Uncertainty on the Impact of Climate Change in Hydrologic Simulations

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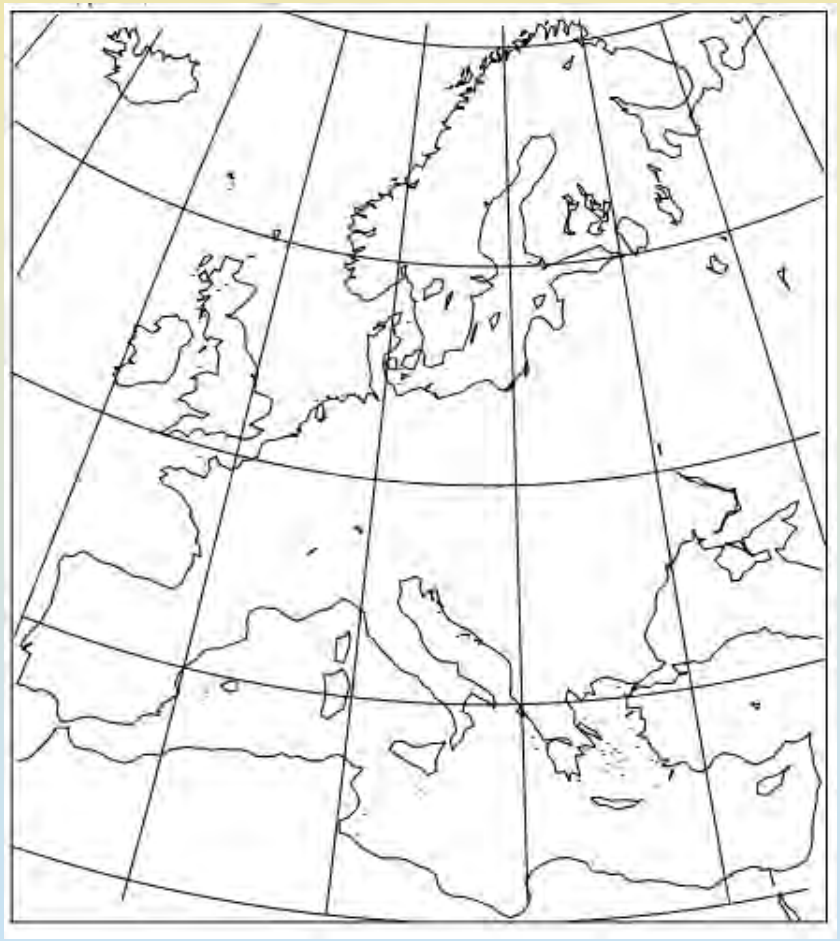
ENSEMBLES RCM Modelling Project



25 km grid

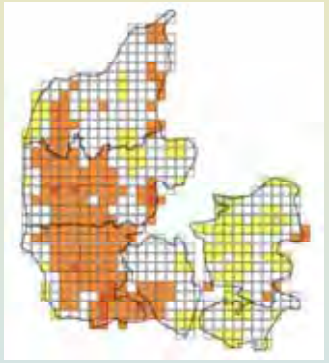
RCM \ GCM	HadCM3	ECHAM5	ARPEGE	BCM2
HadRM3	X			
REMO		X		
RM5.1			X	
HIRHAM5		X	X	X
CLM	X			
RACMO2		X		
RegCM3		X		
RCA3		X		X

Climate model	Organization
GCM	
HadCM3	Met Office Hadley Center (METO-HC), UK
ECHAM5	Max Planck Institute for Meteorology (MPI), Germany
ARPEGE	National Centre of Meteorological Research (CNRM), France
BCM2	Bjerknes Centre for Climate Research (BCCR), Norway
RCM	
HadRM3	Met Office Hadley Center (METO-HC), UK
REMO	Max Planck Institute for Meteorology (MPI)
RM5.1	National Centre of Meteorological Research (CNRM), France
HIRHAM5	Danish Meteorological Institute (DMI)
CLM	Swiss Federal Institute of Technology Zurich (ETHZ)
RACMO2	Royal Netherlands Meteorological Institute (KNMI)
RegCM3	International Centre for Theoretical Physics (ICTP), Italy
RCA3	Swedish Meteorological and Hydrological Institute (SMHI)

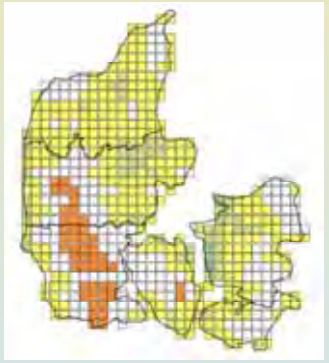
Uncorrected RCM Precpitation Bias

Observed vs. RCM total annual (1991-2010) error (%)

