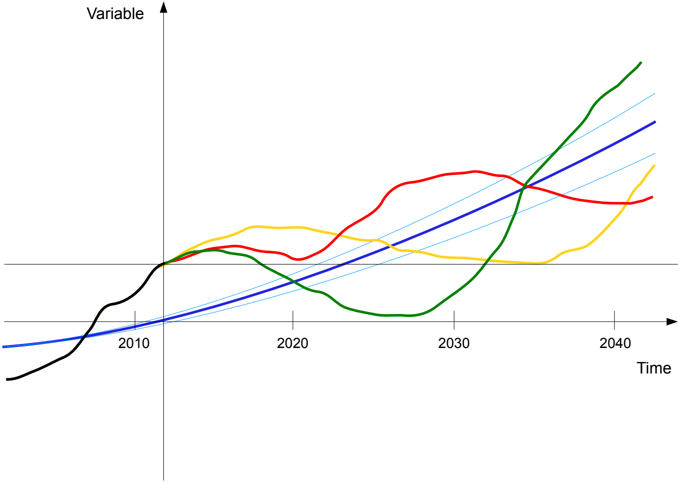
forced signal

observed series,
decadal scale

possible future

possible future

possible future



# The Role of Internal Climate Variability

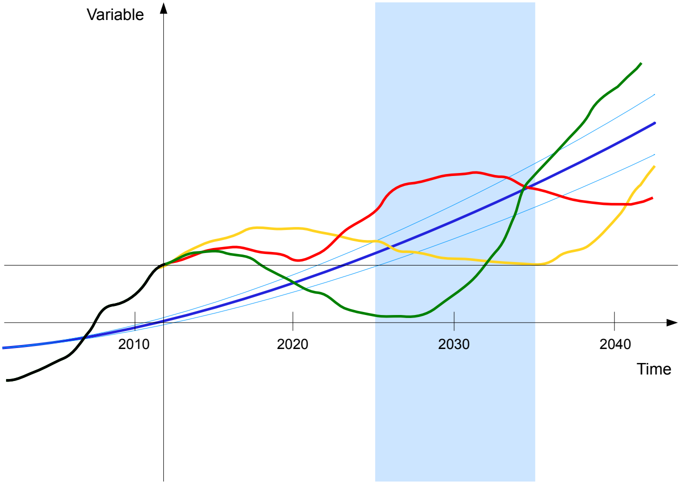
forced signal

observed series, decadal scale

possible future

possible future

possible future



# The Role of Internal Climate Variability

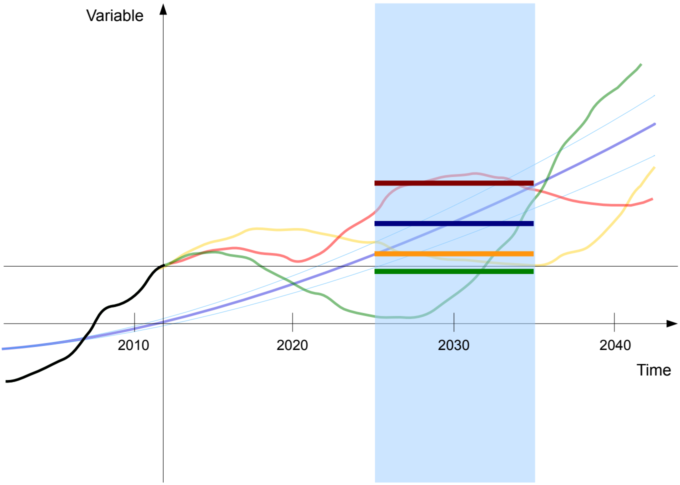
forced signal

observed series,
decadal scale

possible future

possible future

possible future



# The Role of Internal Climate Variability

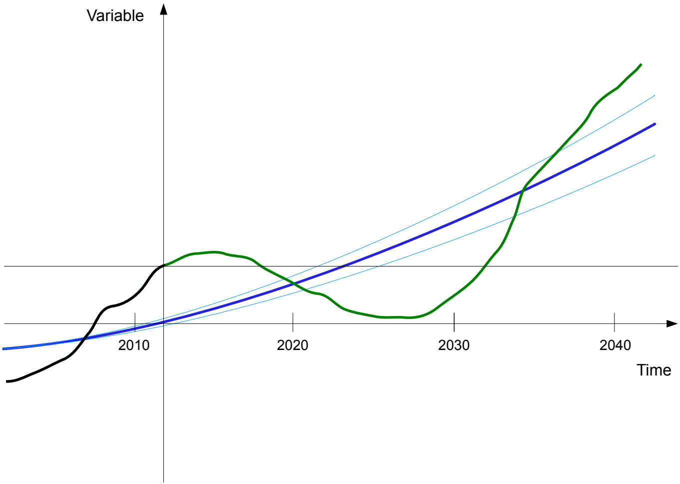
forced signal

observed series,
decadal scale

possible future

possible future

possible future



# The Role of Internal Climate Variability

forced signal

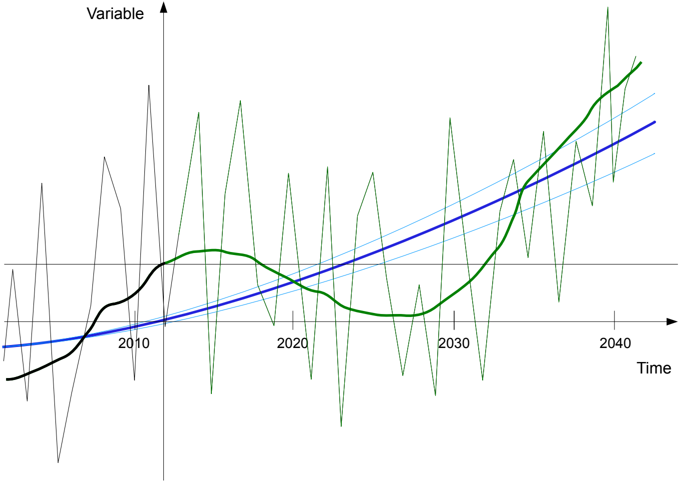
observed series,
decadal scale

possible future

possible future

possible future

observed series,
annual scale



# Representativness and Deep Uncertainty

Does the climate model represent the processes of interest?

- A GCM does not simulate local precipitation extremes
- A GCM does not simulate local elevation dependent warming
- Many GCMs do not realistically simulate monsoonal precipitation

Here, the **simulated uncertainties** (from an ensemble) do not represent **real uncertainties.** The missing uncertainties are **deep uncertainties**.

