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# Evaluation of reanalyses for precipitation in complex terrain: the Alps and the Fennoscandia

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Christoph Frei<sup>1</sup>, and Ole Einar Tveito<sup>2</sup>  
1<sup>st</sup> December 2017



(1) Federal Office of Meteorology and Climatology MeteoSwiss, Zurich, Switzerland  
(2) Norwegian Meteorological Institute, Oslo, Norway

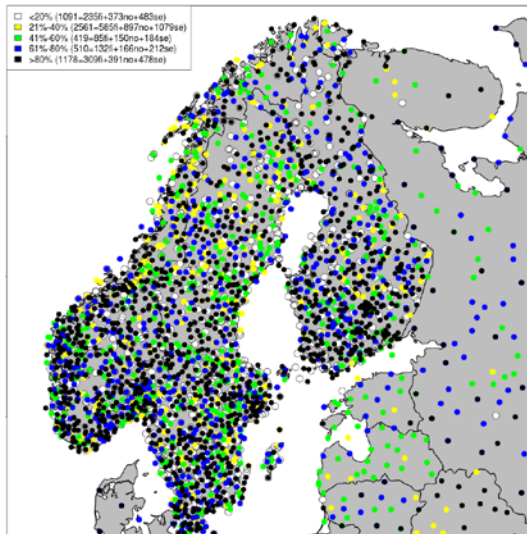


# UERRA Evaluation

- Contributions of MeteoSwiss and Met Norway
  - Evaluate and quantify uncertainties of regional re-analyses using probabilistic forecast verification.
  - Precipitation (06h-06h)
  - Alpine Region and Scandinavia
  - Scale dependency

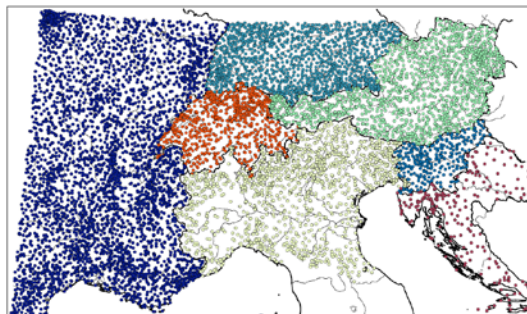
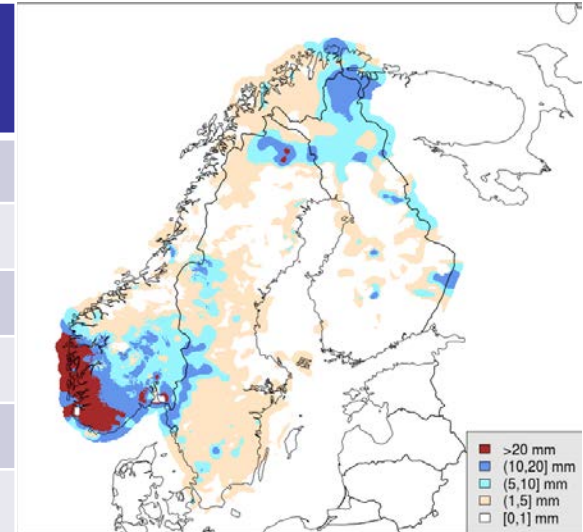
		Dataset	$\Delta x$	Period	Information
GRIDDING		APGD/APGDens (REFERENCE) Alpine Precipitation Gridded Dataset	5 km	1971-2008	Alpine Region Isotta et al., 2014, Int. J. Climatol
		NGCD (REFERENCE) Nordic Gridded Climate dataset	1 km	1981-2010	Finland, Norway, Sweden (mainland)
		E-Obs Gridded daily dataset	0.25° (~27 km)	1950-	Haylock et al. (2008) Klok and Klein Tank (2008)
REGIONAL REANALYSES		UK MetOffice Reanalysis ensemble	0.33° (~36 km)	2005-2010	20 members (→ mean and spread) Static 4DVAR
		UK MetOffice Reanalysis deterministic	0.11° (~12 km)	2005-2010	deterministic, uses ensemble reanalysis uncertainty in the assimilation
		HARMONIE reanalysis SHMI, Météo-France	11 km	1961-2015	deterministic 2 different physics (2006-2010)
		COSMO-REA6 University of Bonn	0.055° (~6 km)	1997-2014	deterministic COSMO + nudging
		COSMO-EU reanalysis University of Bonn	12 km	(2006-2010)	21 members, ensemble-nudging data assimilation (probabilistic observations)
		NORA10 Norwegian Reanalysis 10 km	0.1° (~10 km)	1958-2016	deterministic Norway
GLOBAL DOWN REANAL. SCALING		MESCAN Météo-France	5.5 km	1961-2010	MESCAN-SURFEX-TRIP-HR Model: HARMONIE 11 km 6-8 members (different physics) 2006-2010
		MESAN (EURO4M) HIRLAM model, downscaling	5.5 km	1989-2010	Häggmark et al. 2000, Daley, 1991 (optimal interpol). Mesoscale analysis system, SHMI
		ERA-INTERIM	80 km	1979-	ECMWF, Dee et al. (2011)
		ERA20C	125 km	1900-2010	ECMWF
+ E-Obs Ens, ERA-5					

# Reference Datasets



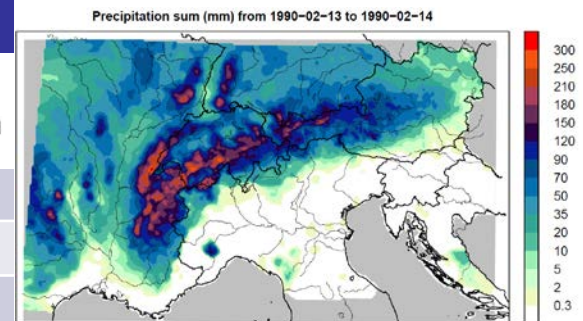
## Nordic Gridded Climate dataset (NGCD)

Variable	Precipitation
$\Delta x$	1km
t	1981-2010, daily
x	Finland, Norway, Sweden (mainland)
Stations	~3850
Source	ECA&D, klima.met.no, SMHI + FMI



## Alpine Precipitation Grid Dataset (APGD)

Variable	Precipitation
$\Delta x$	5km
t	1971-2008, daily
x	Alpine Region (2-17.5E, 43-49N)
Stations	>8500 (~6000 per day)
Quality	Quality checked



→ Rescaling to 25km and 5km grid

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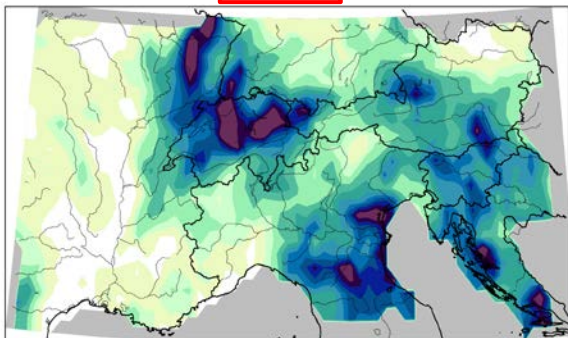
# Main results

- **Regional reanalyses:**
  - additional value compared to global reanalyses
  - tendency to overestimate precipitation amounts and frequency, especially in complex terrain (Alps, Norway)
  - regional reanalysis shows better small scale structures and performance than observational gridded datasets in region of low station density (except wet-day frequency)
  - COSMO6-REA and COSMO-ENS best performance
  - Fennoscandia: HARMONIE best performance
- **Downscaling:**
  - additional value in regions with dense station network
  - improvement especially for fraction of wet days
- Model error mostly bigger than uncertainty of the reference dataset (especially for days >10mm/d precipitation and global reanalyses)
- Scale dependent analyses: more information about the performance of the datasets depending on the application/scale of interest. Biggest differences from the reference and the lowest Brier skill score are found in complex topography, small catchment sizes and for higher precipitation amounts
- Annual cycle is mostly well reproduced in all datasets

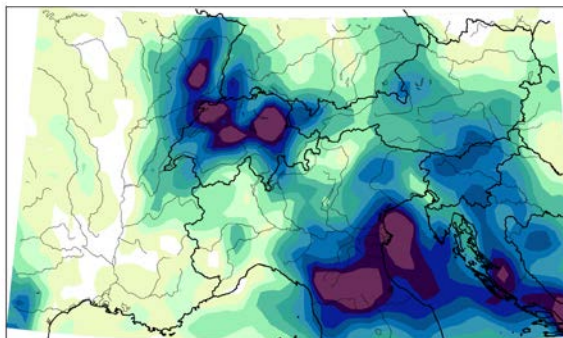
# Precipitation sum 16-18.9.2006

25 km grid

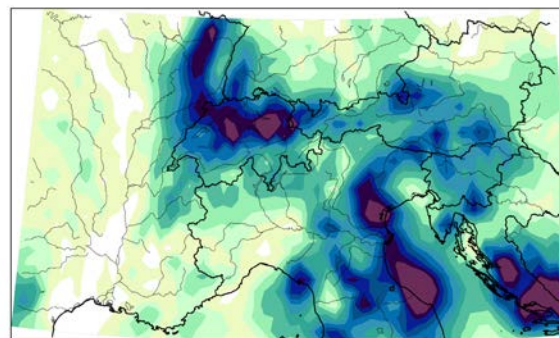
**APGD**



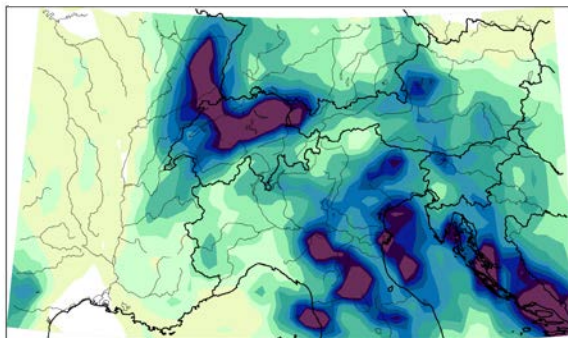
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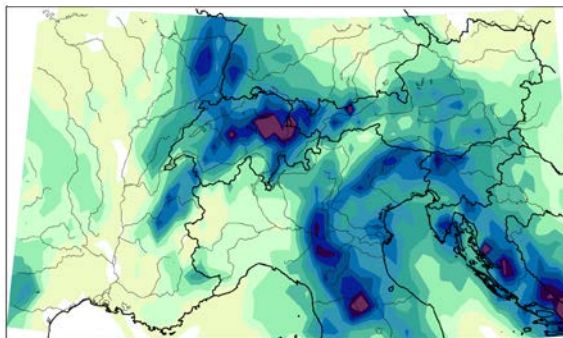
**MESCAN**



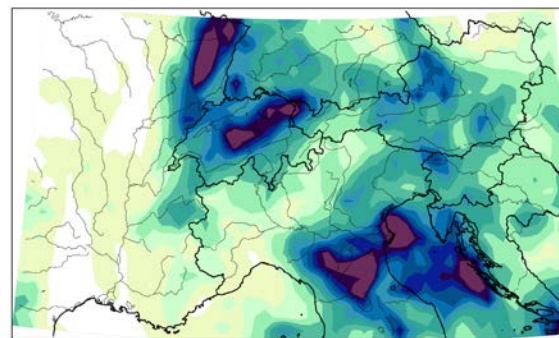
**UKMO**



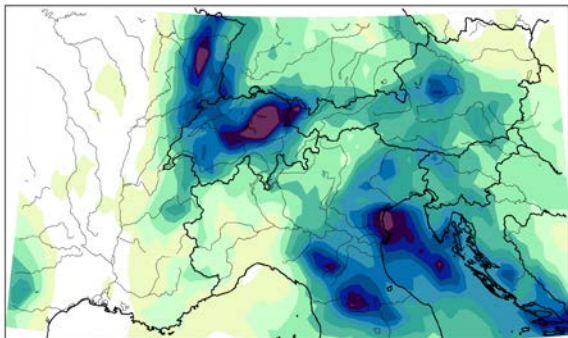
**HARMONIE**



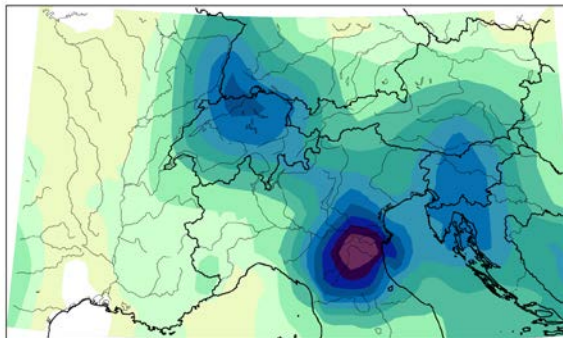
**COSMO6-REA**



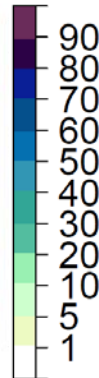
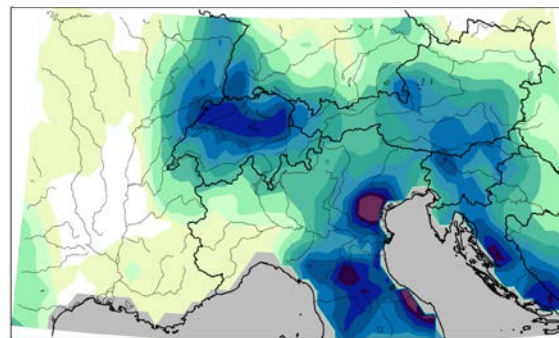
**COSMO-ENS (ens. median)**



**ERAINT**



**E-OBS**

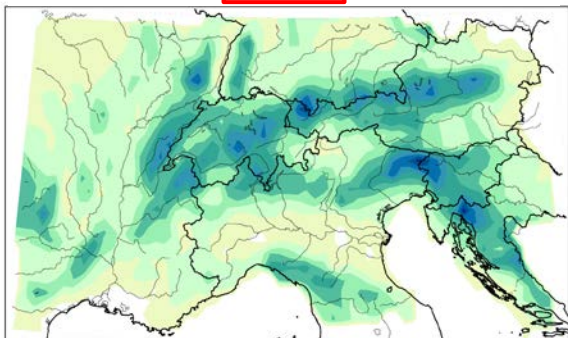




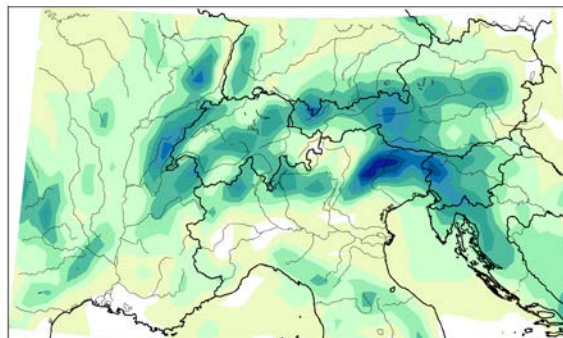
# Mean annual precipitation

2005-2008  
25 km grid  
Gridding  
Regional Rean.  
Downscaling  
Global Rean.