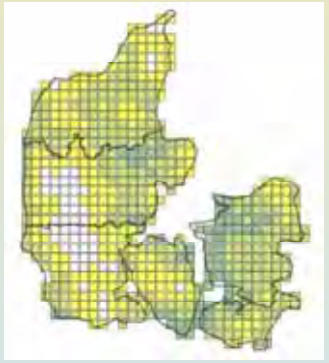
ARPEGE-RM5.1



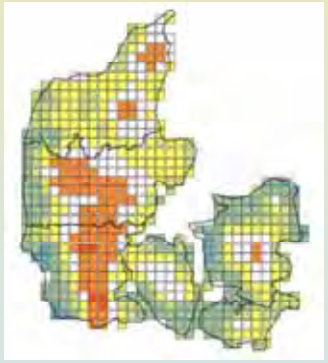
BCM2-RCA3



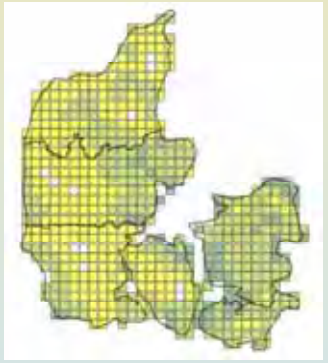
ECHAM5-RCA3



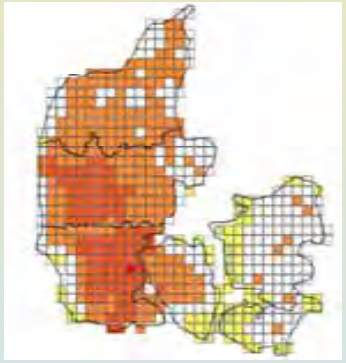
ECHAM5-REMO



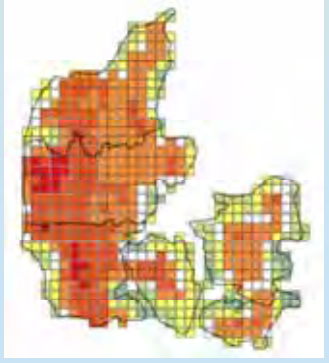
ECHAM5-RegCM3



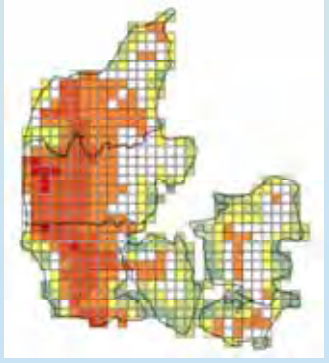
HadCM3-CLM



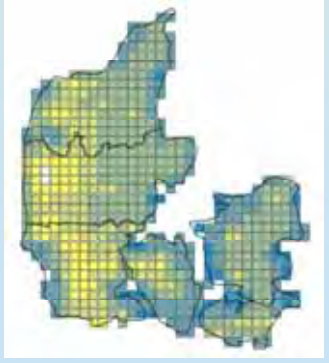
ARPEGE-HIRHAM5



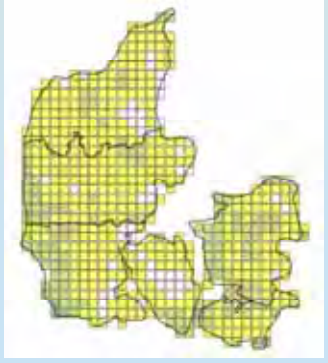
BCM2-HIRHAM5