Climate projections should not be interpreted as reliable probabilistic projections! They at best represent **credible** simulations of future climate

Uncertainties

## Evaluation Framework

Dynamical Model Performance

Statistical Downscaling Performance

Practical Guidelines

# Framework paper

www.value-cost.eu

AGU PUBLICATIONS

Earth's Future

**RESEARCH ARTICLE**

10.1002/2014EF000259

## VALUE: A framework to validate downscaling approaches for climate change studies

**Douglas Maraun[1], Martin Widmann[2], José M. Gutiérrez[3], Sven Kotlarski[4], Richard E. Chandler[5], Elke Hertig[6], Joanna Wibig[7], Radan Huth[8], and Renate A.I. Wilcke[9]**

[1]GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany, [2]School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, UK, [3]Institute of Physics of Cantabria, IFCA, Santander, Spain, [4]Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland, [5]Department of Statistical Science, University College London, London, UK, [6]Institute of Geography, University of Augsburg, Augsburg, Germany, [7]Department of Meteorology and Climatology, University of Lodz, Lodz, Poland, [8]Department of Physical Geography and Geoecology, Faculty of Science, Charles University and Institute of Atmospheric Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic, [9]Rossby Centre, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden

**Key Points:**

- VALUE has developed a framework to validate and compare downscaling methods
- The experiments comprise different observed and pseudo-reality reference data
- The framework is the basis for a comprehensive downscaling comparison study

**Corresponding author:**
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# Key questions

## for regional climate change researcg

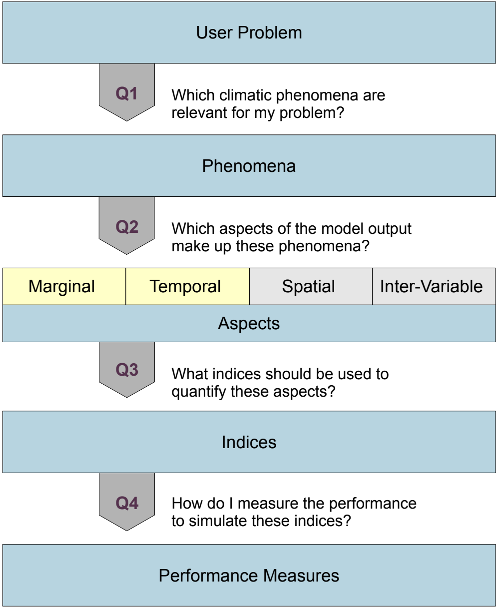
- How well do GCMs simulate the input for regional climate change projections?
- How well do downscaling methods work, in particular under climate change?
- How strong is the signal-to-noise ratio between climate change trends and internal climate variability at regional scales?

*Maraun et al., Earth's Future, 2015*

Evaluation Framework

Evaluation Diagnostics

# Validation tree



# Examples of Indices and Performance Measures

www.value-cost.eu/reports

## Marginal Distributions

| Index | Performance Measure |
|---|---|
| Mean, Variance, 98% Percentile | (relative) bias |

## Temporal Dependence

| Index | Performance Measure |
|---|---|
| Spell statistics | Bias |

## Spatial Dependence

| Index | Performance Measure |
|---|---|
| Decay lengths of correlation/tail dependence | (relative) bias |

## Multivariate Dependence

| Index | Performance Measure |
|---|---|
| Joint threshold exceedances | (relative) bias |
| Variable conditioned on large-scale circulation | (relative) bias |

# Evaluation Framework

## Standard Evaluation Experiments

# Standard Evaluation Experiments

- **Perfect Predictor**
  Predictors/boundary conditions from ERA-Interim Reanalysis
  What is the downscaling skill?

- **GCM-Predictors**
  Predictors/boundary conditions from global climate models
  What is the overall skill of the regional simulation?

# Evaluation Framework
## Trend Evaluation Experiments

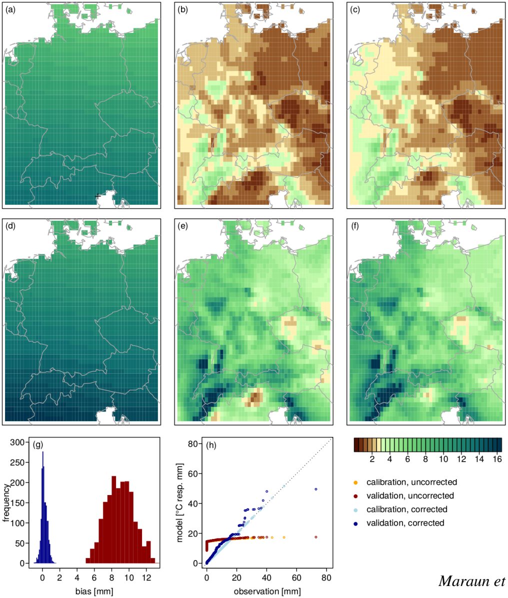
# Trend Evaluation

- **Perfect Predictor**
  Predictors/boundary conditions from reanalysis
  What is the skill of the downscaling approach to capture observed trends?
- **GCM-Predictors**
  Predictors/boundary conditions from global climate models
  What is the overall skill to capture observed trends?
- **Pseudo-Reality**
  Predictors/boundary conditions from global climate models
  What is the downscaling skill to capture simulated future trends?
- **Credibility of GCM and RCM Projections**
  How realistic are large- and local-scale processes controlling climate change, how credible are thus the predictors?