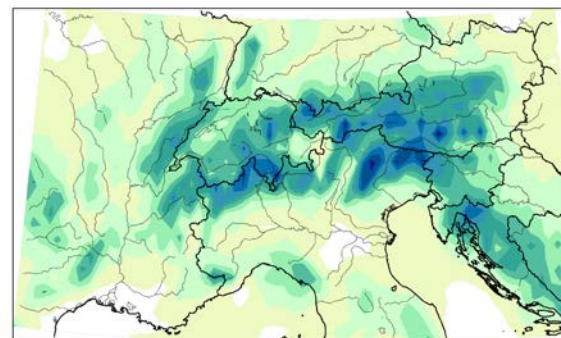
**APGD**



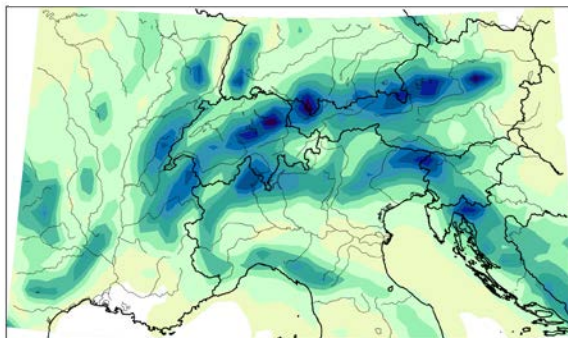
**MESAN (EURO4M)**



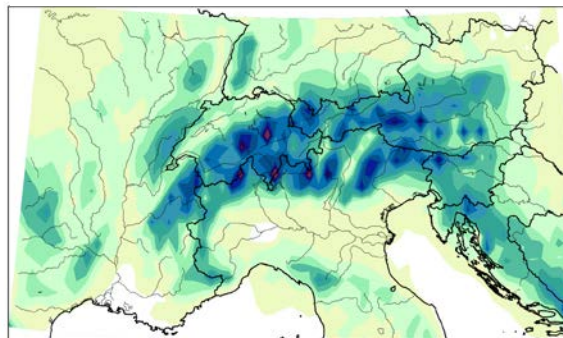
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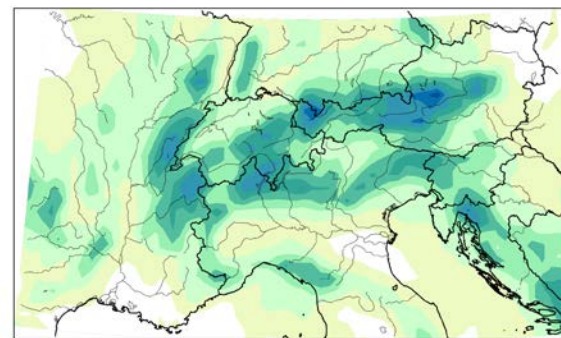
**UKMO det**



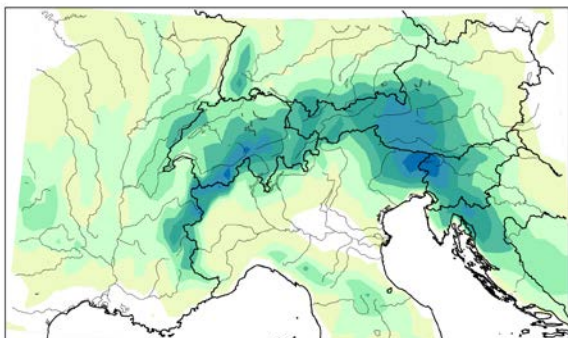
**HARMONIE v1**



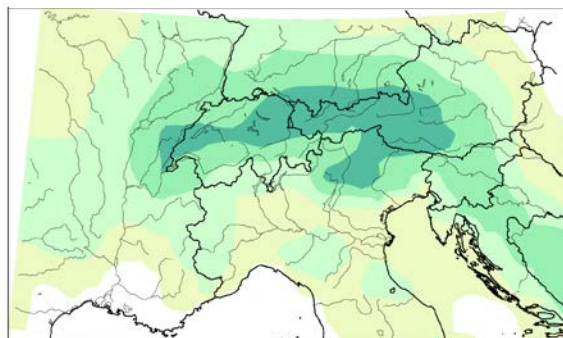
**COSMO6-REA**



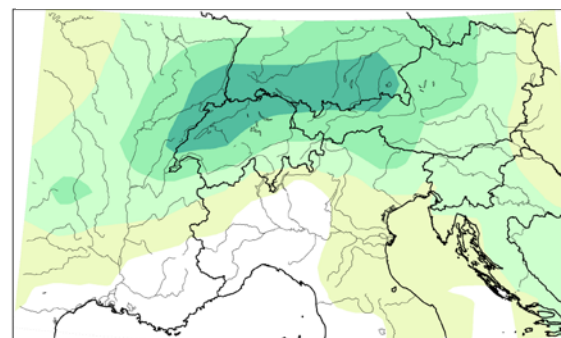
**E-Obs**



**ERAINT**



**ERA20C**

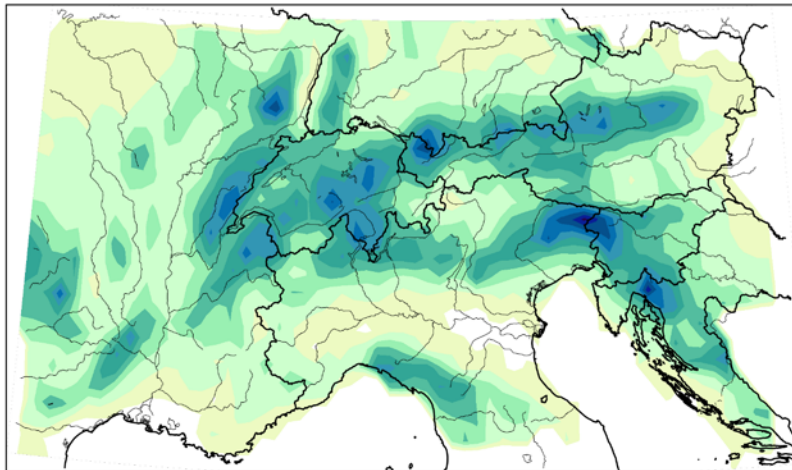


2600  
2400  
2200  
2000  
1800  
1600  
1400  
1200  
1000  
800  
600

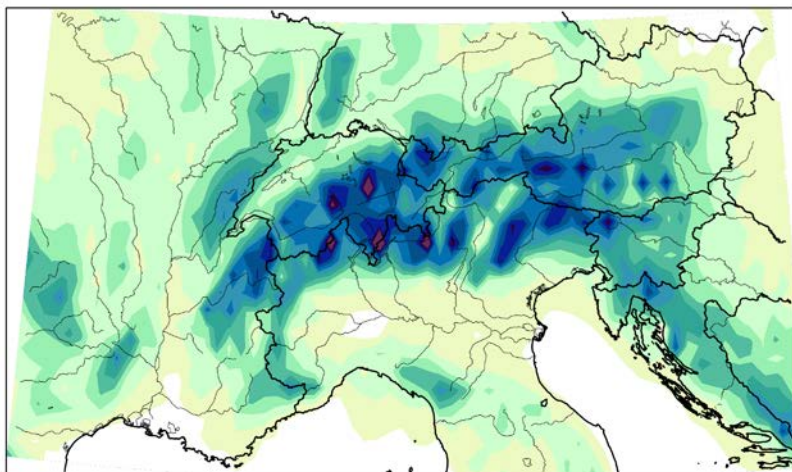
# Mean annual precipitation

2006-2008  
25 km grid

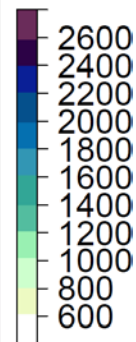
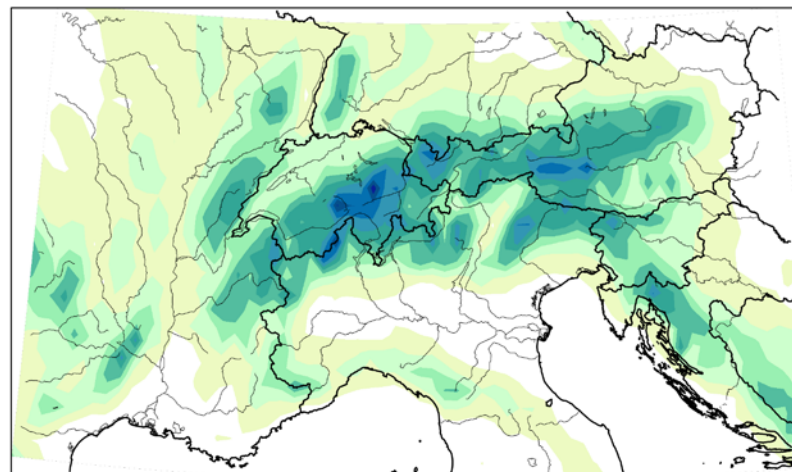
**APGD**



**HARMONIE v1**



**HARMONIE v2**

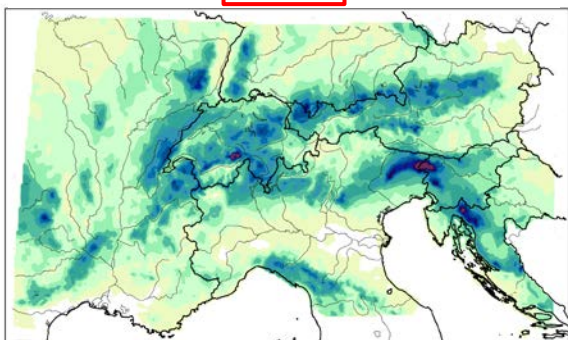




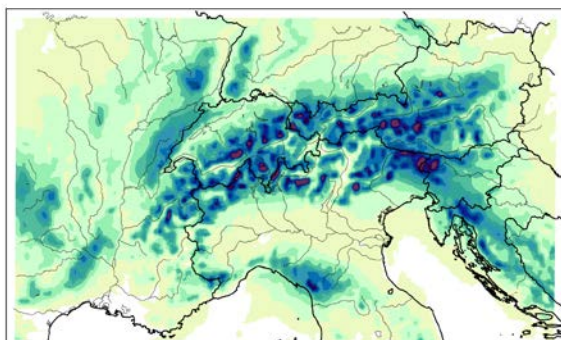
# Mean annual precipitation

2006-2008  
5 km grid

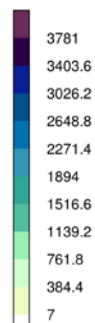
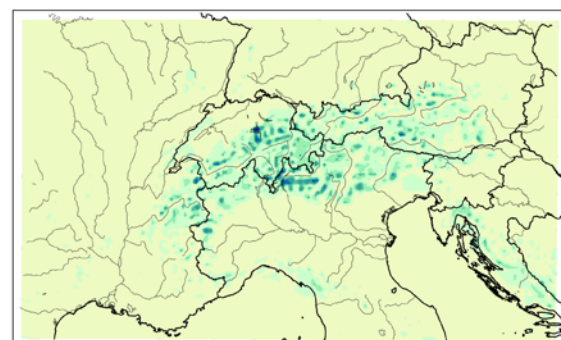
**APGD**



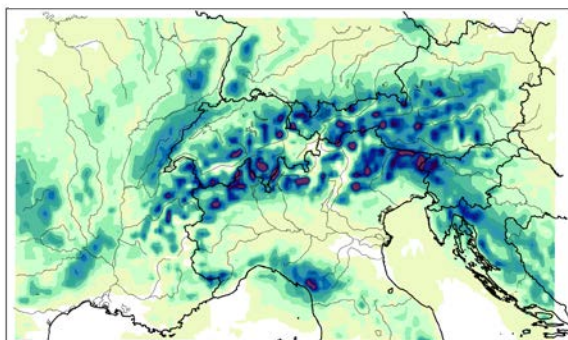
**MESCAN** ensemble median



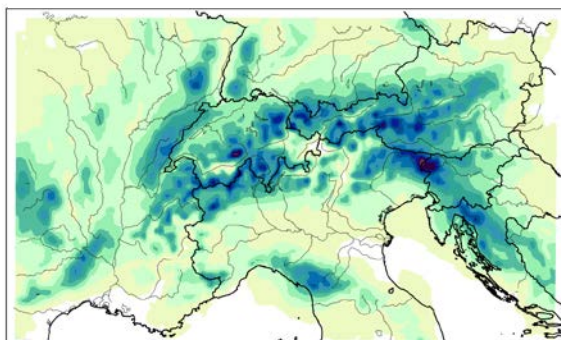
**MESCAN** interquant. (90%-10%)



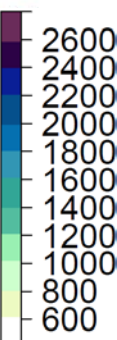
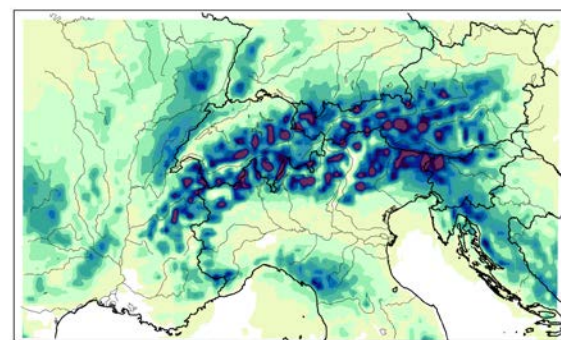
**MESCAN** Bkg:DS/AD,obs:HD