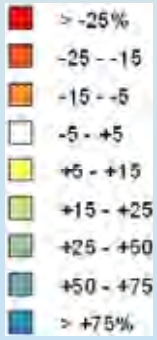


ECHAM5-HIRHAM5

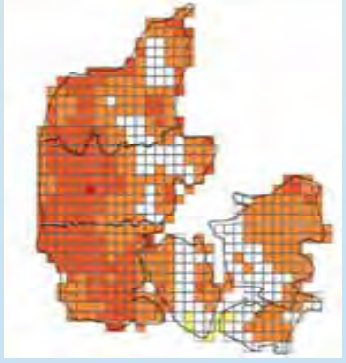


ECHAM5-RACMO2



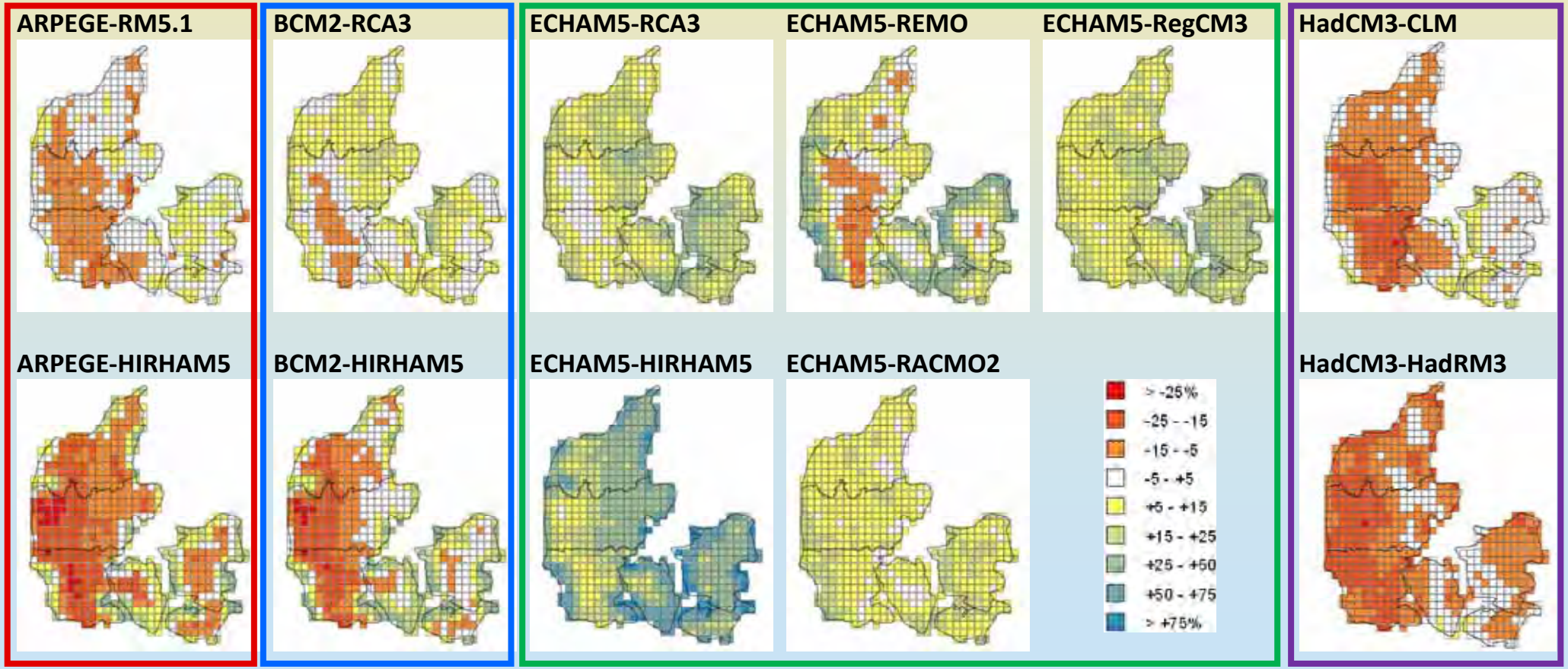


HadCM3-HadRM3



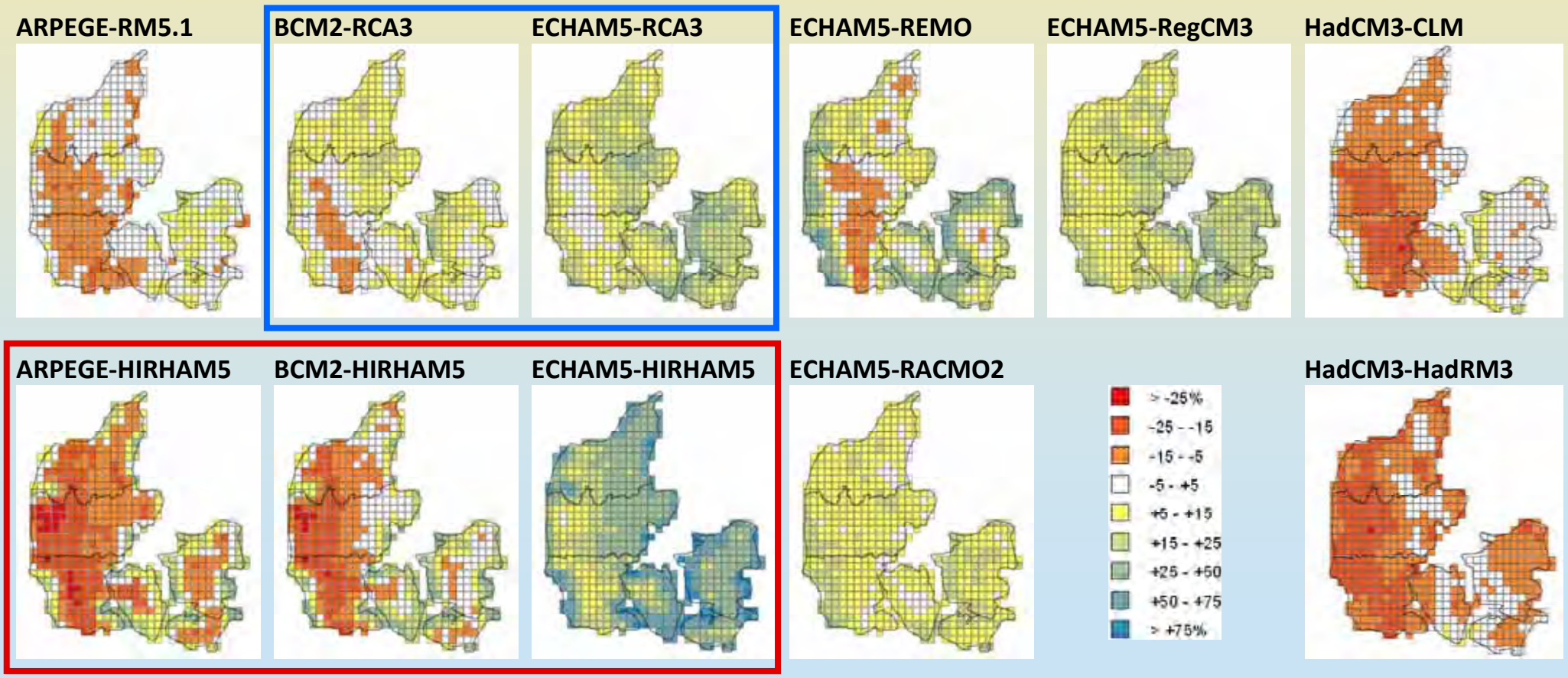
Uncorrected RCM Precpitation Bias

Observed vs. RCM total annual (1991-2010) error (%)

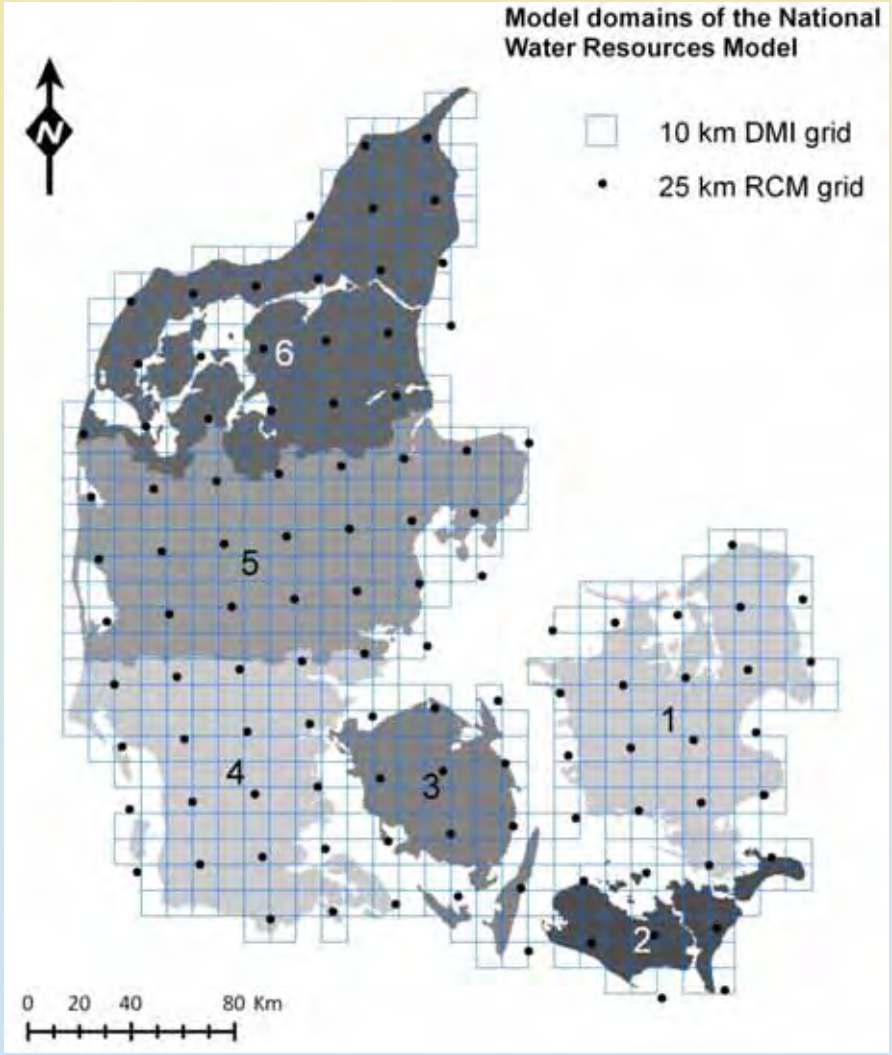


Uncorrected RCM Precpitation Bias

Observed vs. RCM total annual (1991-2010) error (%)