# Evaluation Framework

## Evaluation of Bias Correction Methods

# Validation Problem

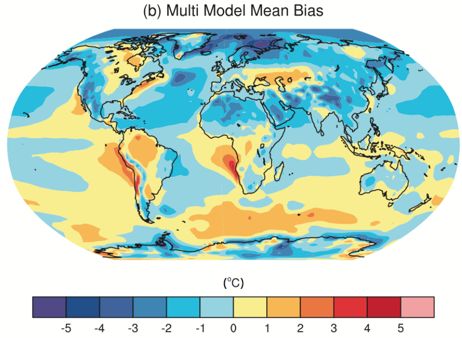


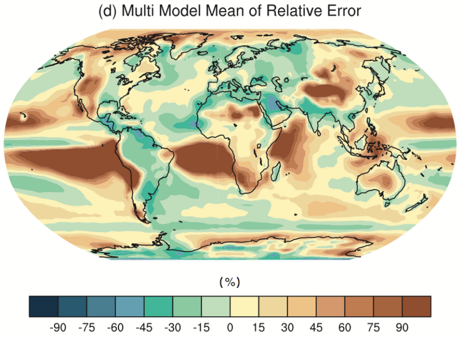

*Maraun et al., in revision*

# Dynamical Model Performance
## Large-Scale Errors

# Temperature and precipitation biases

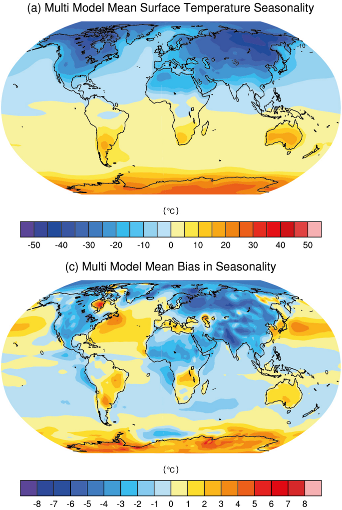
## CMIP5, multi-model mean



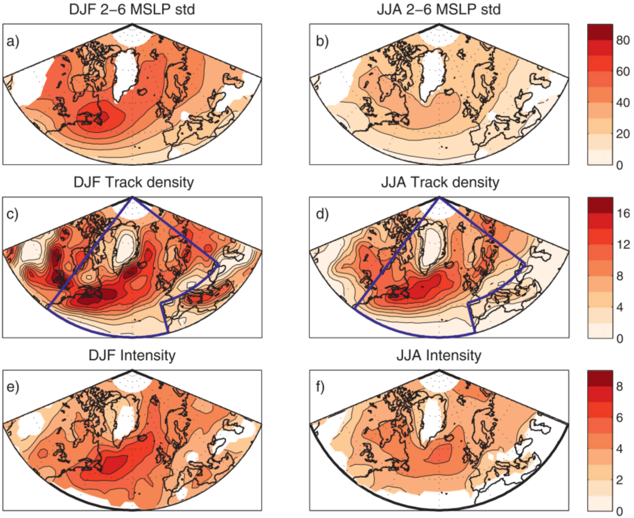

*Flato et al., IPCC AR5, 2013*

# Temperature seasonality



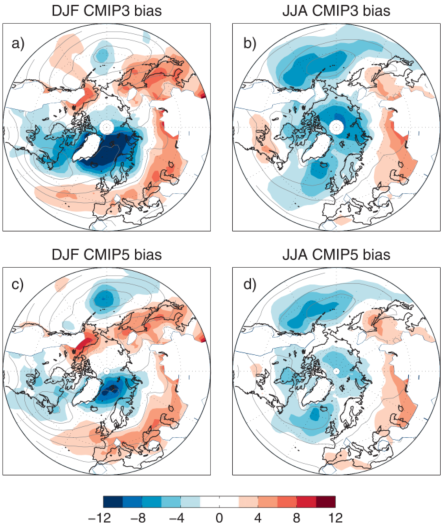

*Flato et al., IPCC, 2013*

# Observed storm track (ERA-Interim)



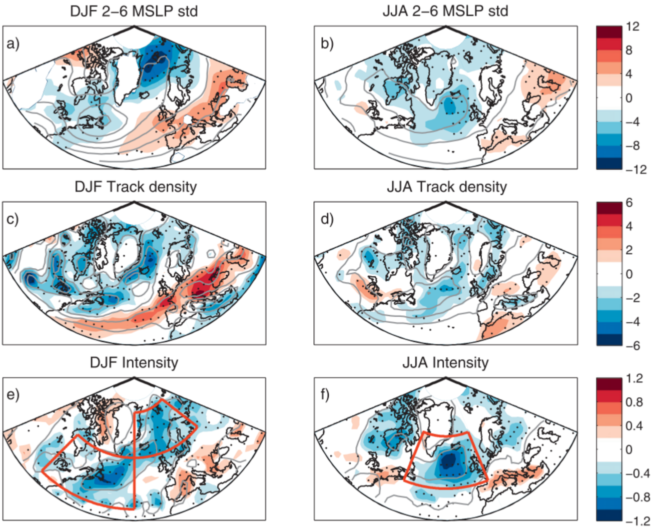

*Zappa et al., J. Climate, 2013*

# Mean bias (2-6 day MSLP sdtdv)



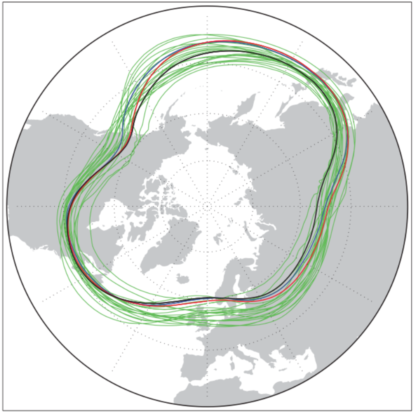

*Zappa et al., J. Climate, 2013*

# Mean bias (CMIP5)




*Zappa et al., J. Climate, 2013*

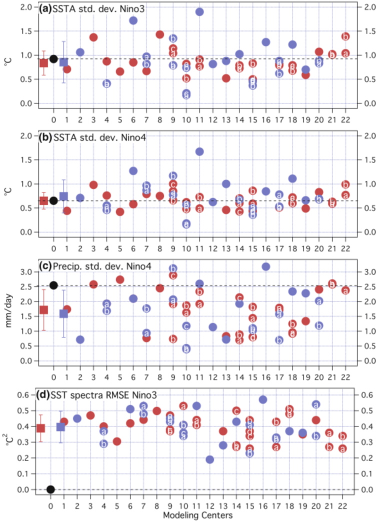
# Displaced storm tracks



black: ERA40; green: CMIP3 models; red, blue: two high resolution models