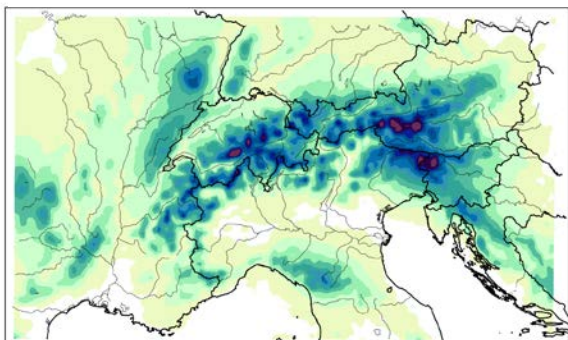
**MESCAN** Bkg:DS/AR,obs:HD



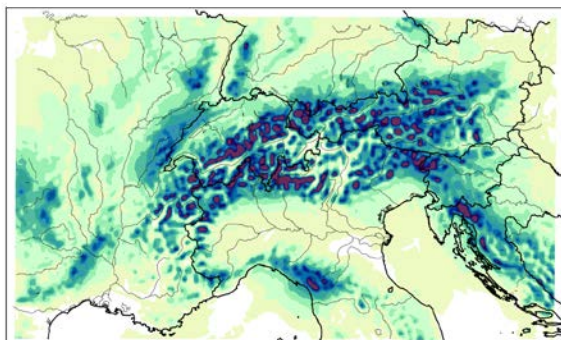
**MESCAN** Bkg:DS/AD,obs:LD



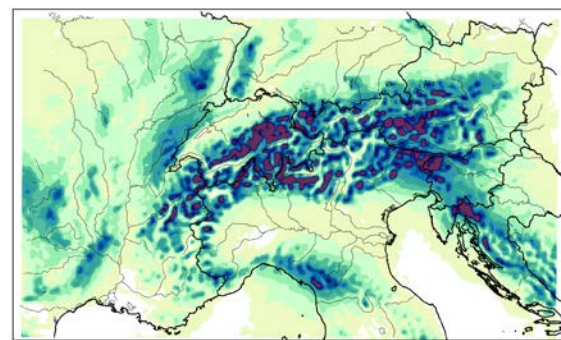
**MESCAN** Bkg:DS/AR,obs:LD



**MESCAN** Bkg:AD,obs:HD



**MESCAN** Bkg:AD,obs:LD

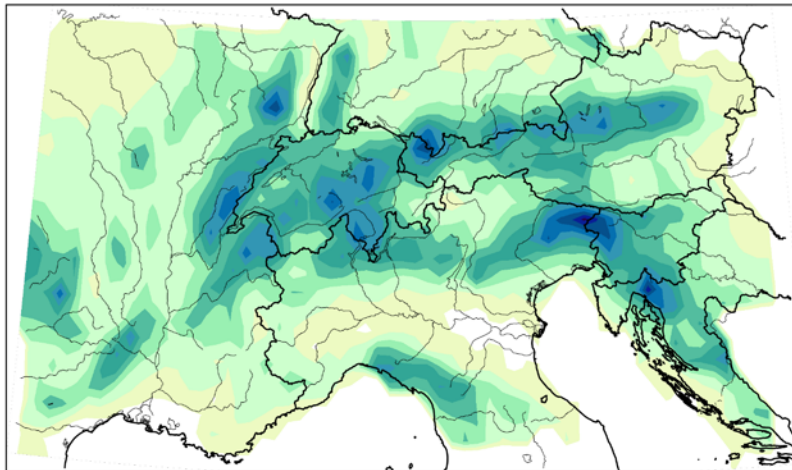




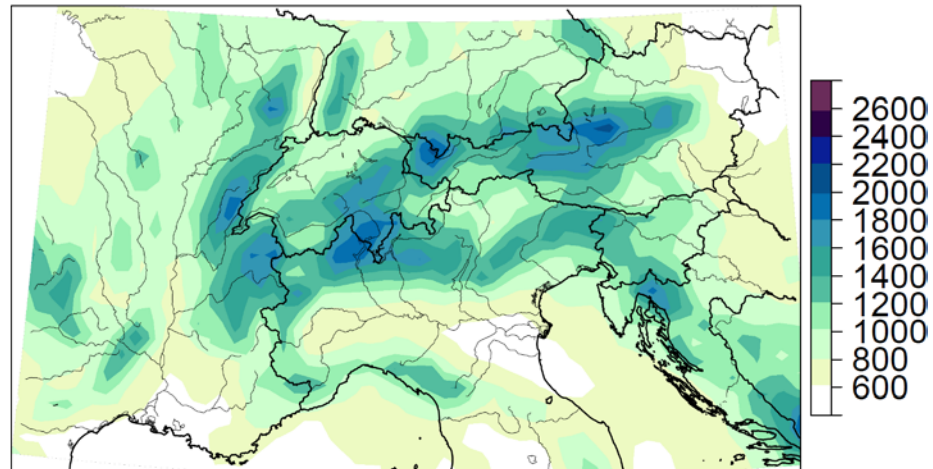
# Mean annual precipitation

2006-2008  
25 km grid

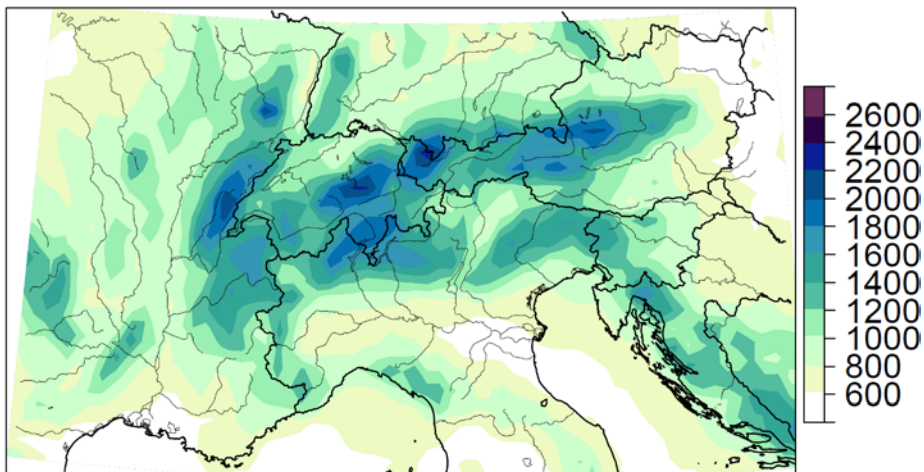
**APGD**



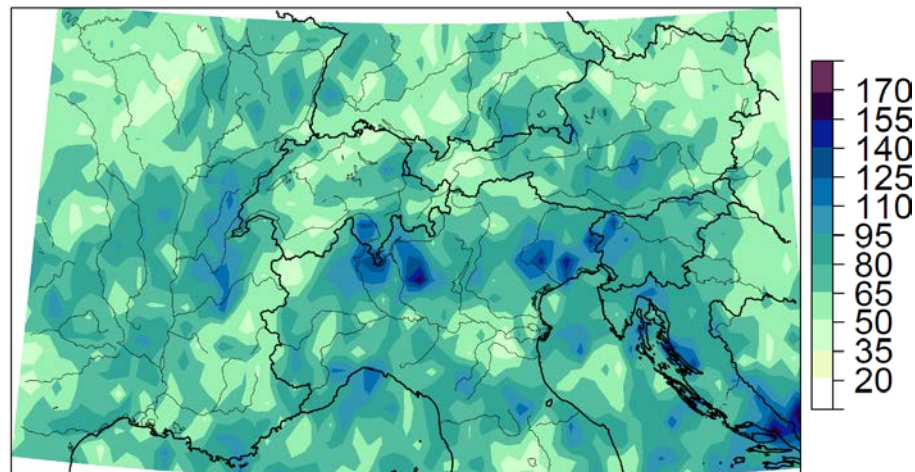
**COSMO6-REA**



**COSMO-ENS ensemble median**



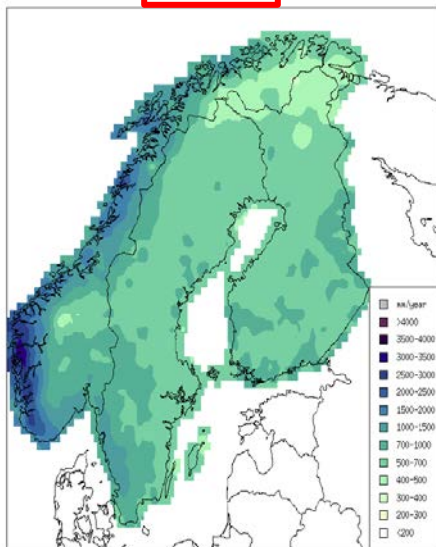
**COSMO-ENS interquant. (90%-10%)**



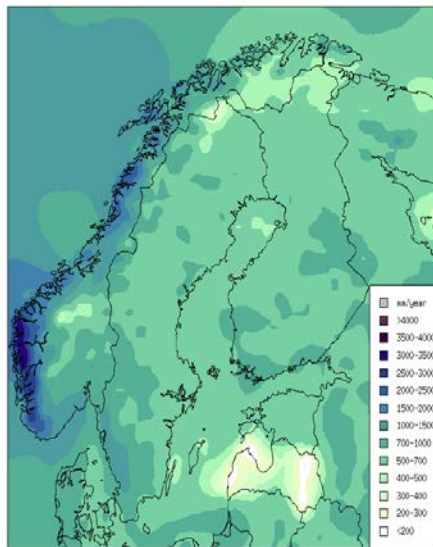
# Mean annual precipitation

2005-2008  
25 km grid  
**Gridding**  
Regional Rean.  
**Downscaling**  
Global Rean.

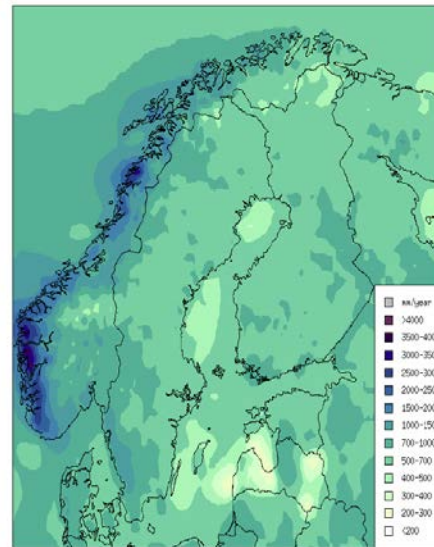
**NGCD**



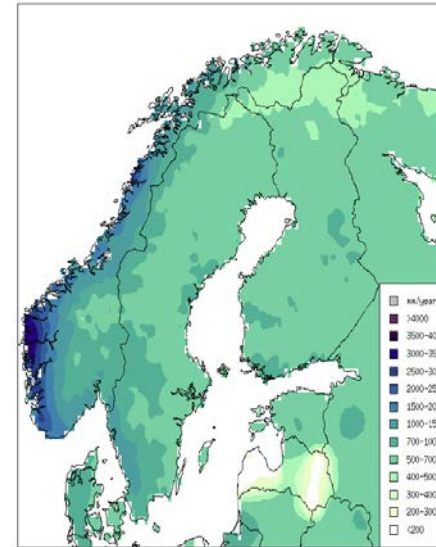
**MESAN**



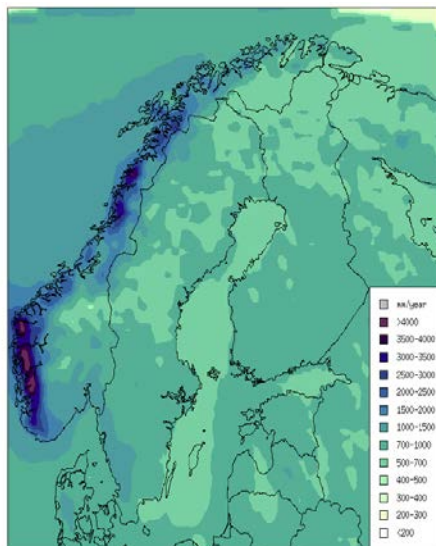
**MESCAN**



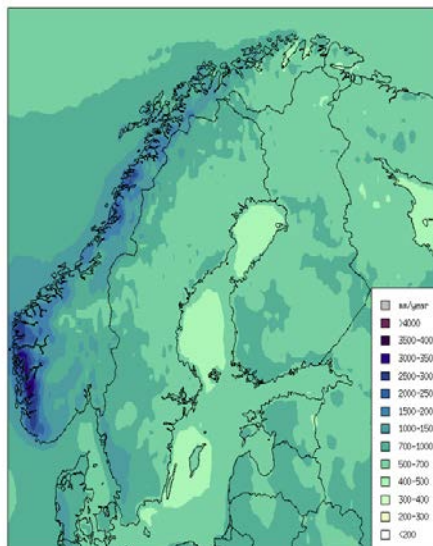
**EOBS**



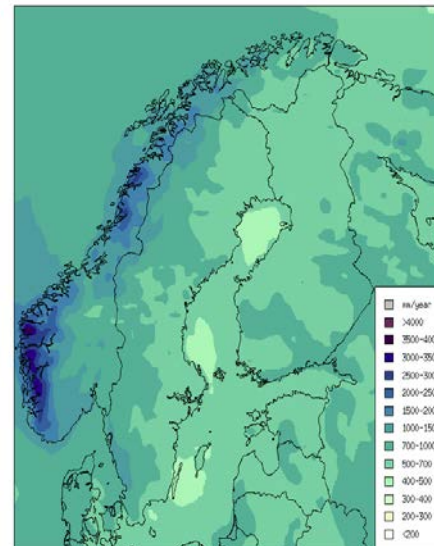
**UKMO det**



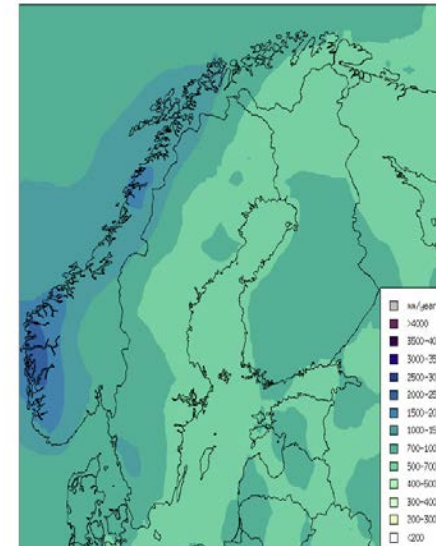
**HARMONIE v1**



**COSMO6-REA**

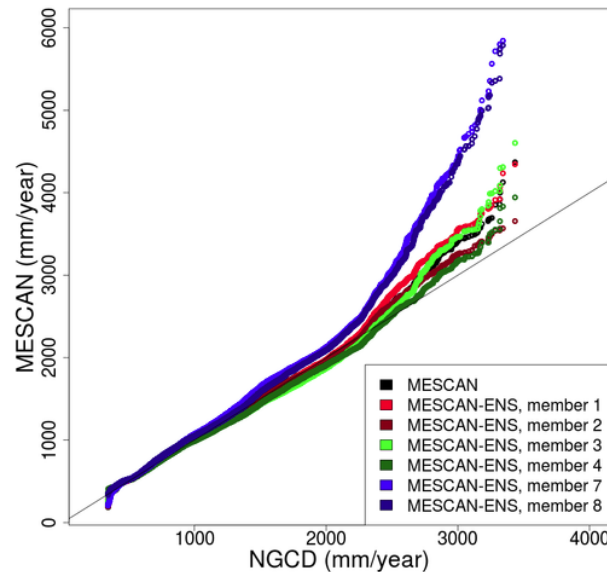
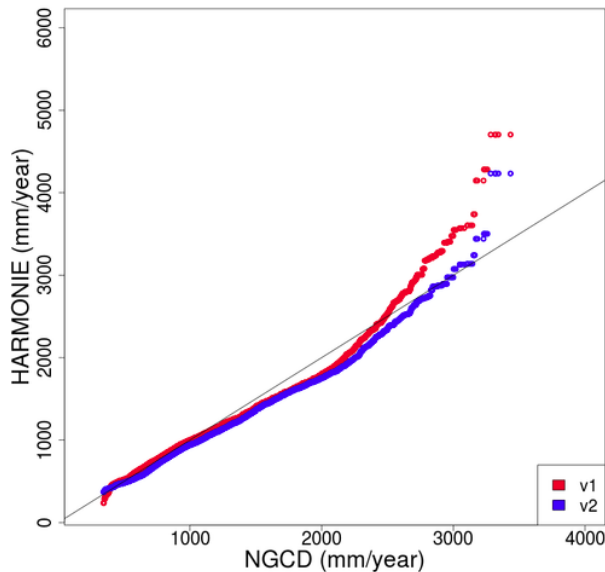
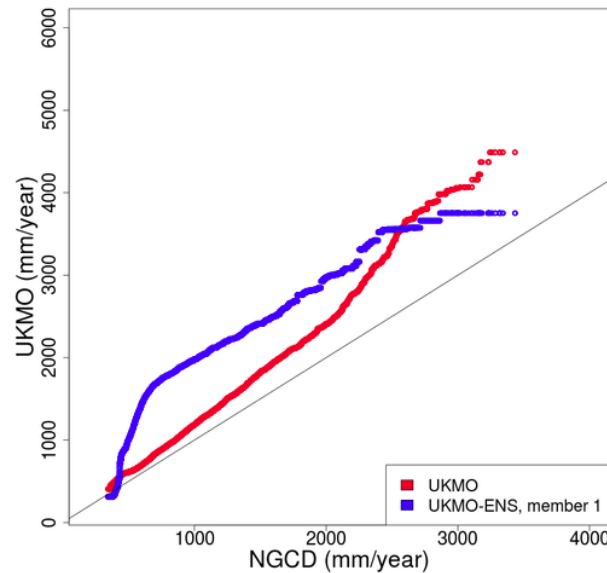
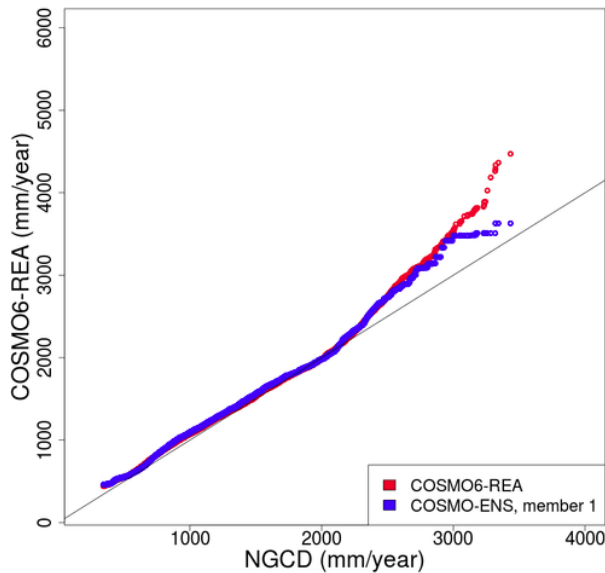


**ERAINT**





# Mean annual precipitation



Quantile-quantile plot for the mean annual precipitation.

The reference (x-axis) is NGCD.

Only UERRA datasets are shown.