Spatial Scales

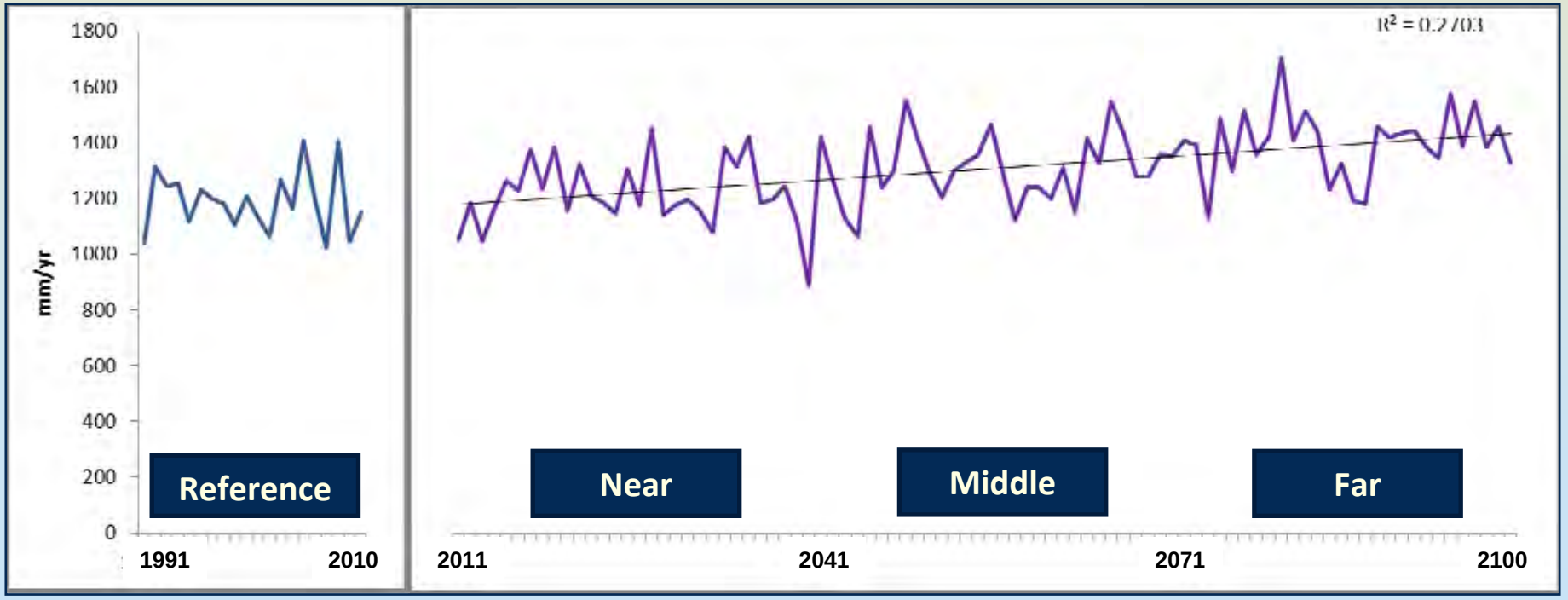


- **DMI Klimagrid (10km)**
- **ENSEMBLES RCM grid (25 km)**
- **Denmark divided into six hydrologically distinct basins**

1. Sjælland (7,163 km^2)
2. Southern Islands (2,042 km^2)
3. Fyn (3,473 km^2)
4. South Jylland (7,897 km^2)
5. Central Jylland (11,578 km^2)
6. North Jylland (9,934 km^2)