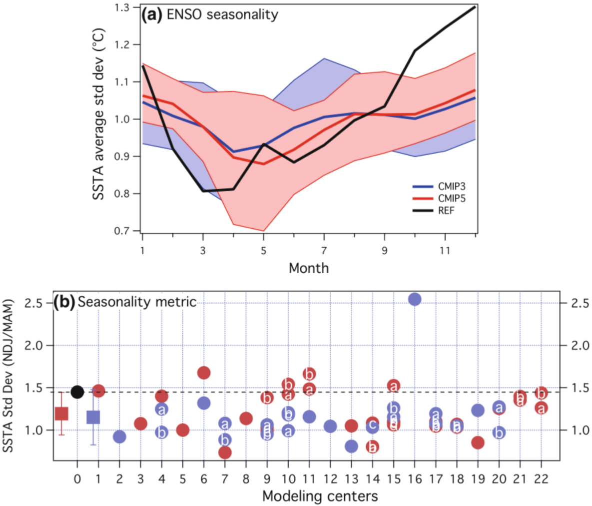
*Woollings, Phil Trans R. Soc, 2010*

# ENSO SST variability



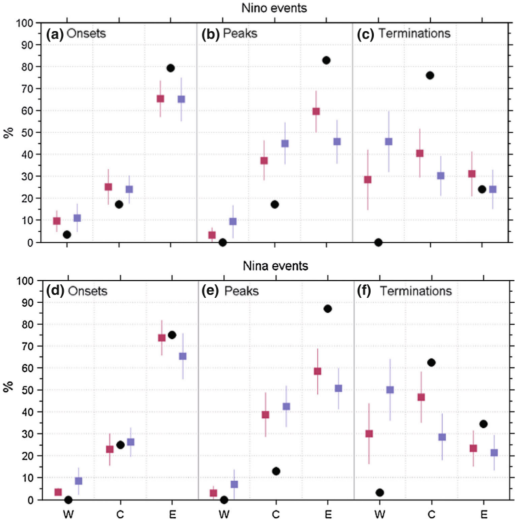

*Bellenger et al., Clim. Dynam., 2014*

# ENSO seasonality



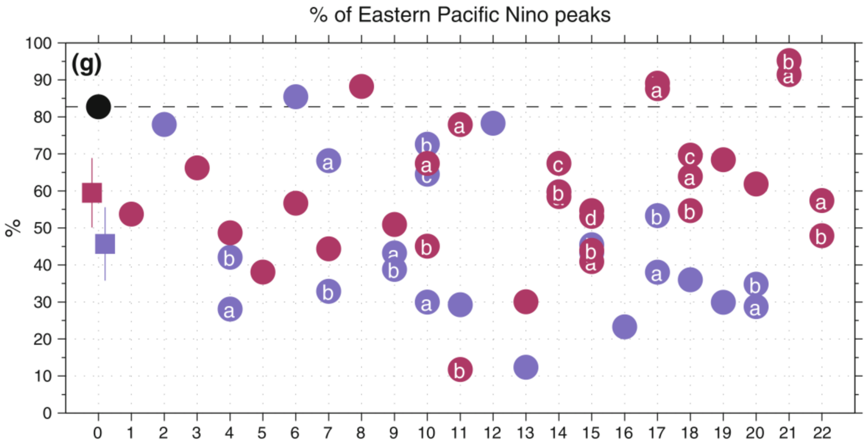

*Bellenger et al., Clim. Dynam., 2014*

# ENSO timing



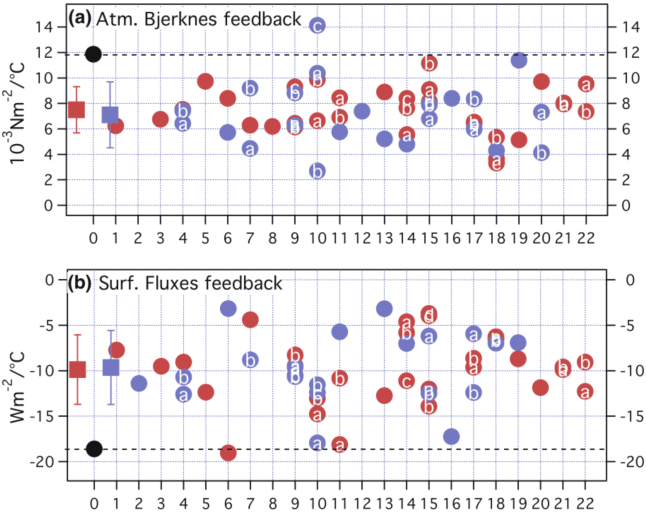

*Bellenger et al., Clim. Dynam., 2014*

# Eastern Pacific ENSOs



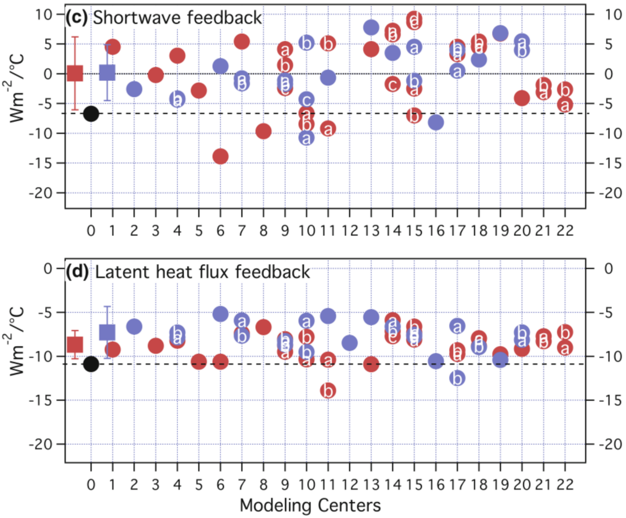

*Bellenger et al., Clim. Dynam., 2014*

# ENSO feedbacks



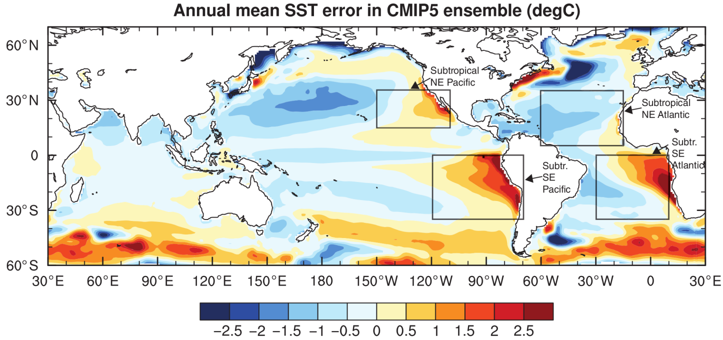

*Bellenger et al., Clim. Dynam., 2014*

# ENSO feedbacks



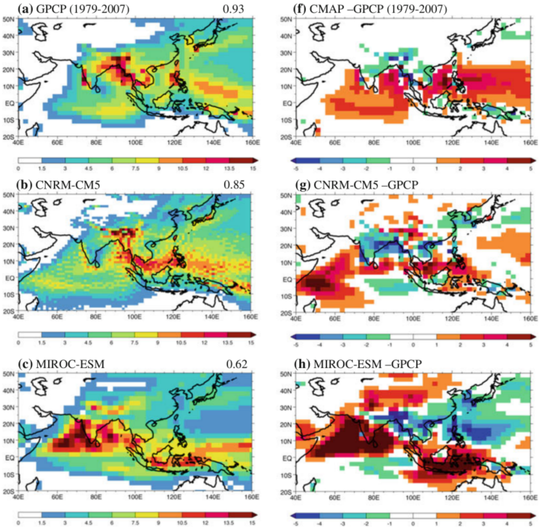

*Bellenger et al., Clim. Dynam., 2014*

# Eastern Tropical Oceans



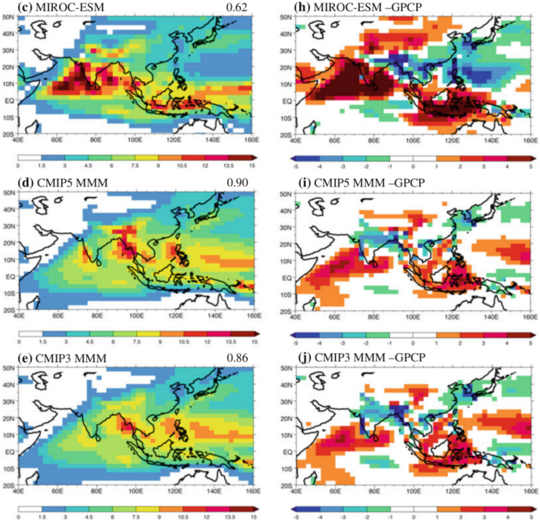

*Richter, WIRES, 2015*

# South Asian Monsoon intensity



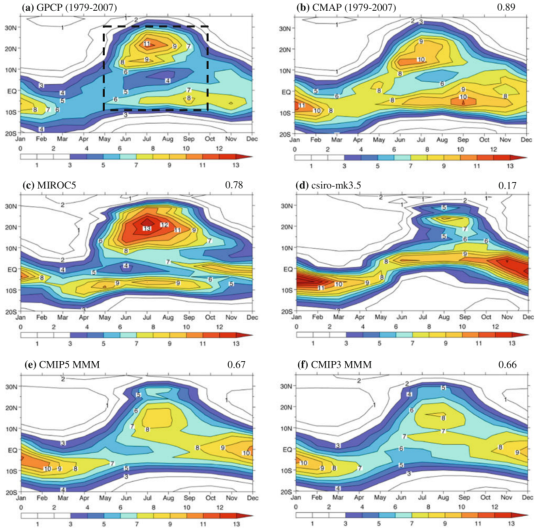