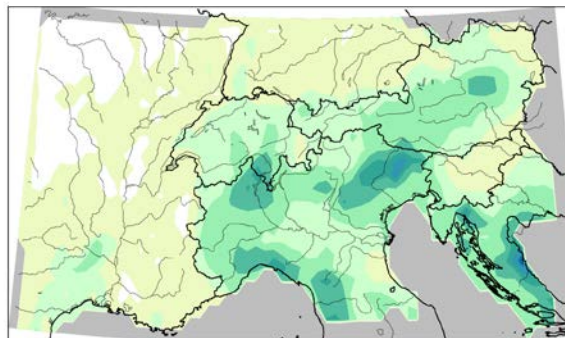
# Main results

- Regional reanalyses:
  - additional value compared to global reanalyses
  - tendency to overestimate precipitation amounts and frequency, especially in complex terrain (Alps, Norway)
  - regional reanalysis shows better small scale structures and performance than observational gridded datasets in region of low station density (except wet-day frequency)
  - COSMO6-REA and COSMO-ENS best performance
  - Fennoscandia: HARMONIE best performance
- **Downscaling:**
  - **additional value in regions with dense station network**
  - improvement especially for fraction of wet days
- Model error mostly bigger than uncertainty of the reference dataset (especially for days >10mm/d precipitation and global reanalyses)
- Scale dependent analyses: more information about the performance of the datasets depending on the application/scale of interest. Biggest differences from the reference and the lowest Brier skill score are found in complex topography, small catchment sizes and for higher precipitation amounts
- Annual cycle is mostly well reproduced in all datasets

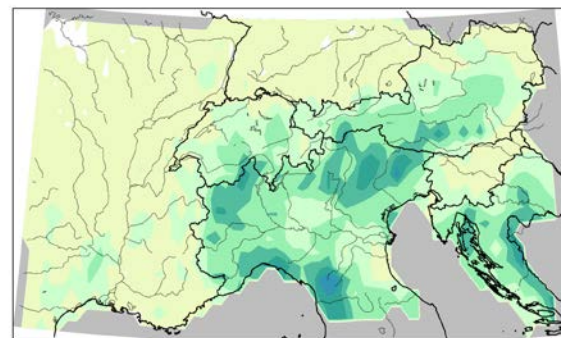
APGD reference

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_i^n (y_i - o_i)^2}$$

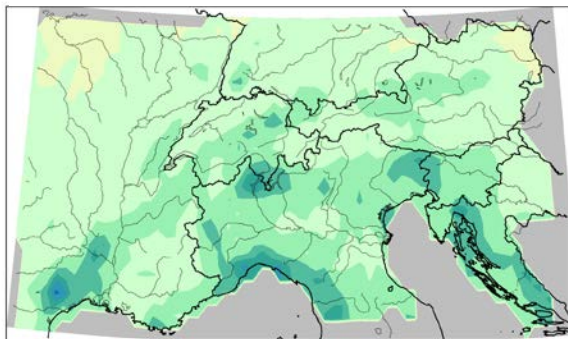
MESAN (EURO4M)



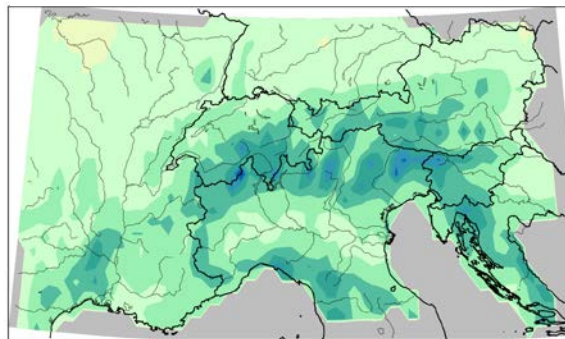
MESCAN



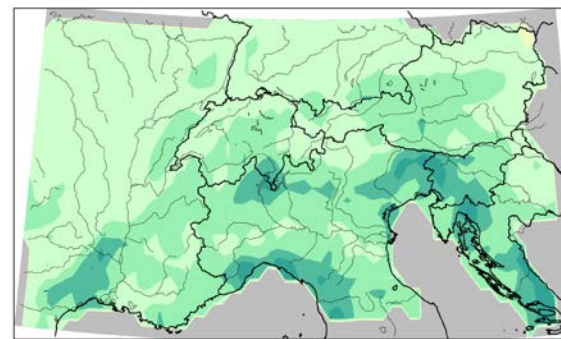
UKMO det



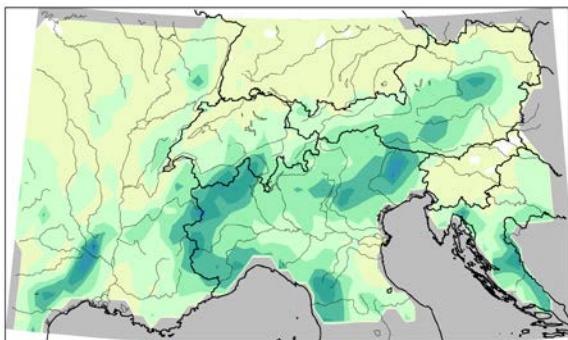
HARMONIE v1



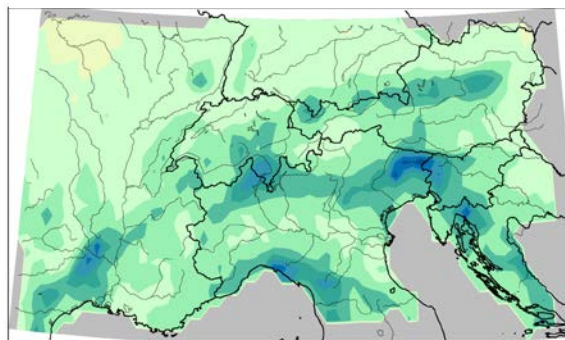
COSMO6-REA



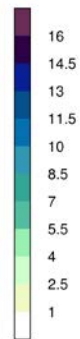
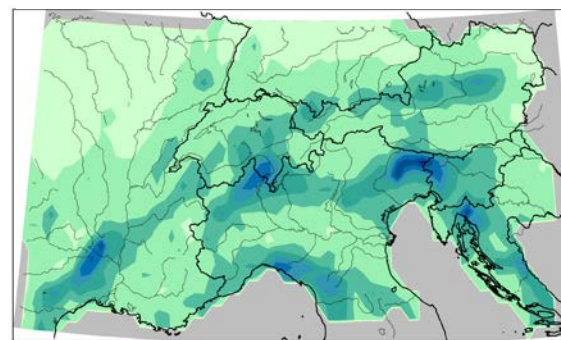
E-Obs



ERAINT



ERA20C

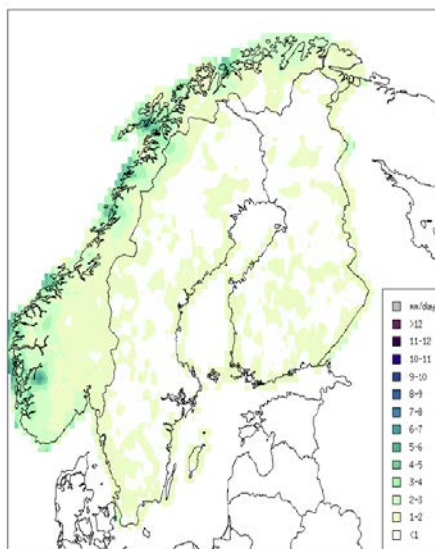




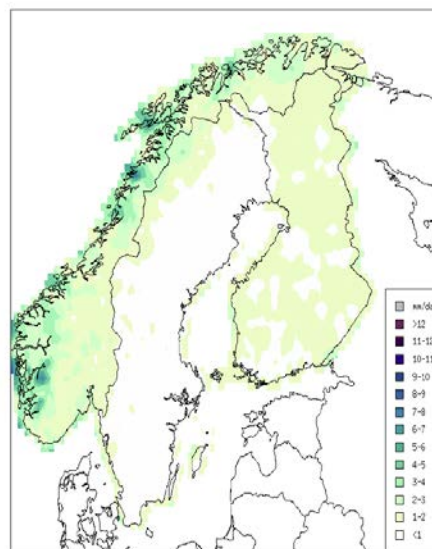
NGCD reference

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_i^n (y_i - o_i)^2}$$

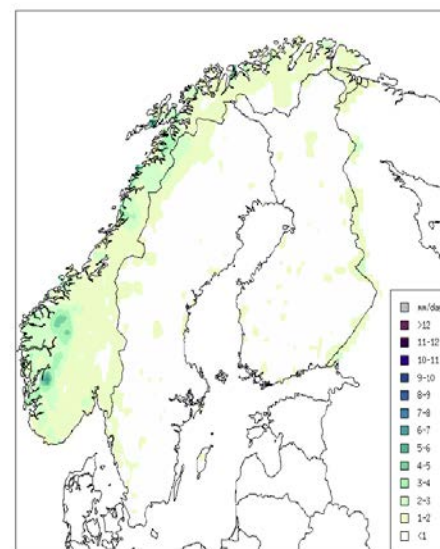
MESAN



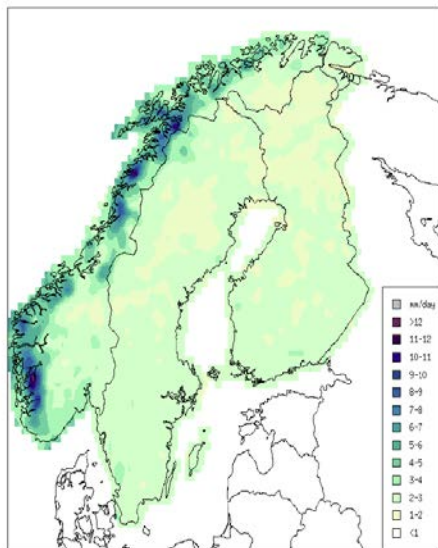
MESCAN



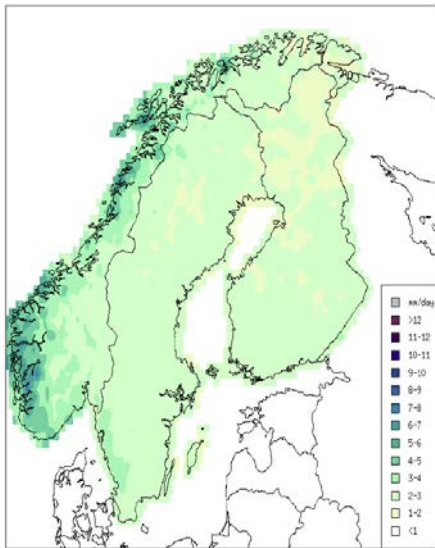
EOBS



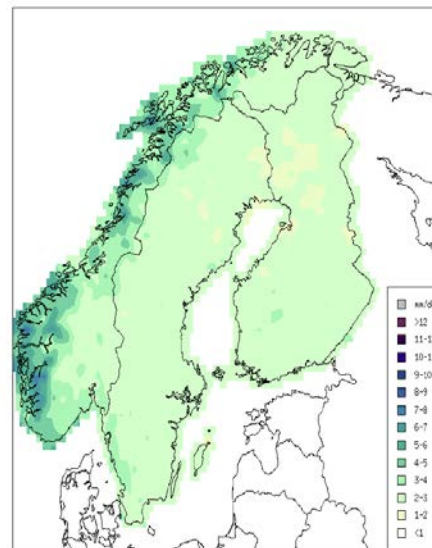
UKMO det



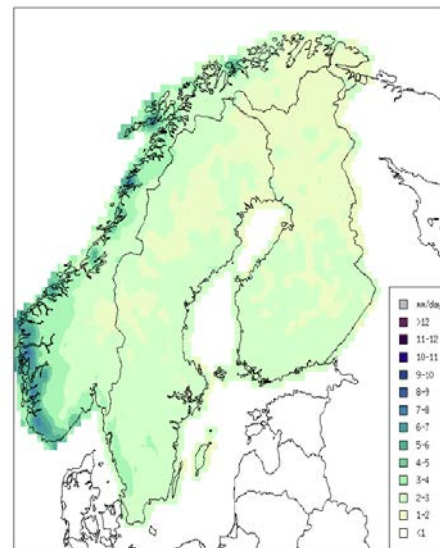
HARMONIE v1



COSMO6-REA



ERAINT



# Main results

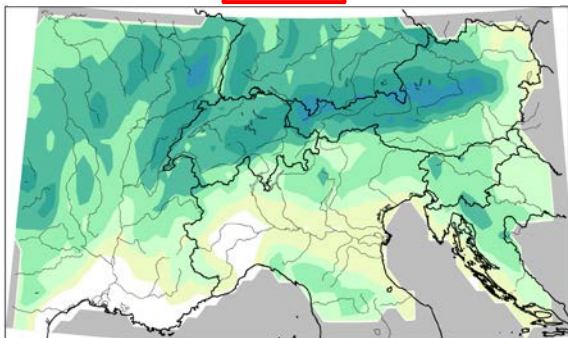
- Regional reanalyses:
  - additional value compared to global reanalyses
  - tendency to overestimate precipitation amounts and frequency, especially in complex terrain (Alps, Norway)
  - regional reanalysis shows better small scale structures and performance than observational gridded datasets in region of low station density (except wet-day frequency)
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- **Downscaling:**
  - additional value in regions with dense station network
  - **improvement especially for fraction of wet days**
- Model error mostly bigger than uncertainty of the reference dataset (especially for days >10mm/d precipitation and global reanalyses)
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- Annual cycle is mostly well reproduced in all datasets



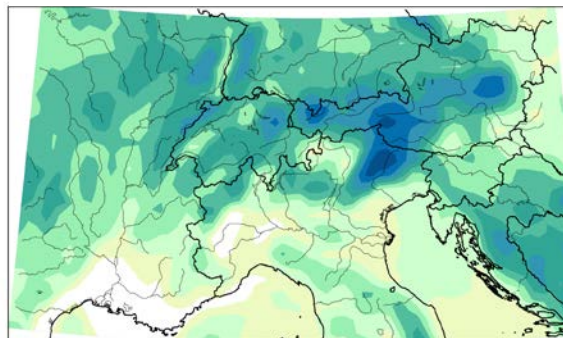
# Wet-days frequency $\geq 1\text{mm/d}$