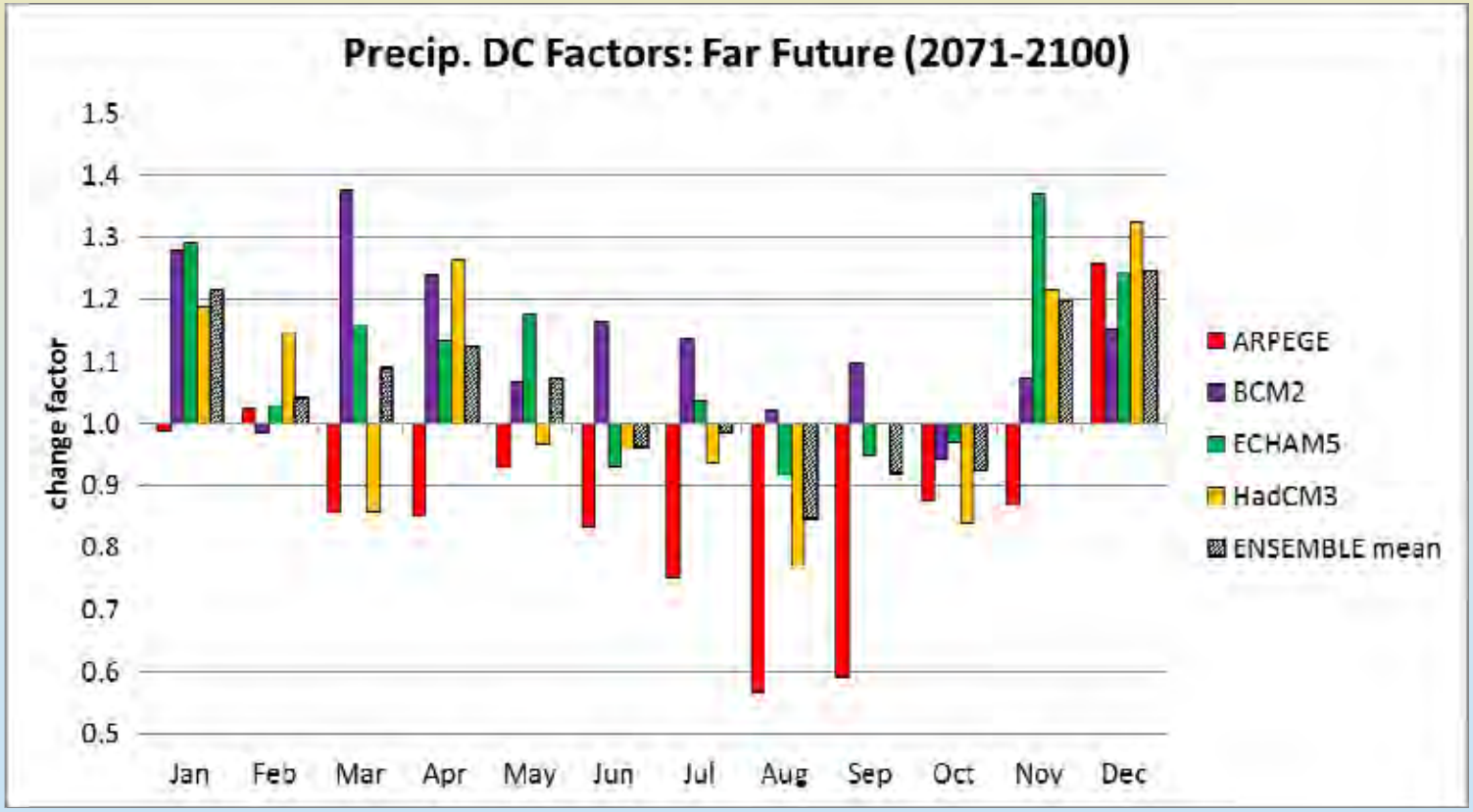
Temporal Scales

Climate Models	past 1961-1990	near 2011-2040	mid 2041-2070	far 2071-2100
Preciptitation (p-values)				
ARPEGE-RM5.1	0.32	0.42	0.22	**0.05**
ARPEGE-HIRHAM5	**0.09**	0.50	**0.08**	**0.00**
BCM2-HIRHAM5	**0.08**	0.26	**0.02**	**0.00**
BCM2-RCA3	0.17	0.05	**0.01**	**0.00**
ECHAM5-HIRHAM5	**0.01**	0.28	**0.00**	**0.00**
ECHAM5-RegCM3	0.43	0.93	0.31	**0.01**
ECHAM5-RACMO2	0.75	0.66	0.13	**0.01**
ECHAM5-REMO	0.23	0.88	0.46	0.13
ECHAM5-RCA3	0.21	0.50	0.17	**0.01**
HadCM3-CLM	0.96	0.17	**0.01**	**0.03**
HadCM3-HadRM3	0.69	0.48	0.23	0.56



Delta Change (DC) Method

$$P_{\Delta}(i,j) = \Delta_P(j) * P_{obs}(i,j) \quad \text{where} \quad \Delta_P(j) = \frac{\overline{P}_{scen}(j)}{\overline{P}_{cont}(j)}$$

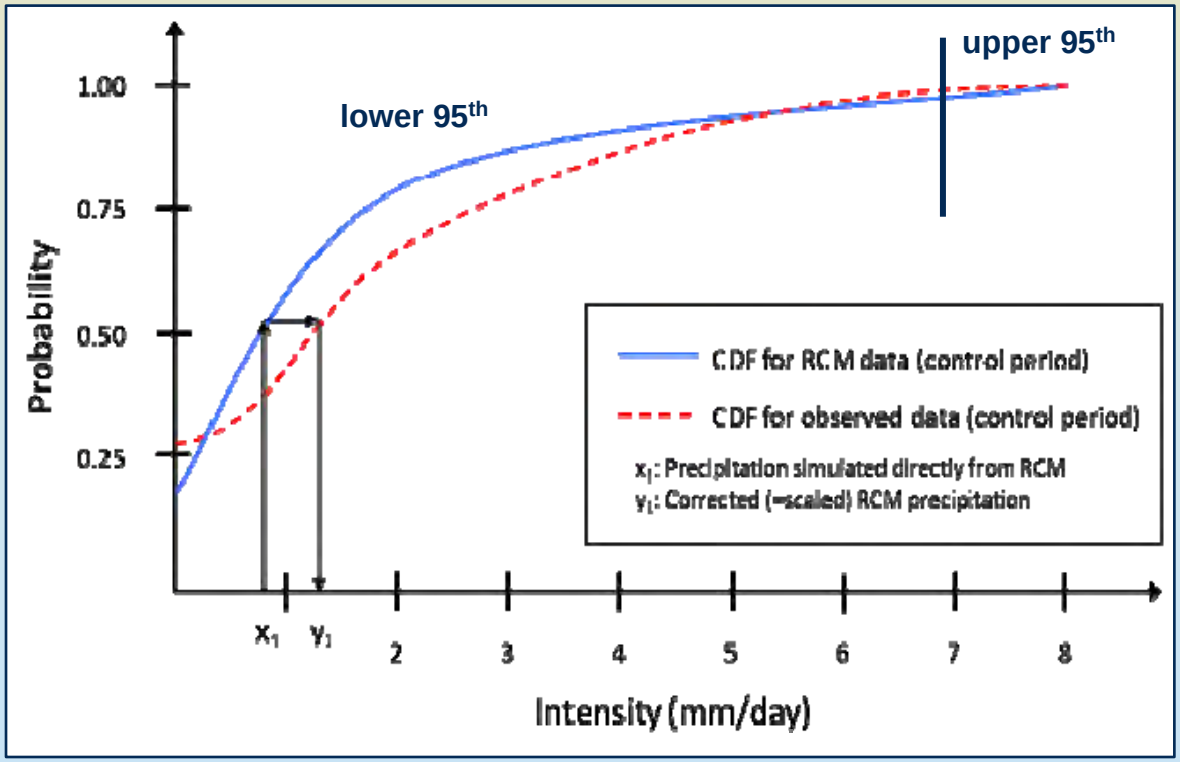


- Compare RCM past with RCM future simulated values
- Perturb mean montly relative change onto observed daily values

Distribution Based Scaling (DBS)

$$f(x) = \frac{(x/\beta)^{\alpha-1}\exp(-x/\beta)}{\beta\Gamma(\alpha)} \quad ; x, \alpha, \beta > 0$$

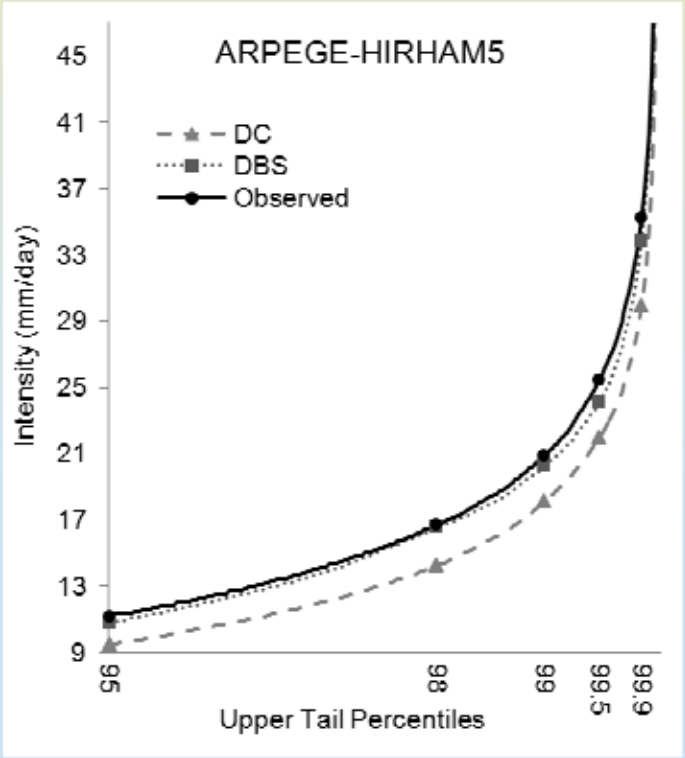
where x is precipitation, α and β are shape and scale parameters, and Γ(α) is the gamma function