*Sperber et al., Clim. Dynam., 2013*

# South Asian Monsoon intensity



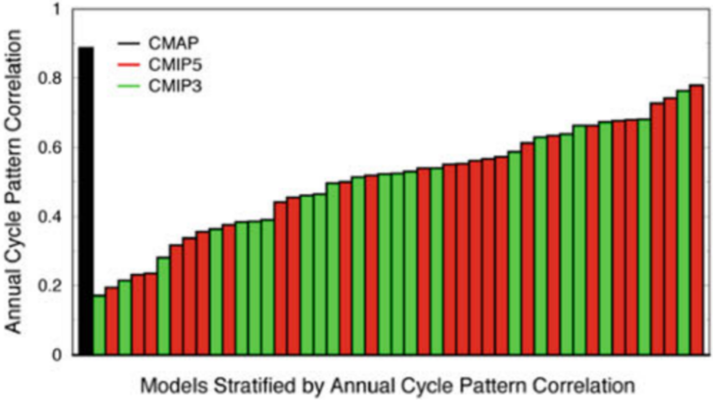

*Sperber et al., Clim. Dynam., 2013*

# Monsoon seasonality




*Sperber et al., Clim. Dynam., 2013*

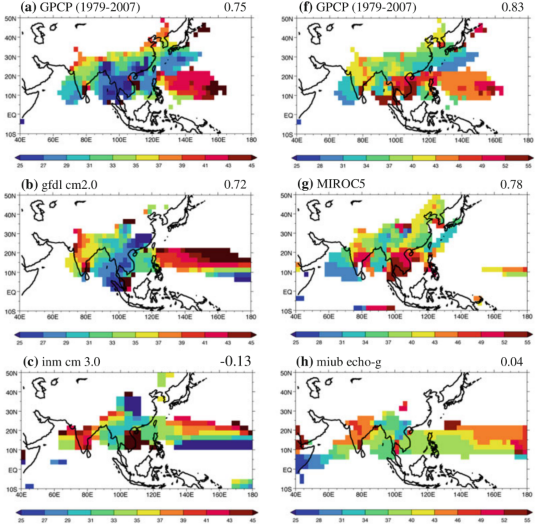
# Monsoon pattern agreement




*Sperber et al., Clim. Dynam., 2013*

# Monsoon Onset and Peak

## Number of 5-day period for onset (left) and peak (right)




*Sperber et al., Clim. Dynam., 2013*

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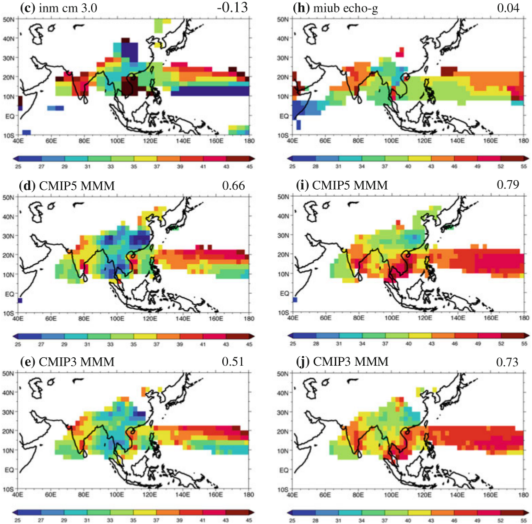
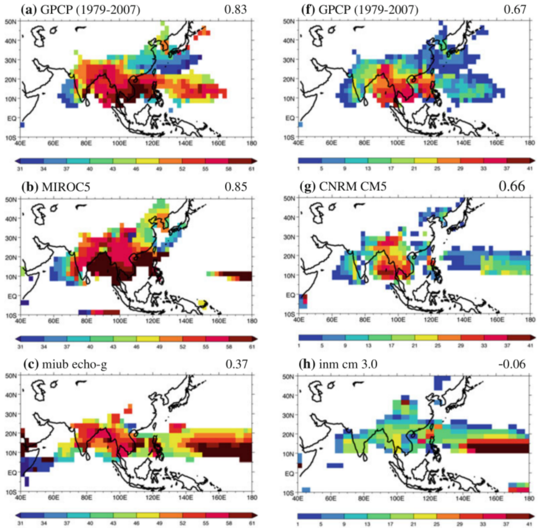



*Sperber et al., Clim. Dynam., 2013*

# Monsoon Withdrawal and Duration

## Number of 5-day period for withdrawal (left) and length in 5-day periods (right)




*Sperber et al., Clim. Dynam., 2013*

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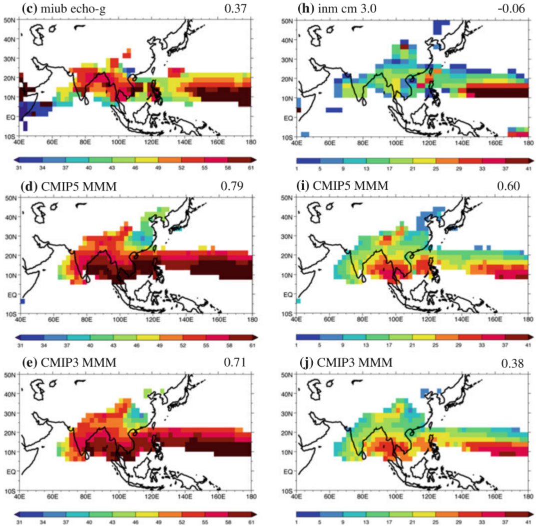
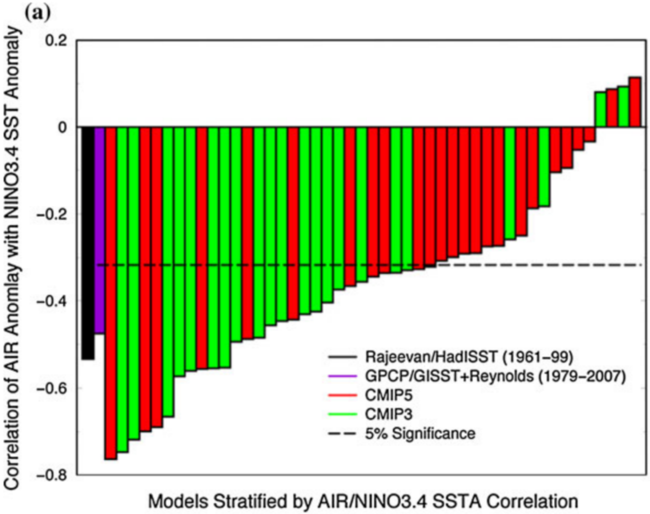