2005-2008  
25 km grid

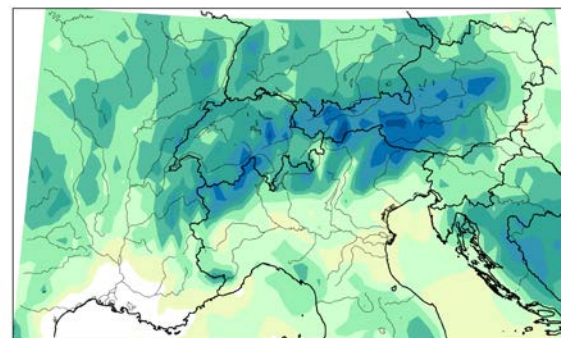
**APGD**



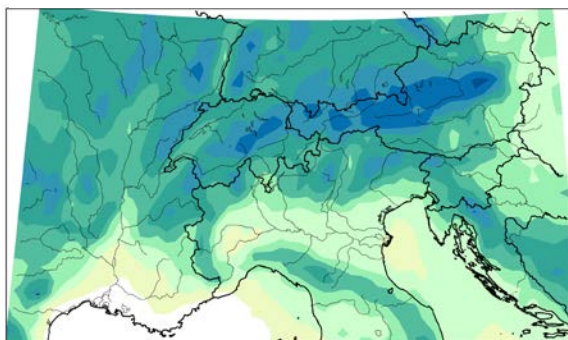
**MESAN (EURO4M)**



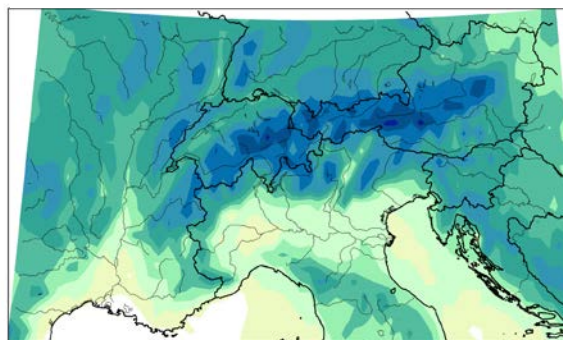
**MESCAN**



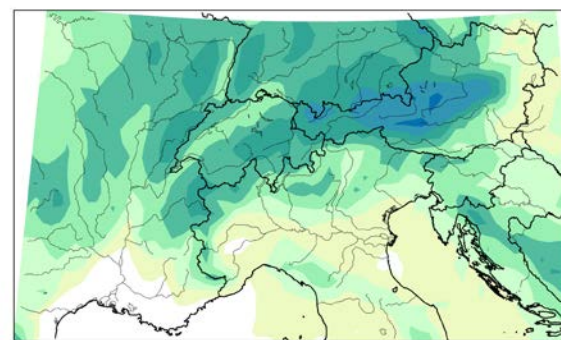
**UKMO**



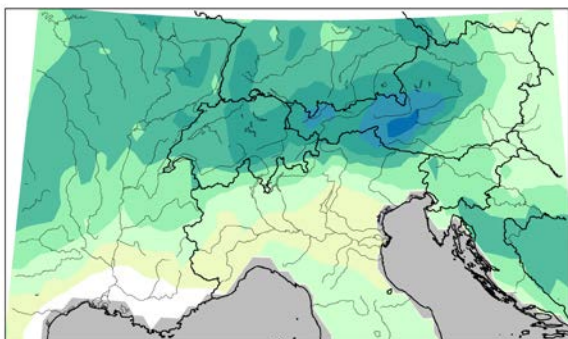
**HARMONIE v1**



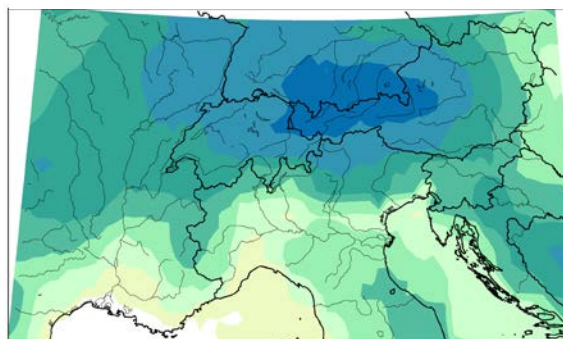
**COSMO6-REA**



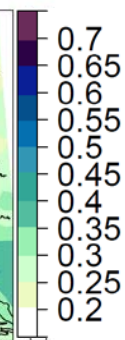
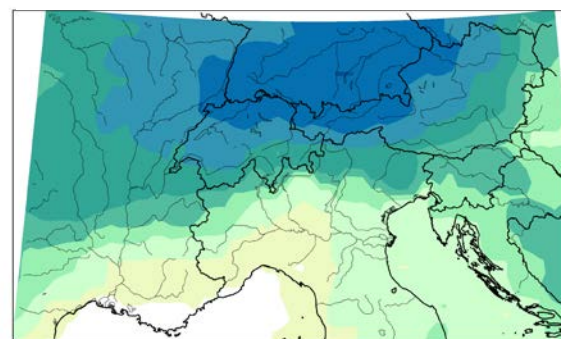
**E-Obs**



**ERAINT**



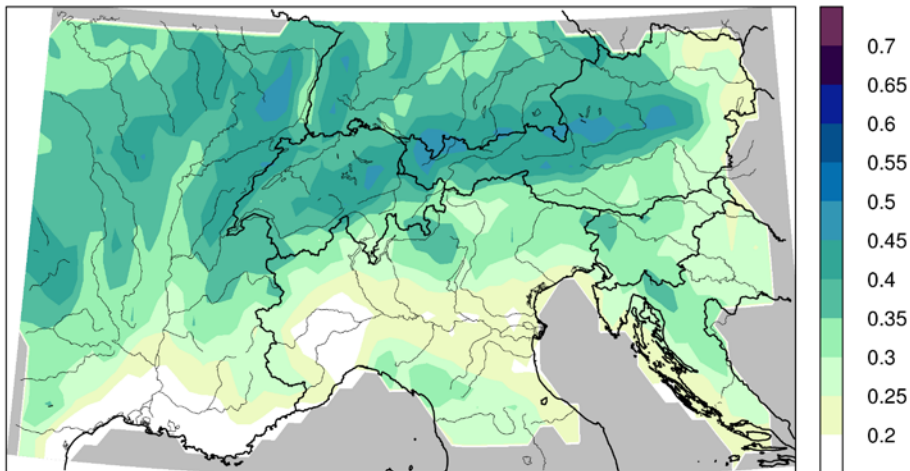
**ERA20C**



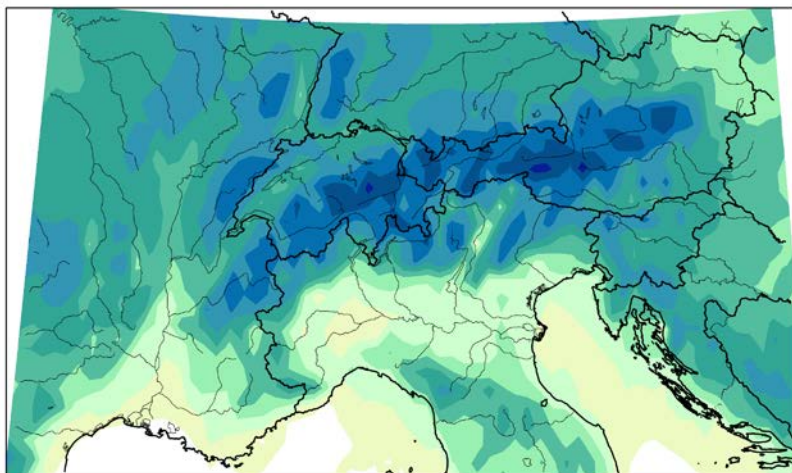
# Wet-days frequency $\geq 1\text{mm/d}$

2006-2008  
25 km grid

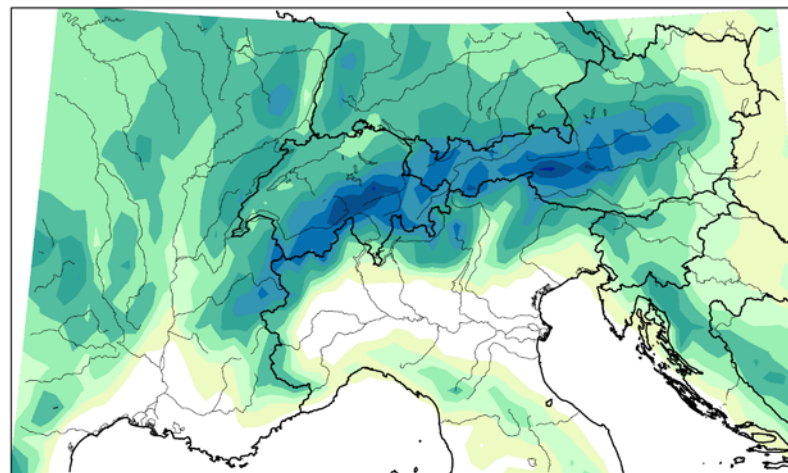
**APGD**



**HARMONIE v1**



**HARMONIE v2**

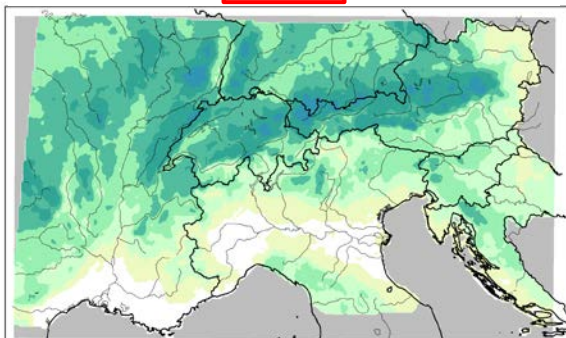




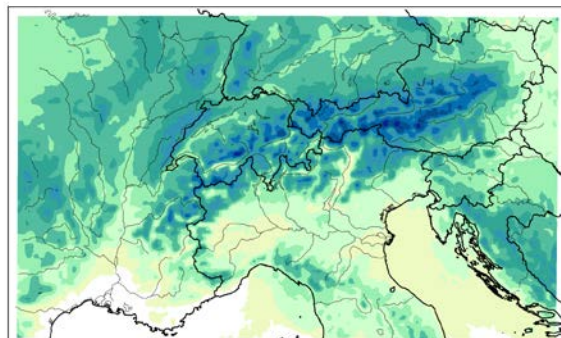
# Wet-days frequency $\geq 1\text{mm/d}$

2006-2008  
5 km grid

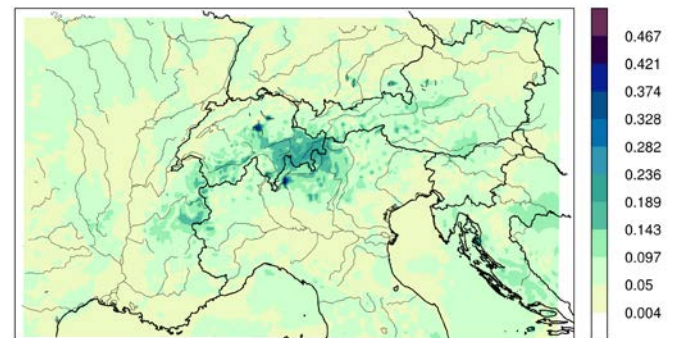
**APGD**



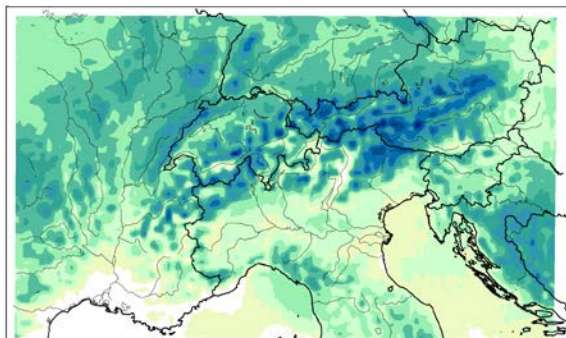
**MESCAN ensemble median**



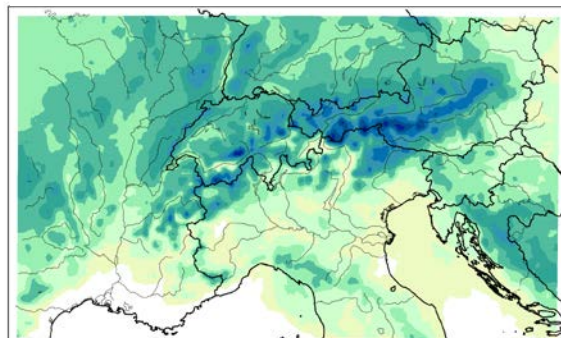
**MESCAN interquant. (90%-10%)**



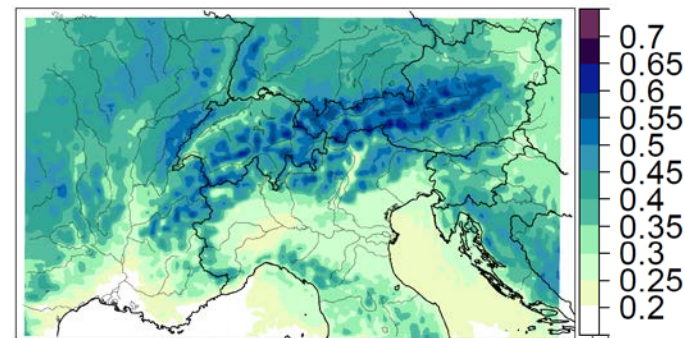
**MESCAN Bkg:DS/AD,obs:HD**



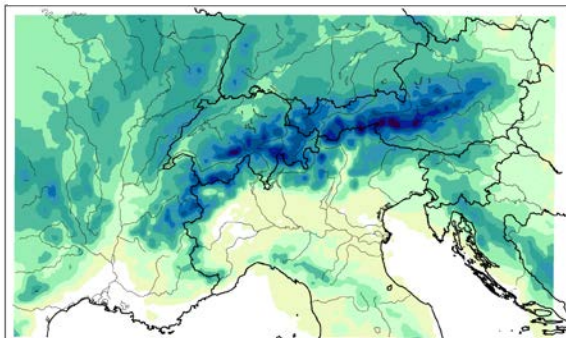
**MESCAN Bkg:DS/AR,obs:HD**



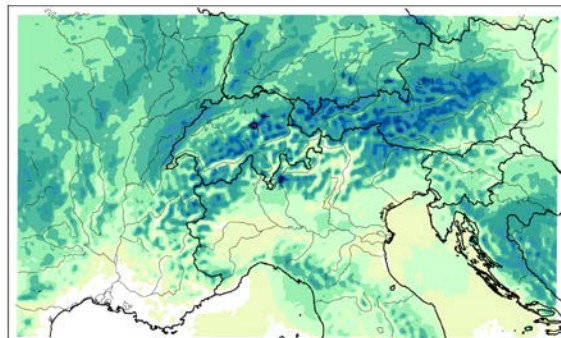
**MESCAN Bkg:DS/AD,obs:LD**



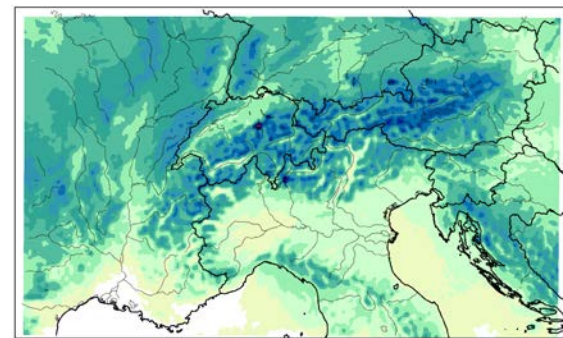
**MESCAN Bkg:DS/AR,obs:LD**



**MESCAN Bkg:AD,obs:HD**



**MESCAN Bkg:AD,obs:LD**

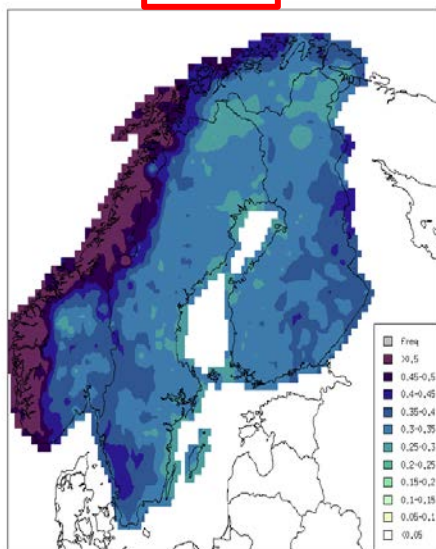




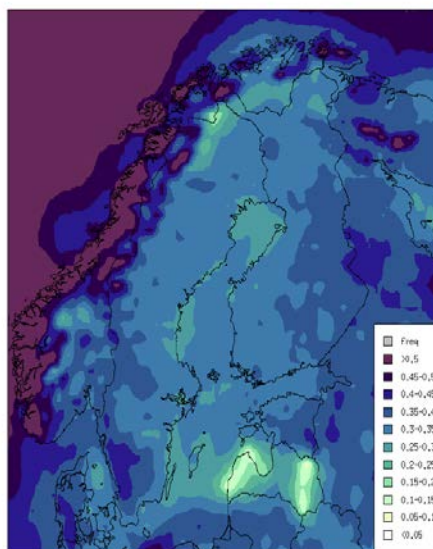
# Wet-days frequency $\geq 1\text{mm/d}$

2005-2008  
25 km grid  
Gridding  
Regional Rean.  
Downscaling  
Global Rean.