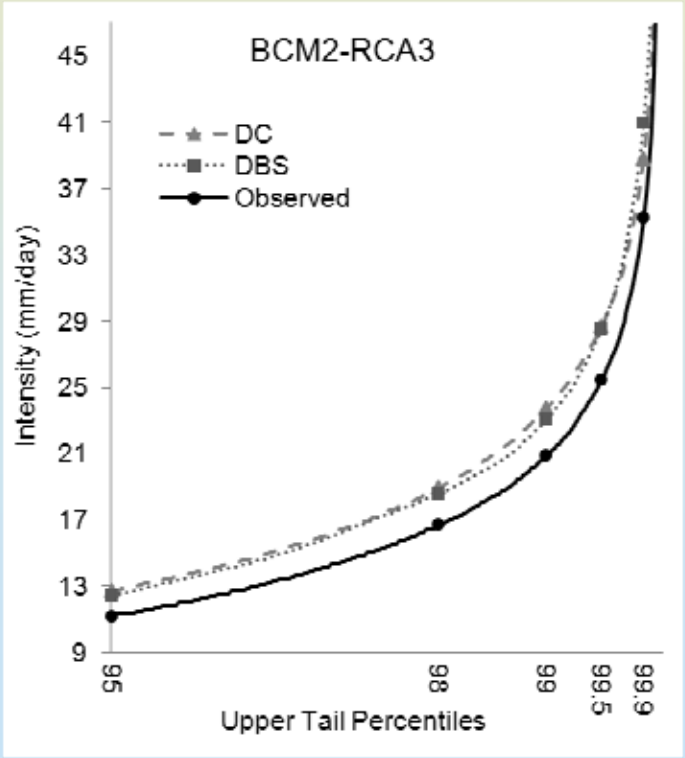


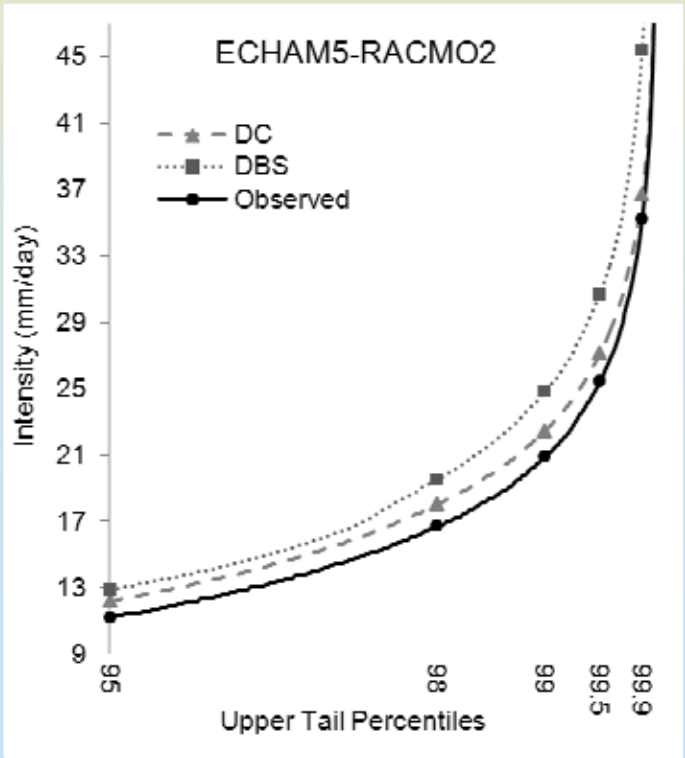
- "Double gamma" approach split at the 95th percentile
- Projected changes correspond with variability as simulated by the RCM and with the same statistical intensity distribution as the observations
- Intensity depedent method allows for correcting and extreme values differently than a mean value

High Intensity Precipitation

DBS vs DC methods in far future (2071-2100) displayed with observed precipitation (1991-2010)



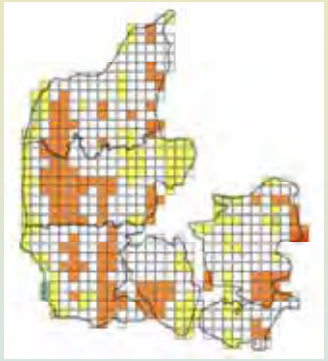




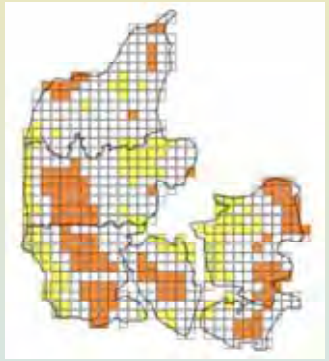
Spatial Biases

Observed vs. DBS (basin) total annual (1991-2010) error (%)