*Sperber et al., Clim. Dynam., 2013*

# ENSO-Monsoon teleconnection




*Sperber et al., Clim. Dynam., 2013*

# Dynamical Model Performance
## Regional- and Local-Scale Errors

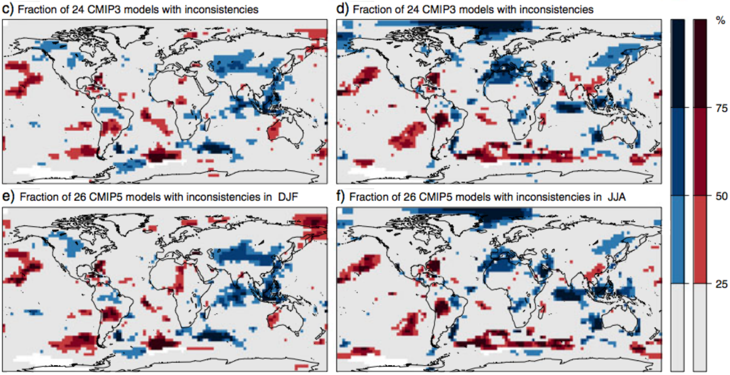
# Regional Errors and Uncertainties

- Mesoscale circulation in mountain regions
- Soil moisture temperature and precipitation feedbacks
- Snow albedo feedbacks
- Extreme convective precipitation

# Dynamical Model Performance
## Representation of Observed Trends

# GCM vs. Observed Trends

Inconsistencies between model and observed trends, mean temperature; top: CMIP5, bottom: CMPI3; left: DJF, right: JJA.




*Bhend & Whetton, Clim. Change, 2013*

Uncertainties

Evaluation Framework

Dynamical Model Performance

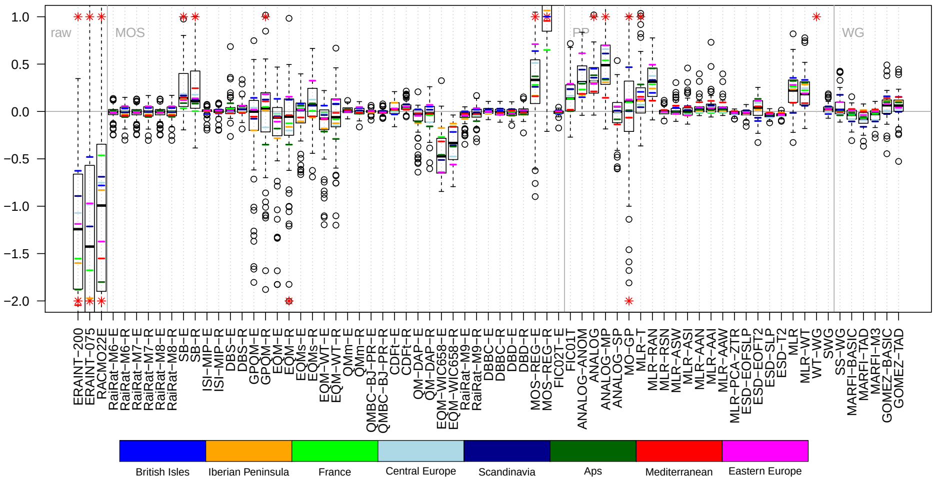
## Statistical Downscaling Performance

Practical Guidelines

## Statistical Downscaling Performance
### Temperature

# Tmax - mean, winter (DJF)

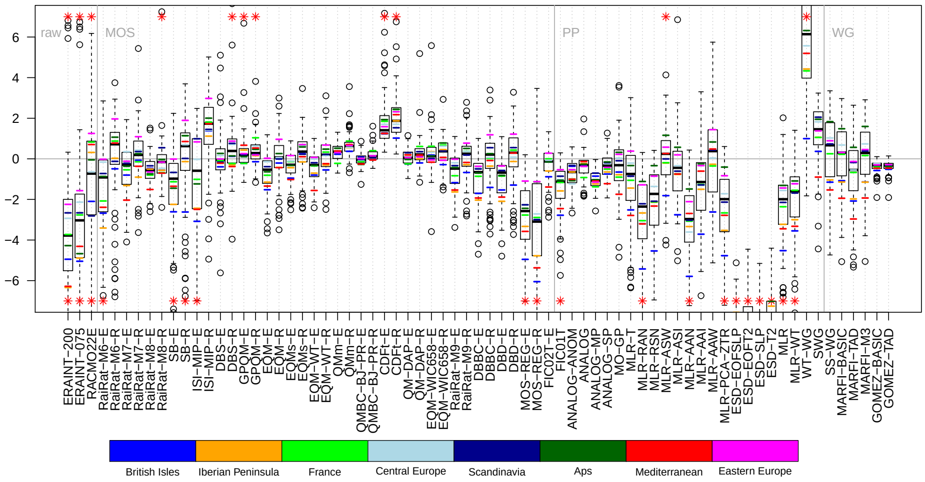
## Biases across all stations [°C]




* values outside plotted range

# Tmax - 20 season return level, summer (JJA)

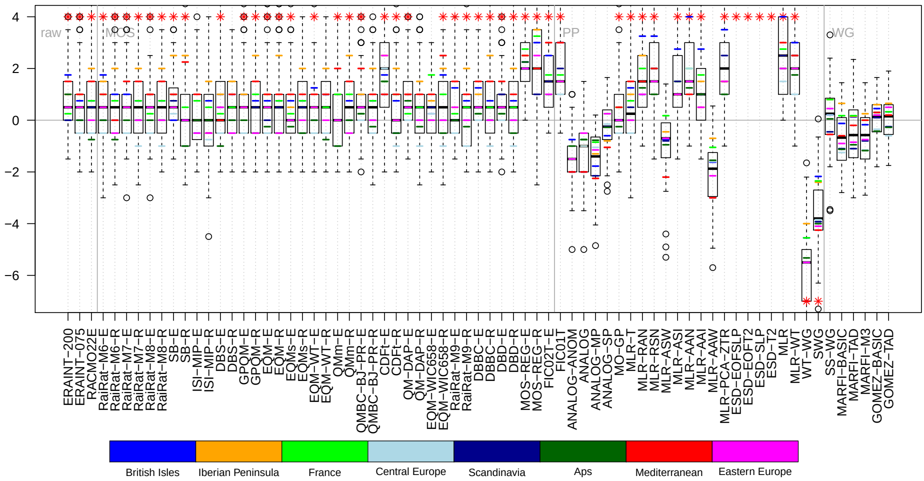
## Biases across all stations [°C]




* values outside plotted range

# Tmax - mean annual maximum warm spell

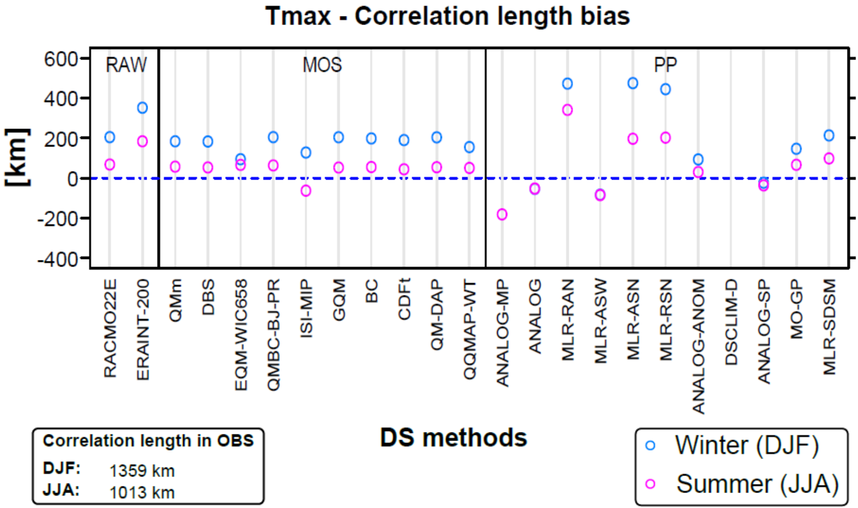
## Biases across all stations [days]