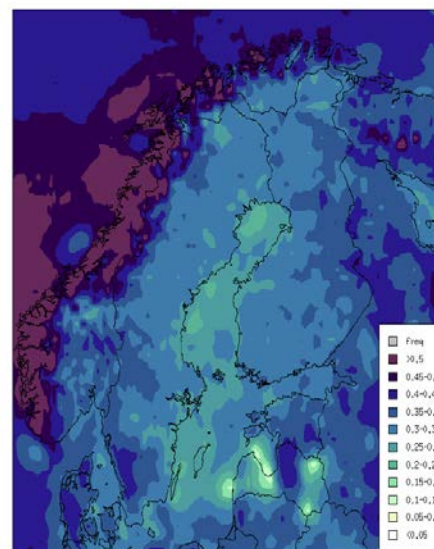
**NGCD**



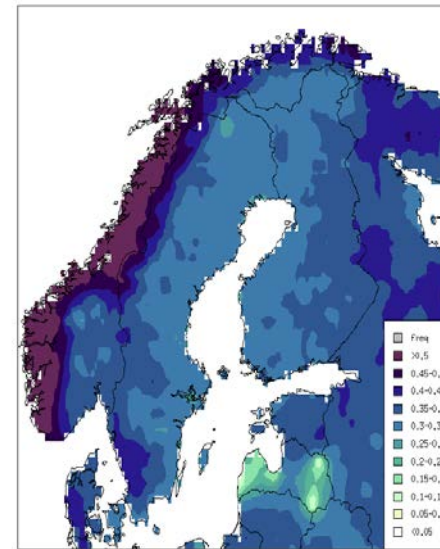
**MESAN**



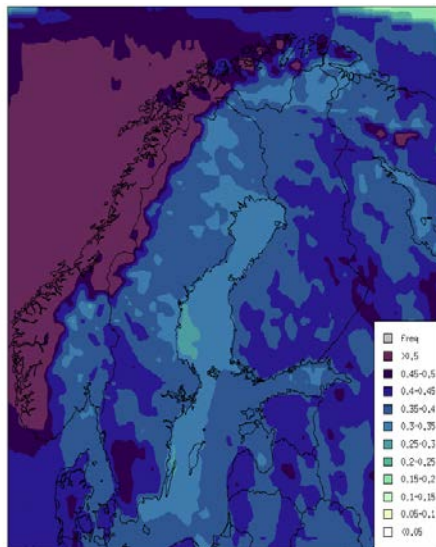
**MESCAN**



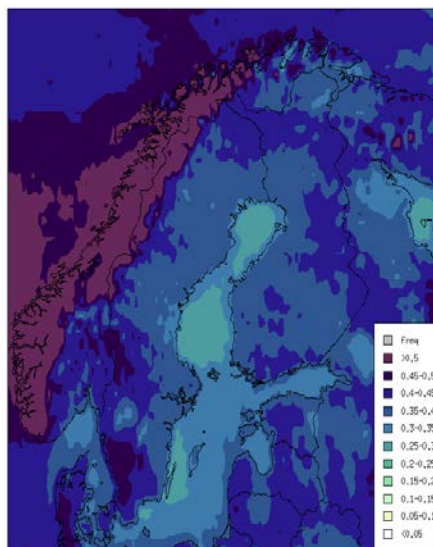
**EOBS**



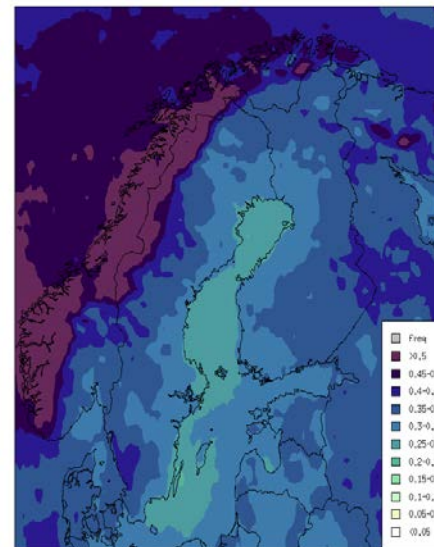
**UKMO det**



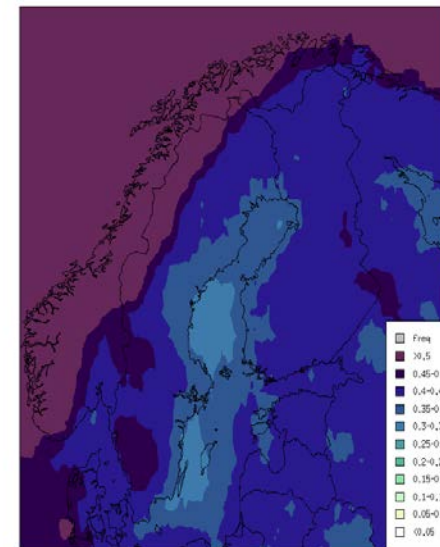
**HARMONIE v1**



**COSMO6-REA**



**ERAINT**



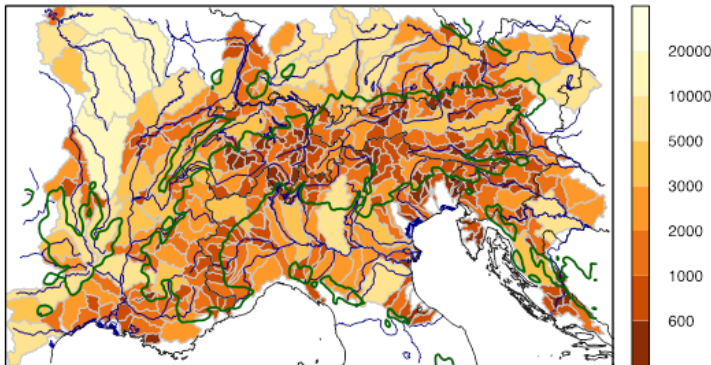
# Main results

- Regional reanalyses:
  - additional value compared to global reanalyses
  - tendency to overestimate precipitation amounts and frequency, especially in complex terrain (Alps, Norway)
  - regional reanalysis shows better small scale structures and performance than observational gridded datasets in region of low station density (except wet-day frequency)
  - COSMO6-REA and COSMO-ENS best performance
  - Fennoscandia: HARMONIE best performance
- Downscaling:
  - additional value in regions with dense station network
  - improvement especially for fraction of wet days
- **Model error mostly bigger than uncertainty of the reference dataset (especially for days >10mm/d precipitation and global reanalyses)**
- **Scale dependent analyses: more information about the performance of the datasets depending on the application/scale of interest. Biggest differences from the reference and the lowest Brier skill score are found in complex topography, small catchment sizes and for higher precipitation amounts**
- Annual cycle is mostly well reproduced in all datasets

# Scale dependency

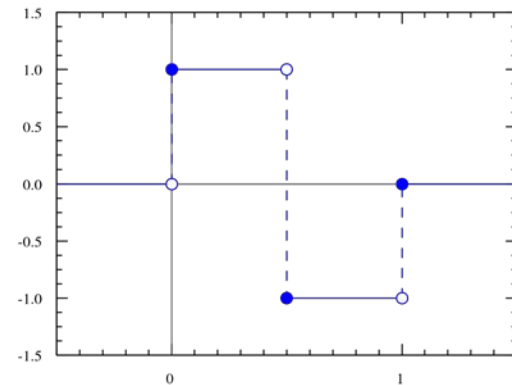
- Skill of models, uncertainty depend on scale
- Scale dependent evaluation

Two methods



## «Polygoning»

Scale separation on catchment areas  
of different size classes



## «Wavelet»

Mathematical-theoretical scale separation



# Verification method: Wavelet

Scale decomposition approach based on the Haar wavelet filter

Key points:

1. Decompose reanalysis and observation fields into the sum of spatial components on different scales (wavelets)
2. Perform verification on different scale components, separately

Account for the field coherent spatial structure:

- Assess scale structure
- Bias, error and skill on different scales

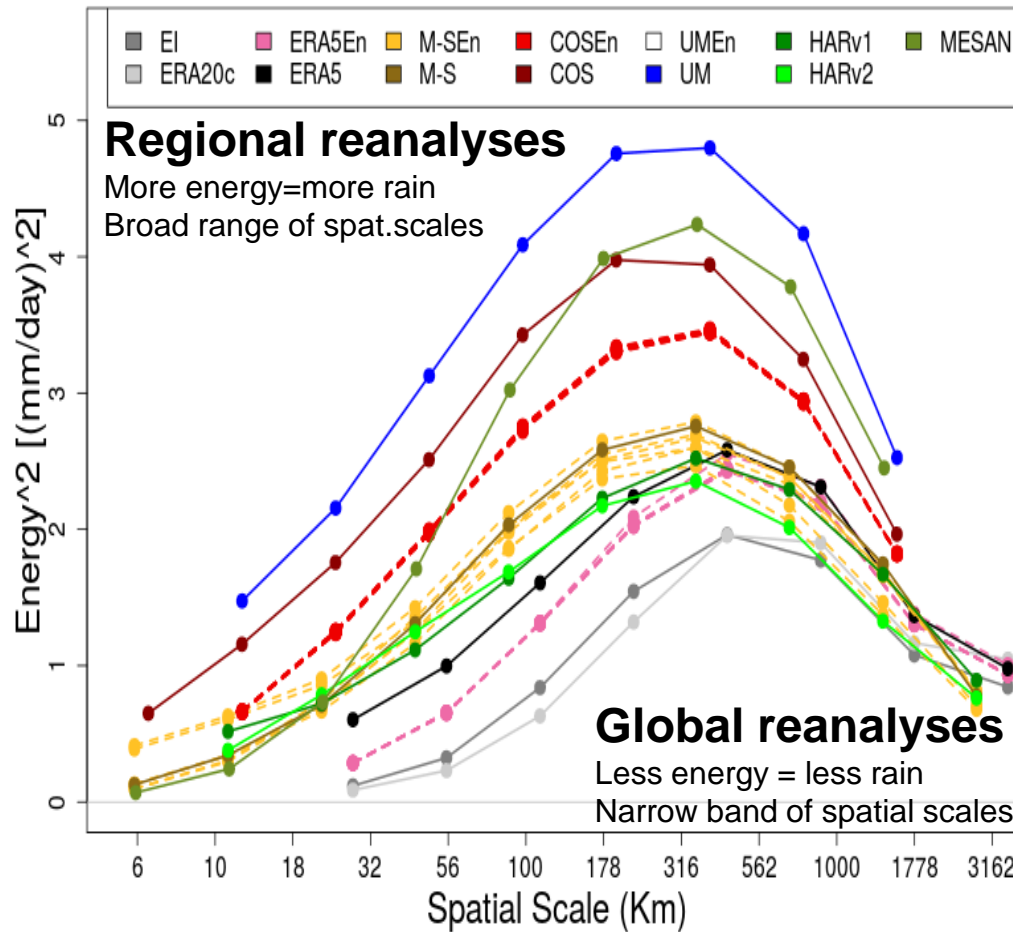
References: Casati et al. (2004), Casati (2010)

# Wavelet: Europe

no regridding

time period (model-dependent): 2000-2016

days with more than 5% of the domain with  $> 1$  mm/d



Mean Energy<sup>2</sup> as a function of the spatial scale (i.e. resolution)

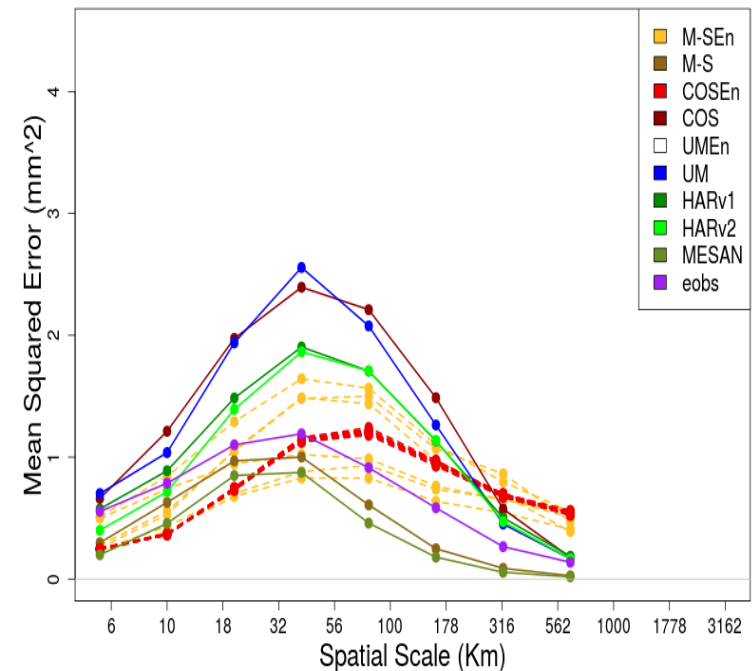
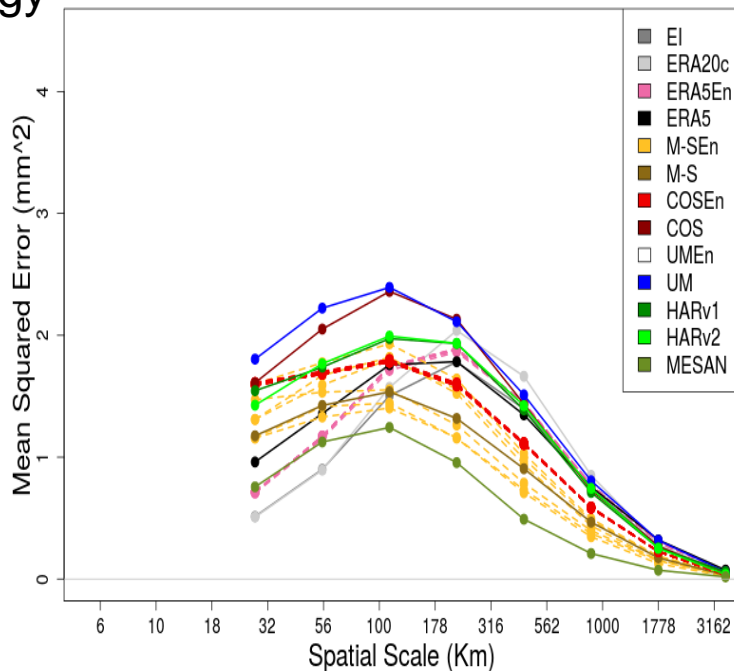


# Mean squared error (MSE)



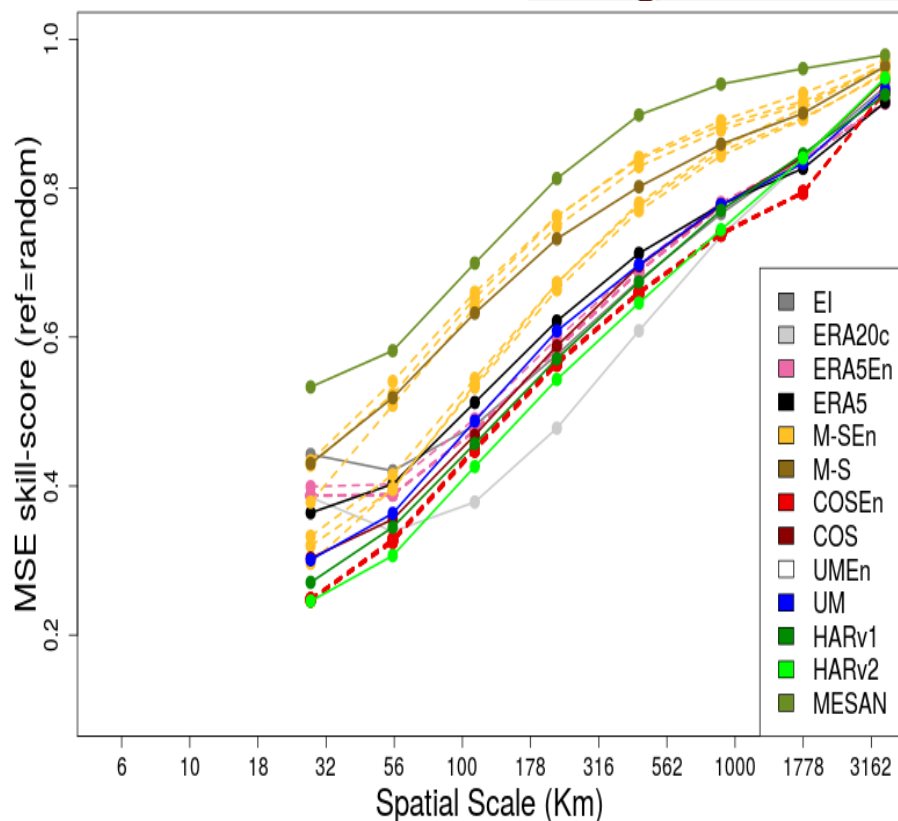
RRAs show greater MSE for smaller spat.scales, but they also have more energy