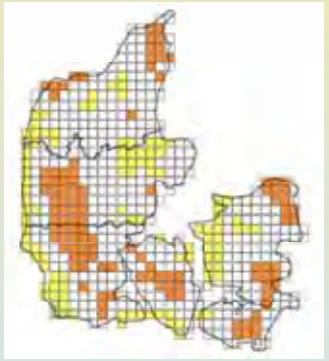
ARPEGE-RM5.1



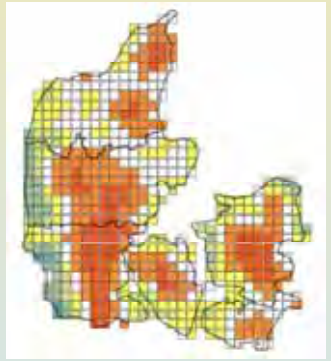
BCM2-RCA3



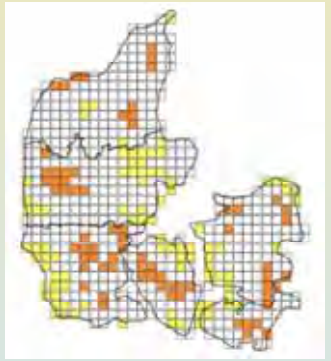
ECHAM5-RCA3



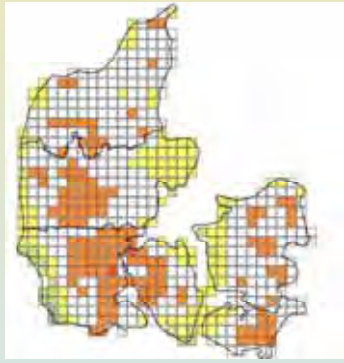
ECHAM5-REMO



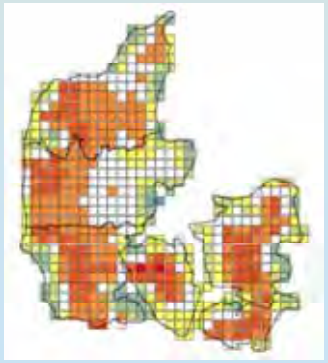
ECHAM5-RegCM3



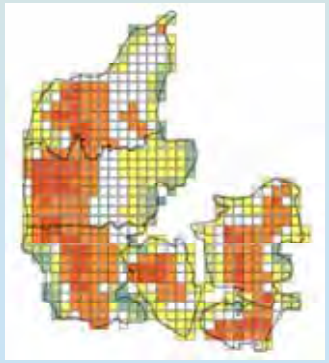
HadCM3-CLM



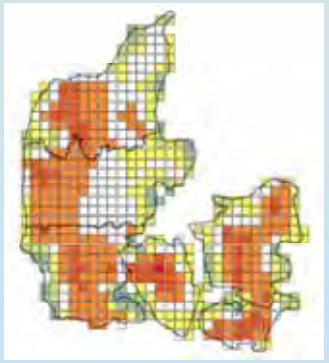
ARPEGE-HIRHAM5



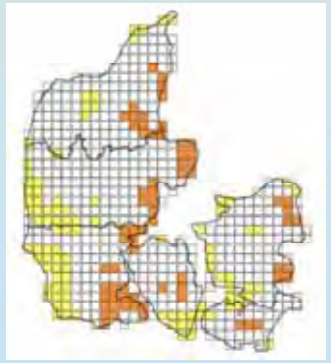
BCM2-HIRHAM5

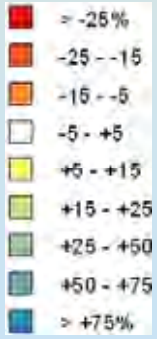


ECHAM5-HIRHAM5

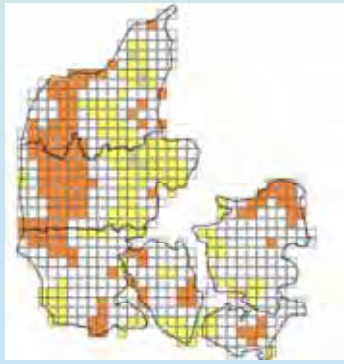


ECHAM5-RACMO2





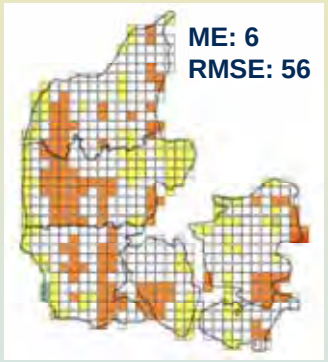
HadCM3-HadRM3



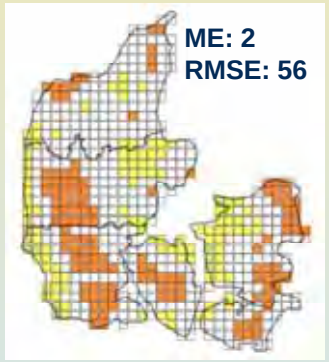
Spatial Biases: Mean Error, RMSE

Observed vs. DBS (basin) total annual (1991-2010) error (%)