* values outside plotted range

# Temperature - de-correlation length

## Biases across all stations



# Temperature Summary

| Aspect | MOS | | | | PP | | | | WG[1] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BC | QM emp. | QM para. | QM extreme | REG det. | REG infl. | REG stoch. | ANA SS/MS | RI U SS/MS | RI C SS/MS | POI SS/MS | HM U/C |
| **Temperature, marginal** | | | | | | | | | | | | |
| mean | + | + | + | + | + | + | + | ○ | + | + | + | + |
| variance | ○ | + | + | + | - | ○ | + | ○ | + | + | + | + |
| extremes[2] | ○ | + | + | + | - | ○ | + | + | + | + | + | + |
| **Temperature, temporal variability** | | | | | | | | | | | | |
| autocorrelation | + | + | + | + | + | + | - | - | + | + | + | + |
| mean spells | + | + | + | + | ○ | ○ | - | - | + | + | + | + |
| extreme spells | + | + | + | + | + | + | - | ○ | + | + | + | + |
| interannual variance | + | ○ | ○ | ○ | - | ○ | - | - | - | ○ | - | -/○ |
| climate change | + | ○ | ○ | ○ | + | - | + | - | + | + | + | + |
| **Temperature, spatial variability** | | | | | | | | | | | | |
| means | + | + | + | + | ○ | ○ | - | -/+ | -/? | -/? | -/? | ? |
| extremes | + | + | + | + | - | - | - | -/+ | -/? | -/? | -/? | ? |

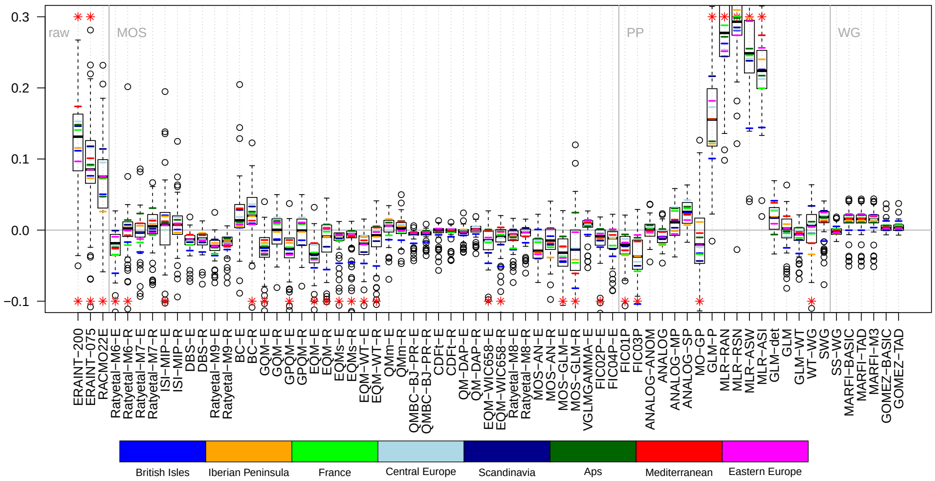
[1] We consider standard WGs with Gaussian distribution for temperature.

[2] We consider extreme events within the range of observed values. No extrapolation is assessed.

# Statistical Downscaling Performance
## Precipitation

# Precipitation - wet day probability, winter (DJF)

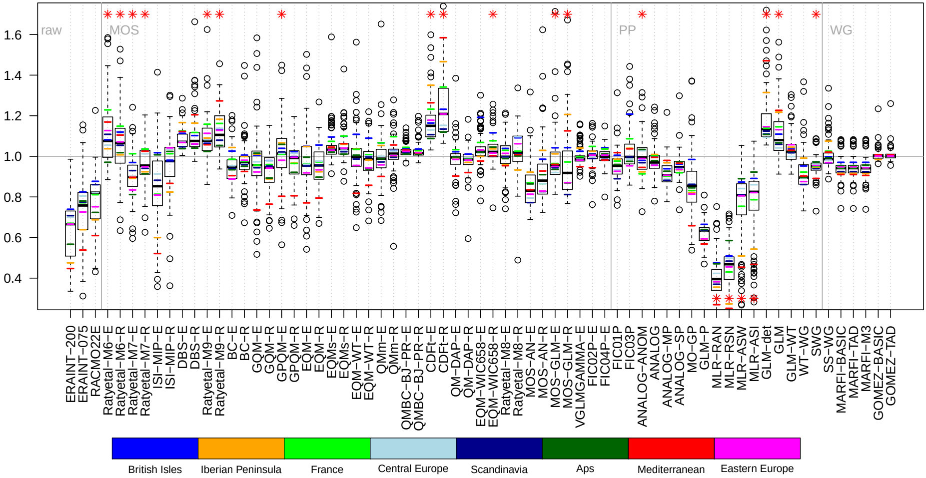
## Biases across all stations




* values outside plotted range

# Precipitation - intensity, summer (JJA)

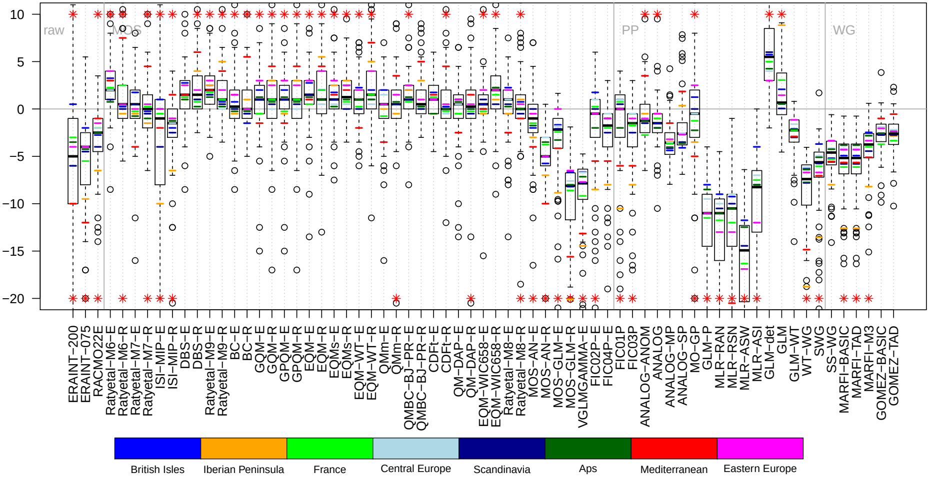
## Relative errors across all stations [mm/wet day]