MSE peaks are 32-56 Km  
Ens differs from det

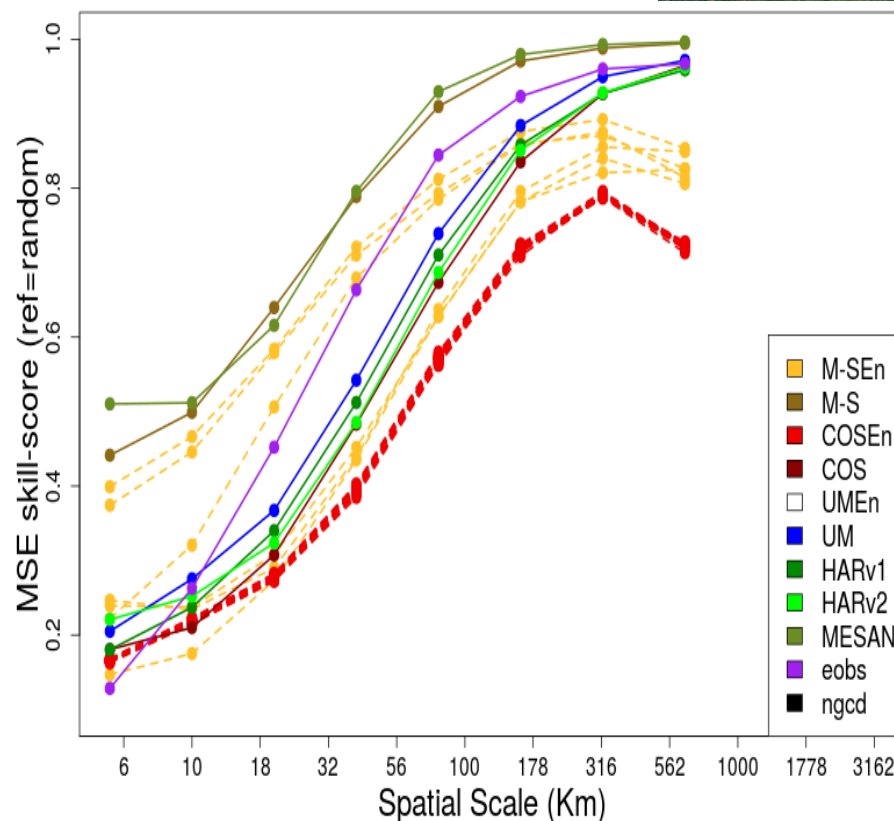


# Mean squared error (MSE)

European domain  
25km regridding  
E-Obs reference



Fennoscandia domain  
5km regridding  
NGCD reference

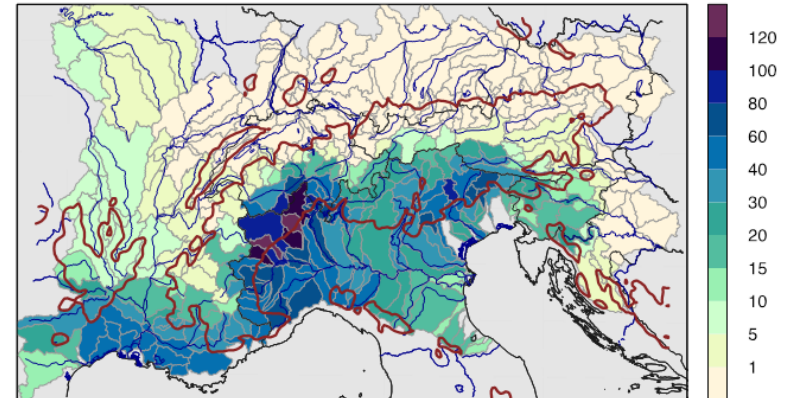




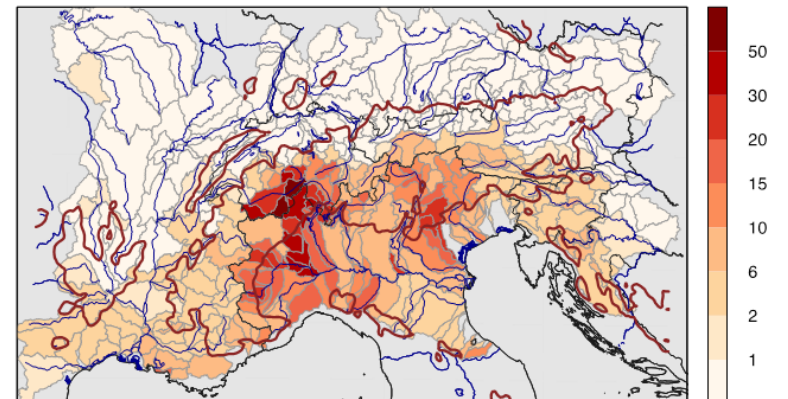
# Pan-Alpine Probabilistic Dataset

2008.11.04

ensemble median (mm)



90% ensemble inter-quantile (mm)



Area-mean precipitation over hydrological units in the Alps

Same data as for APGD

100 ensemble members

534 hydrological units,

- at four hierarchical scales
- 325 elementary units (EEA)

consistent within 68 super-units

daily, 1971-2008 (in process)

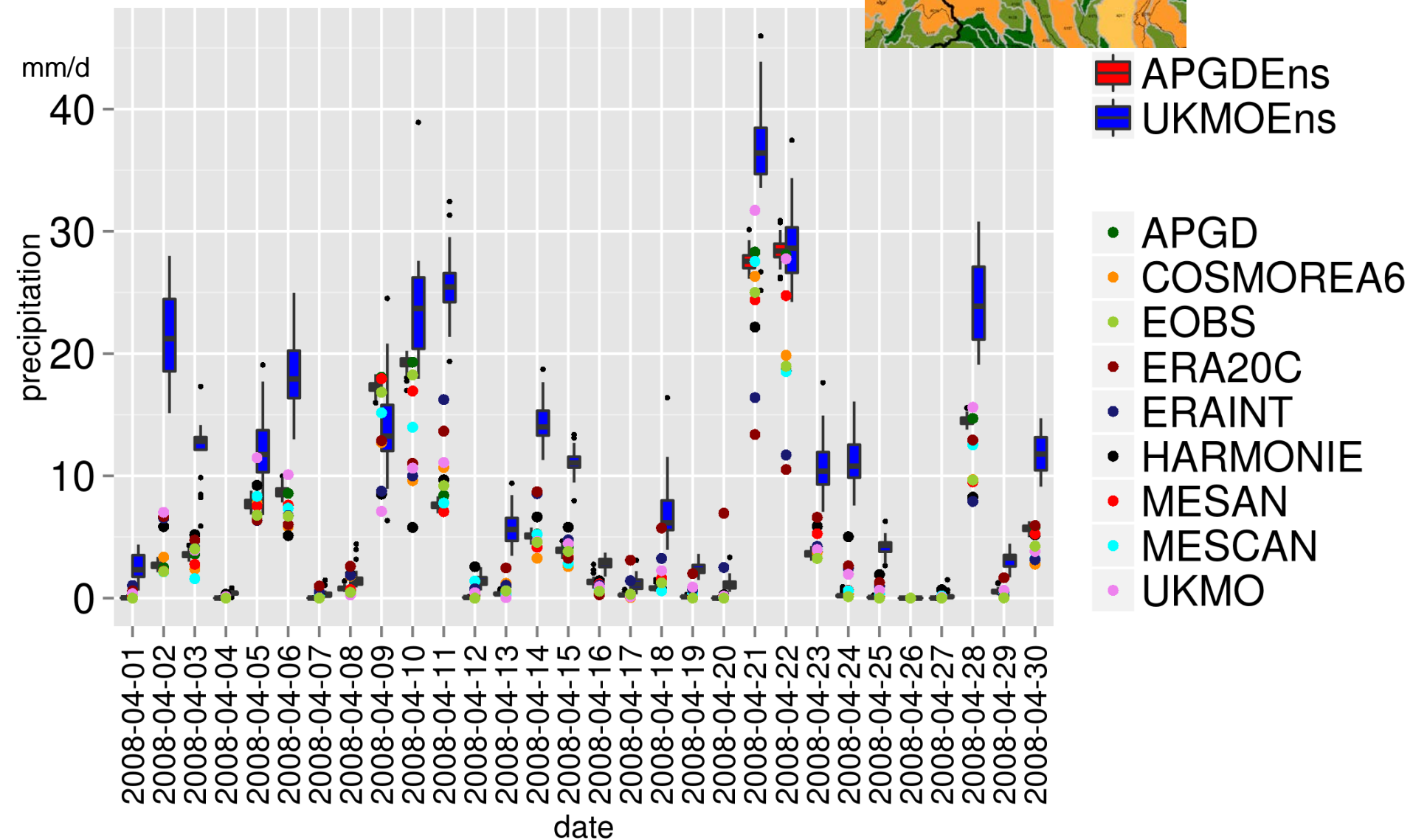
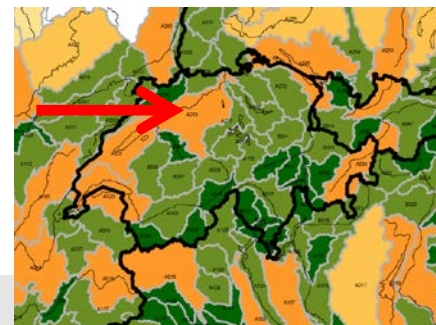
1981-1985, 2000-2008 processed

→ **APGDEns**



# Daily precipitation

Aare catchment (part), April 2008

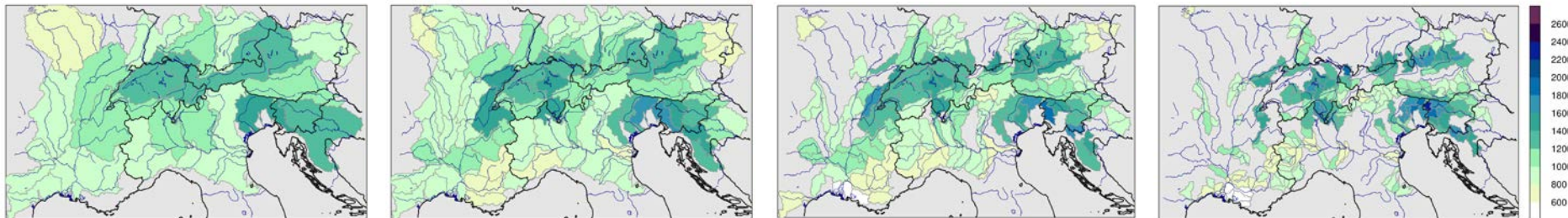




# Mean annual precipitation

2005-2008  
25 km grid  
Catchments

## APGDEnS

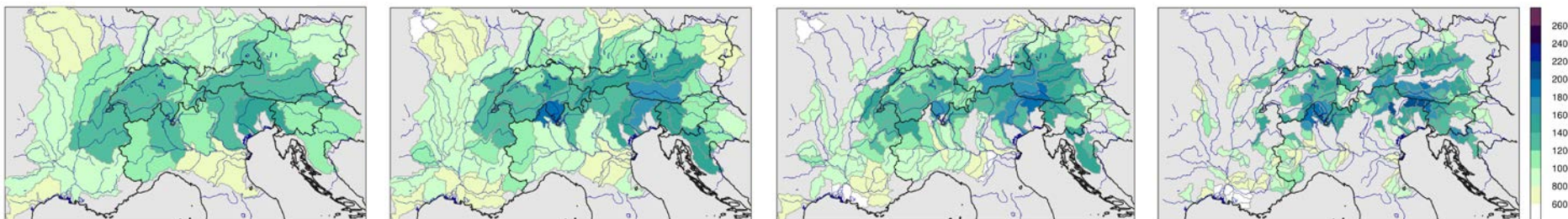


**Scale A**  
14'000-44'000 km<sup>2</sup>

**Scale B**  
3'500-14'000 km<sup>2</sup>

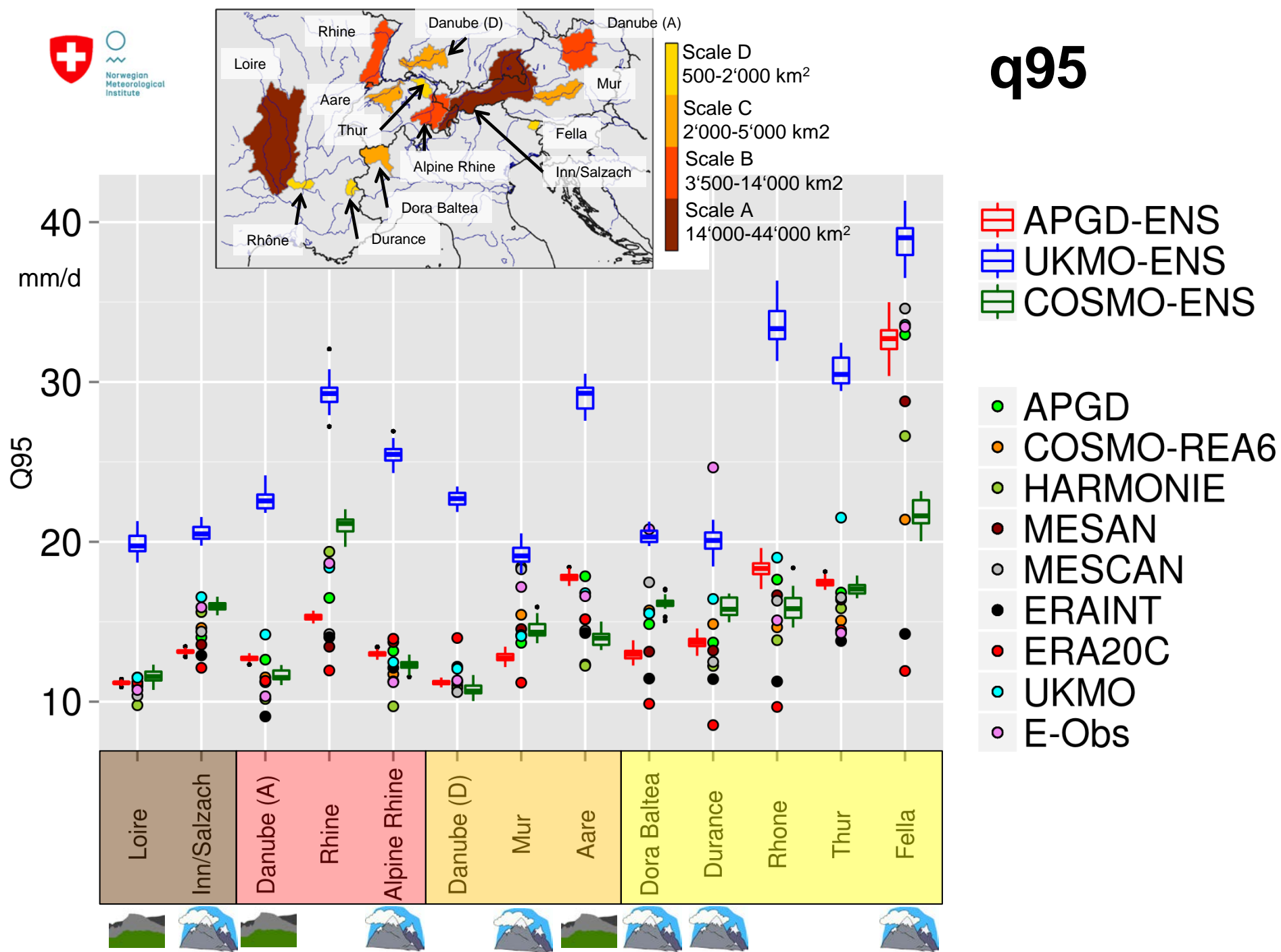
**Scale C**  
2'000-5'000 km<sup>2</sup>