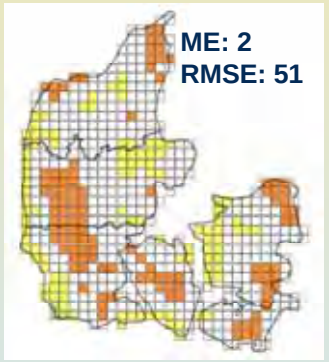
ARPEGE-RM5.1



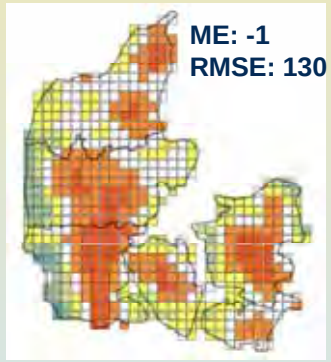
BCM2-RCA3



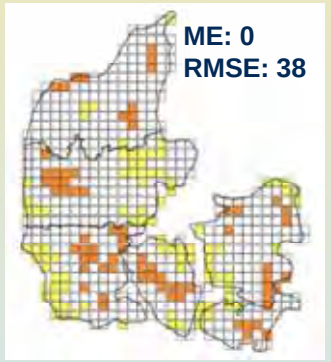
ECHAM5-RCA3



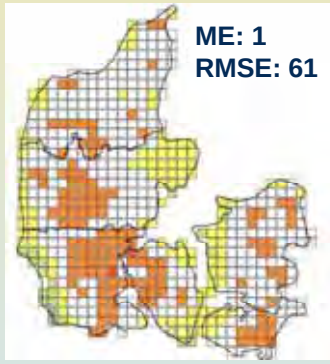
ECHAM5-REMO



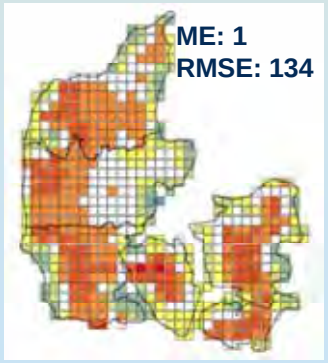
ECHAM5-RegCM3



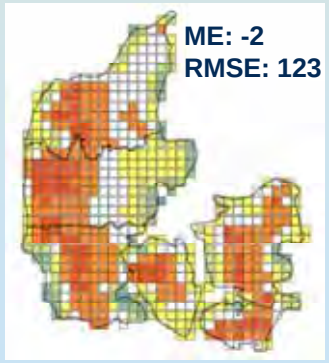
HadCM3-CLM



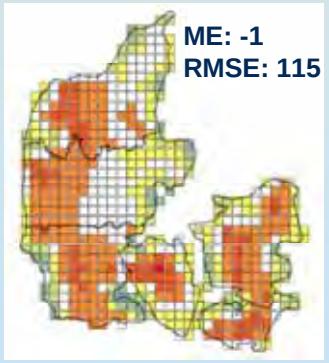
ARPEGE-HIRHAM5



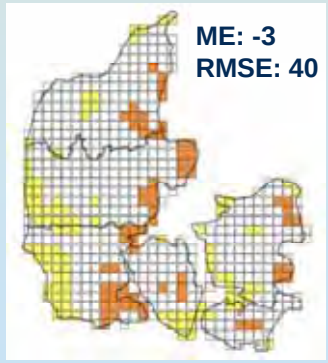
BCM2-HIRHAM5

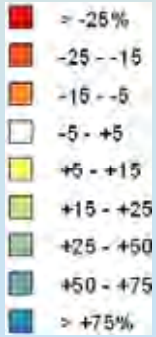


ECHAM5-HIRHAM5

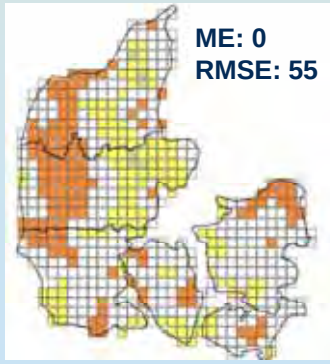


ECHAM5-RACMO2





HadCM3-HadRM3



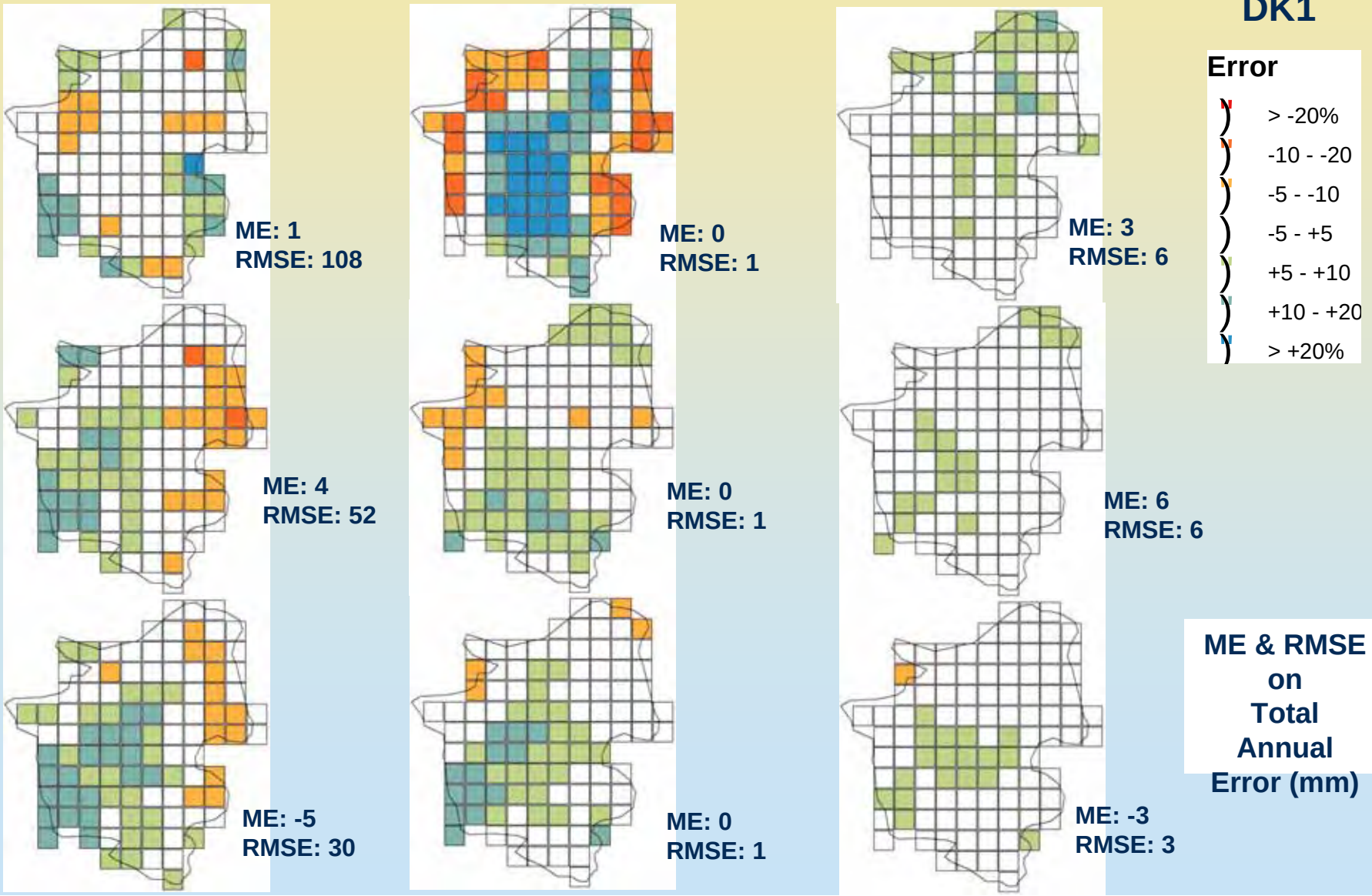
DBS methods considering spatial bias

- **DBS (basin)**
  - Basinwide scaling (i.e. DK1 is 105 10km grids)
  - 4 paramaters per basin per season
- **DBS (spatial)**
  - Basinwide scaling + spatial bias factor at grid scale (10km)
  - 4 parameters per grid per season + 1 paramater per grid per season
- **DBS (grid)**
  - Grid by grid scaling (10km)
  - 4 parameters per grid

99th percentile error (1991-2010)
Observed - RCM

HYACINTS

	DBS basin	DBS spatial	DBS grid
ARPEGE-HIRHAM5	ME: 1 RMSE: 108	ME: 0 RMSE: 1	ME: 3 RMSE: 6
BCM2-RCA3	ME: 4 RMSE: 52	ME: 0 RMSE: 1	ME: 6 RMSE: 6
ECHAM5-RACMO2	ME: -5 RMSE: 30	ME: 0 RMSE: 1	ME: -3 RMSE: 3



ME & RMSE on Total Annual Error (mm)

Mean GW Head Error (1991-2010)
Observed – ARPEGE-HIRHAM4

Conclusions about Bias Correction

- There is variability between climate models on the strengh and direction of climate change signals
- The DBS methods are better suited to capture future precipitation regimes (mean and high intensity values) compared to DC methods
- Basinwide DBS applications might not overcome the high spatial bias seen in some RCMs
- In general, the least paramaterised yet effective bias correction is preferable

Conclusions about Uncertainty

- GCMs contribute the most uncertainty in terms of the direction and strength of climate change signals
- RCMs contribute the most uncertainty in terms of spatial patterns and biases
- Choice of bias correction method contributes varying amounts of uncertainty depending on the nature of the climate model bias and the hydrological variables of interest
- Knowlegde of the hydrological variables and impacts of interest can narrow the aproach with regards to choice of climate models and downscaling methods.