* values outside plotted range

# Precipitation - mean annual maximum dry spell

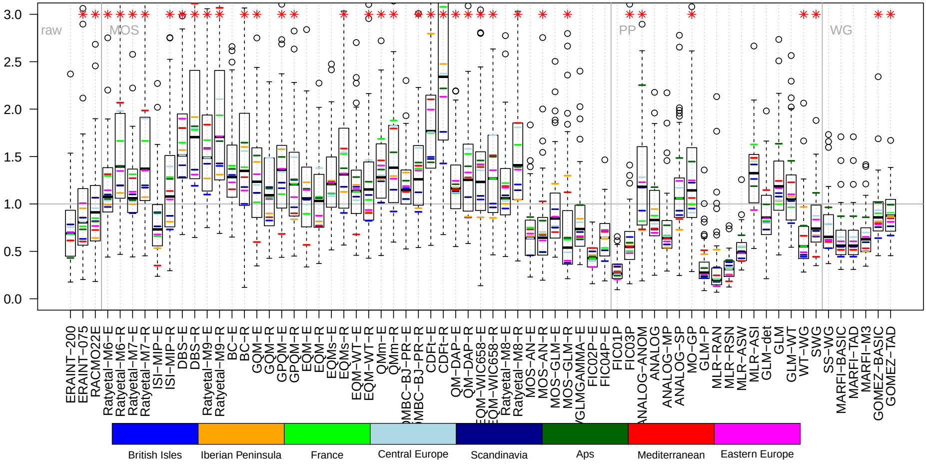
## Biases across all stations [days]




* values outside plotted range

# Precipitation - interannual variability, summer

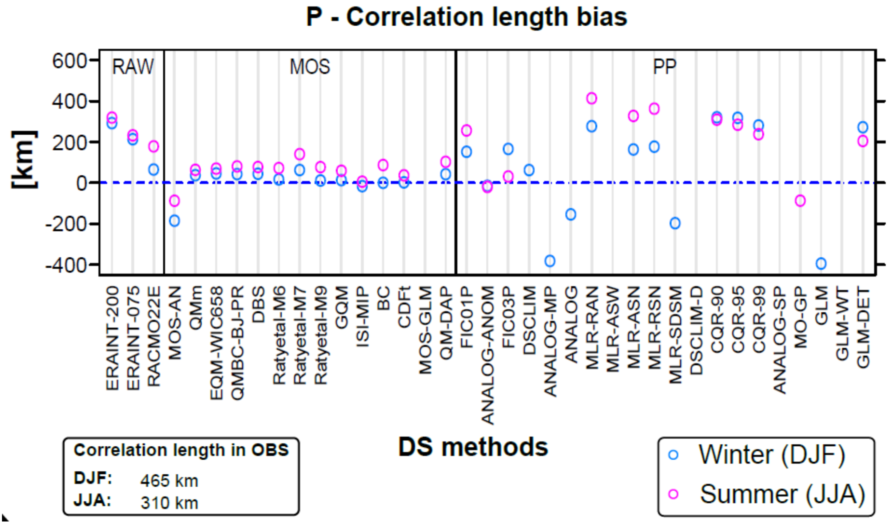
## Relative errors across all stations




* values outside plotted range

# Precipitation - de-correlation length

## Biases across all stations



# Precipitation Summary

| Aspect | MOS | | | | PP | | | | WG[3] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BC | QM emp. | QM para. | QM extreme | REG det. | REG infl. | REG stoch. | ANA SS/MS | RI U SS/MS | RI C SS/MS | POI SS/MS | HM U/C |
| **Precipitation, marginal** | | | | | | | | | | | | |
| wet-day probabilities | + | + | + | + | - | - | + | + | + | + | + | + |
| mean intensity | + | + | + | + | - | - | + | + | + | + | + | + |
| extremes[b] | ○ | + | ○ | + | - | - | + | + | ○ | ○ | ○ | ○ |
| **Precipitation, temporal variability** | | | | | | | | | | | | |
| transition probabilities | ○ | + | + | + | - | - | + | + | + | + | + | + |
| mean spells | ○ | + | + | + | - | - | + | + | ○ | + | ○ | ○/+ |
| extreme spells | + | + | + | + | - | - | + | + | - | ○ | - | -/○ |
| interannual variance | + | ○ | ○ | ○ | - | ○ | ○ | ○ | - | ○ | - | -/○ |
| climate change | + | ○ | ○ | ○ | + | - | + | ○ | + | + | + | + |
| **Precipitation, spatial variability** | | | | | | | | | | | | |
| means | ○ | + | + | + | - | - | - | -/+ | -/○ | -/○ | -/○ | ○ |
| extremes | ○ | ○ | ○ | ○ | - | - | - | -/+ | -/? | -/? | -/? | ? |
| **Multivariable** | | | | | | | | | | | | |
| bulk | + | + | + | + | - | - | - | + | + | + | + | + |

[3] We consider standard WGs with gamma distribution for precipitation.

Uncertainties

Evaluation Framework

Dynamical Model Performance

Statistical Downscaling Performance

## Practical Guidelines

# Assessing the Relevance of Climate Change

- **Is climate change a relevant factor?**
  Socio-economic or environmental factors might dominate over the influence of climate change in a given context.

- **Is climate information relevant?**
  Decision makers may be able to sufficiently reduce vulnerability to climate change by implementing low regret measures. In some cases, adaptation measures can be designed to be easily extendable.

# Assessing the Climate Information Requirements

- **Understanding the Spatial-Temporal Scales of the Impact:** what are the relevant impact processes and their characteristic time and space-scales (might be different from the input resolution of the chosen impact model).
- **Understanding the Relevant Climatic Phenomena:** different meteorological and climatic phenomena, spanning a wide range of scales, might control the considered impact.

# Choosing the Driving GCMs

**Select GCMs that**

- well represent the relevant large-scale processes and their response to climate change
- have no major location biases of the large-scale circulation
- span the range of uncertainty in global climate sensitivity

# Choosing the Downscaling and Bias Correction Options

- **Is Downscaling Required?**
  Do the driving GCMs represent the relevant climate phenomena at the scale of interest?

- **Is Dynamical Downscaling Required?**
  Is bias correction sufficient? Can PP statistical downscaling be used instead of dynamical downscaling?
  Dynamical downscaling may be required if local feedbacks or small-scale processes are important.
- **Choosing the Statistical Downscaling Method**
  Determined by the desired statistical climate aspects (see summary tables in previous section). Select methods that provide **salient information.**

## Resources:


- www.value-cost.eu
- Maraun et al. (2015): VALUE: A framework to validate downscaling approaches for climate change studies, Earth's Future 3, 1–14, doi:10.1002/2014EF000259.
- Maraun (2016): Bias Correcting Climate Change Simulations - A Critical Review, Curr. Clim. Change. Rep. 2, 211-220, DOI 10.1007/s40641-016-0050-x.
- IPCC (2015): IPCC Workshop on Regional Climate Projections and their Use in Impacts and Risk Analysis Studies, Sao Jose dos Campos, Workshop Report.
- Maraun and Widmann (2017): Statistical Downscaling and Bias Correction for Climate Research, Cambridge University Press.


Thank you for your attention!