**Scale D**  
500-2'000 km<sup>2</sup>

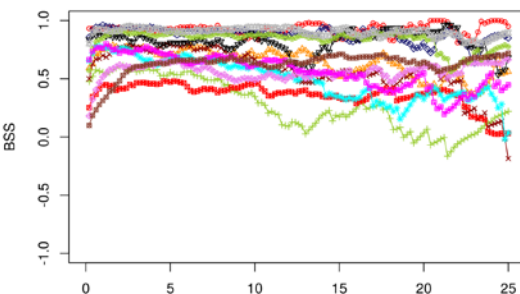


## MESCAN

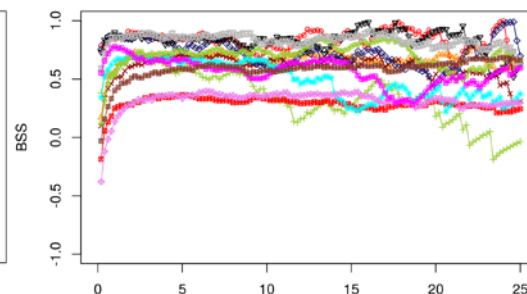
# q95



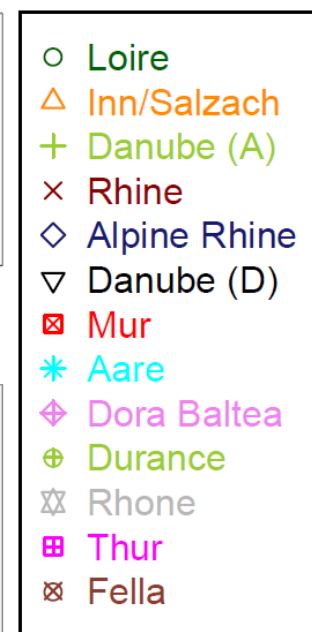
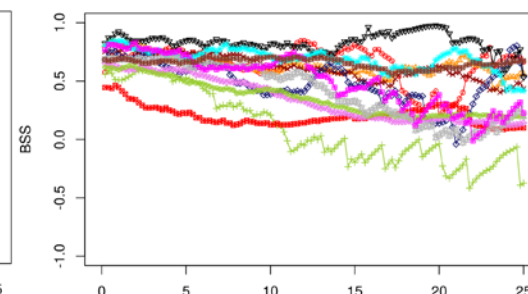
MESAN



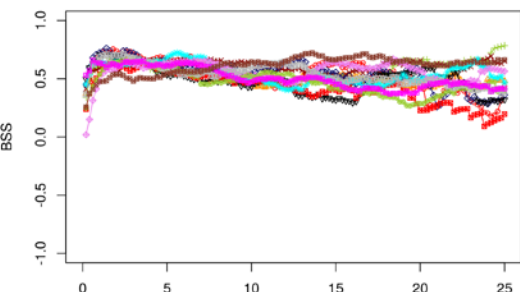
MESCAN



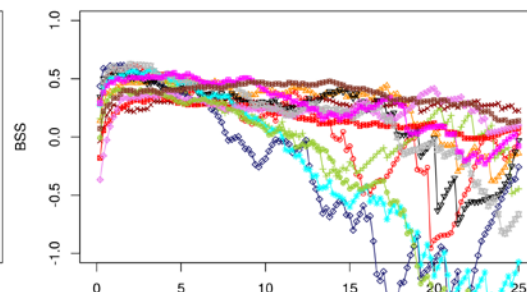
E-Obs



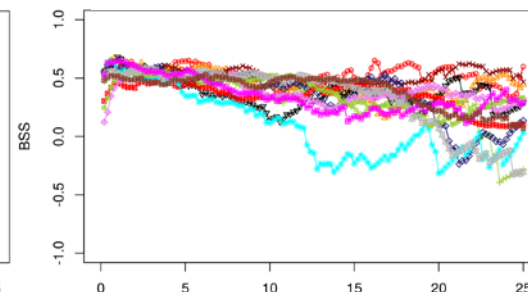
UKMOdet



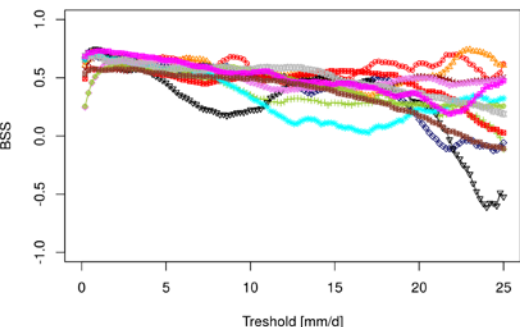
HARMONIE v1



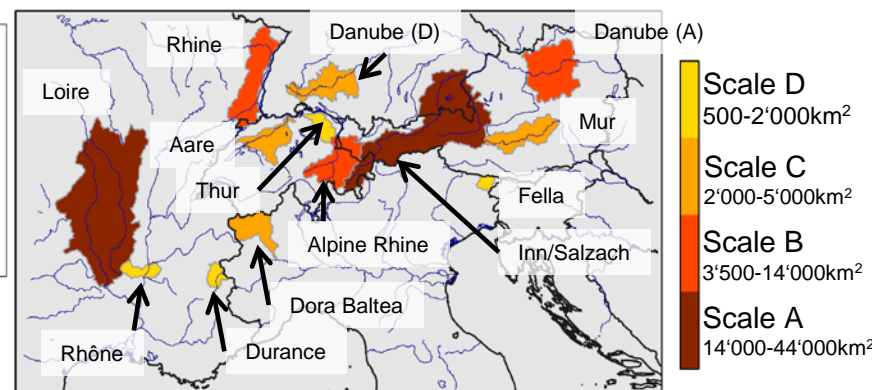
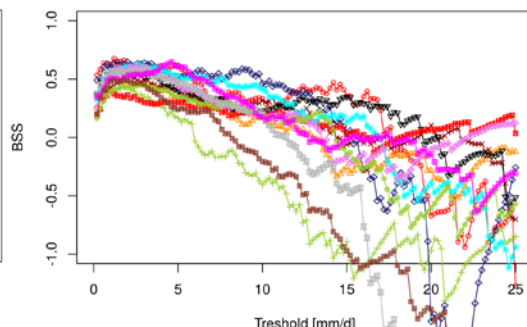
COSMO6-REA



COSMOEns



ERAINT







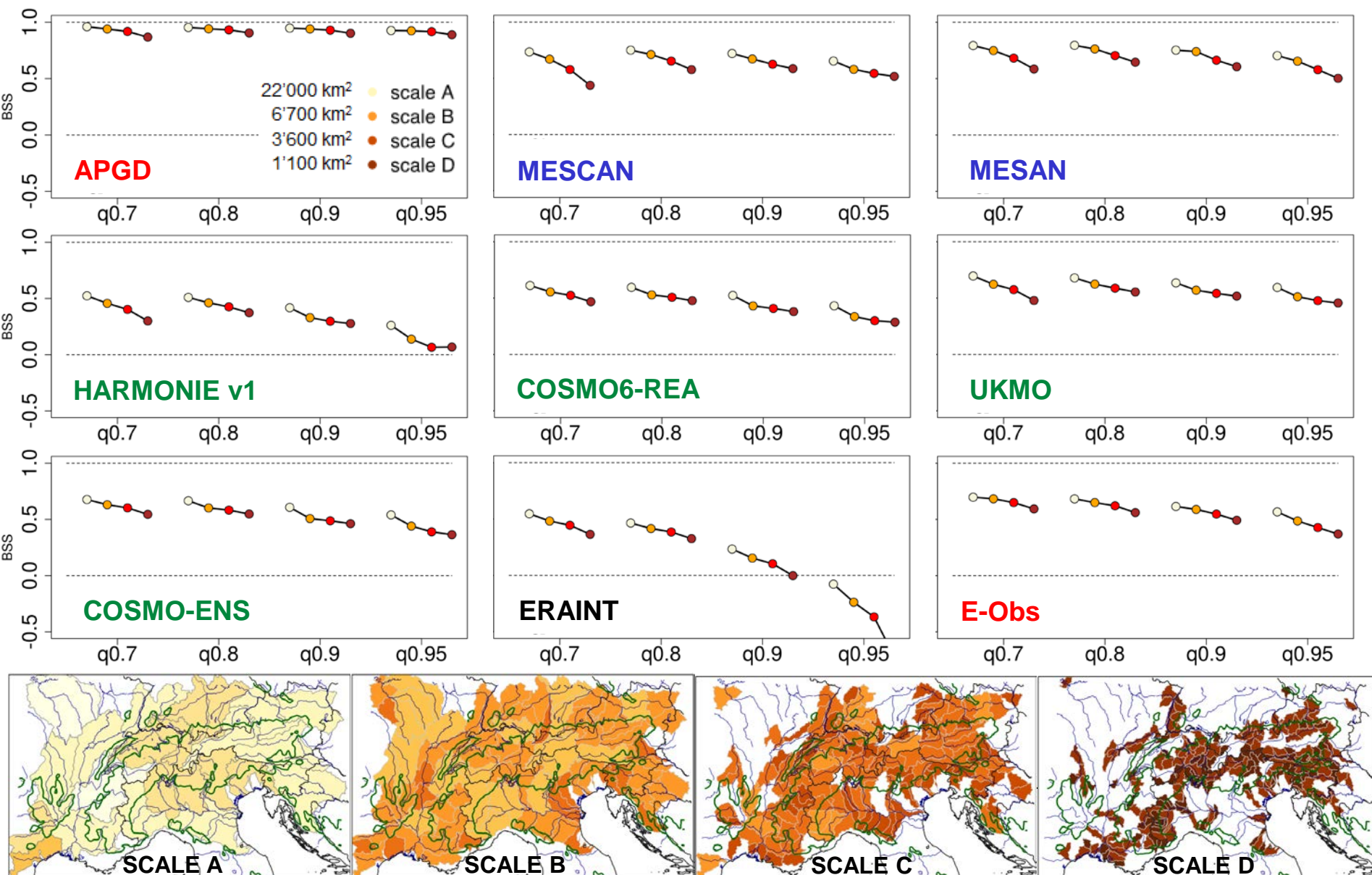
# BSS vs scale

$$\frac{1}{n} \sum_i^n (Y_i - O_i)^2$$

(forecasted/observed  
event probability)

Gridding  
Regional Rean.  
Downscaling  
Global Rean.

2006-2008  
25 km grid  
APGD\_Ens ref

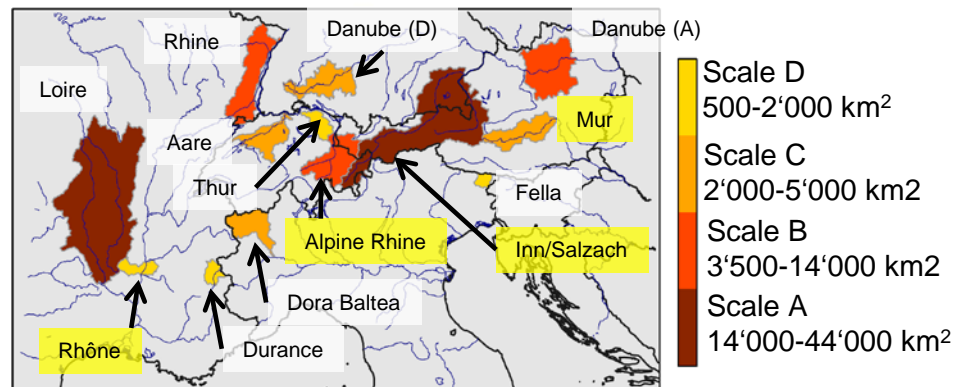


# Main results

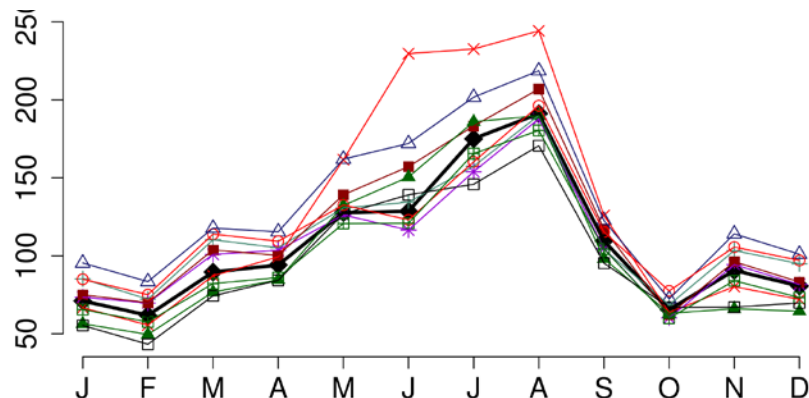
- Regional reanalyses:
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- Scale dependent analyses: more information about the performance of the datasets depending on the application/scale of interest. Biggest differences from the reference and the lowest Brier skill score are found in complex topography, small catchment sizes and for higher precipitation amounts
- **Annual cycle is mostly well reproduced in all datasets**

# Yearly cycle

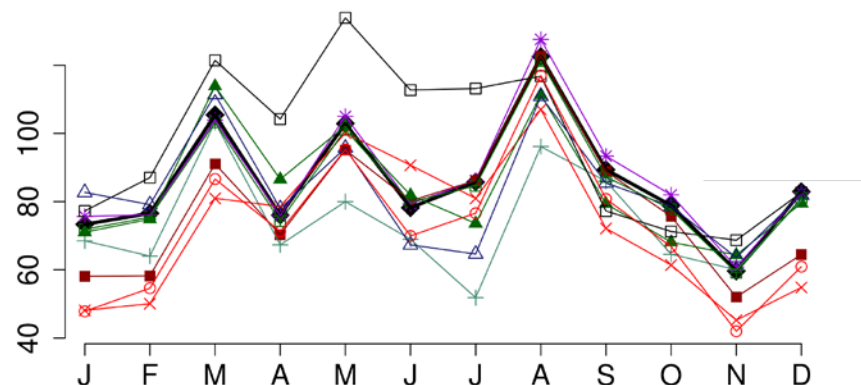
Monthly mean total precipitation  
2005-2008 (25 km grid)



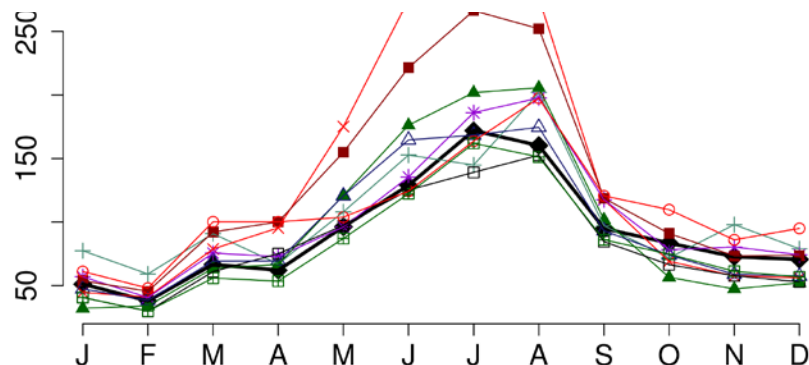
Inn/Salzach



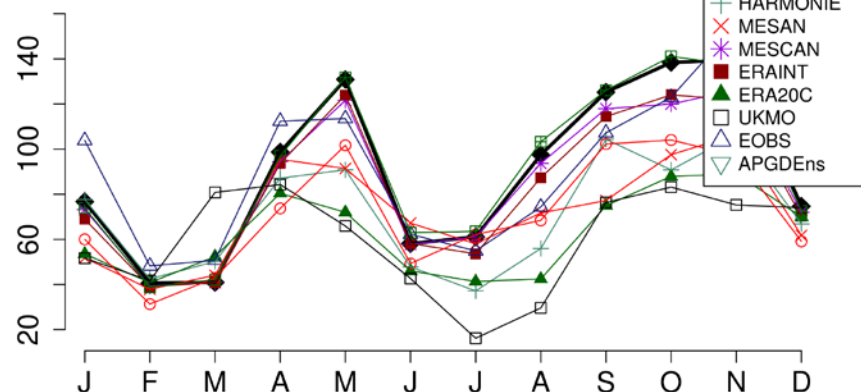
Alpine Rhine



Mur



Rhône



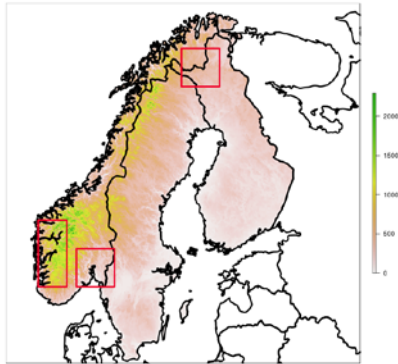




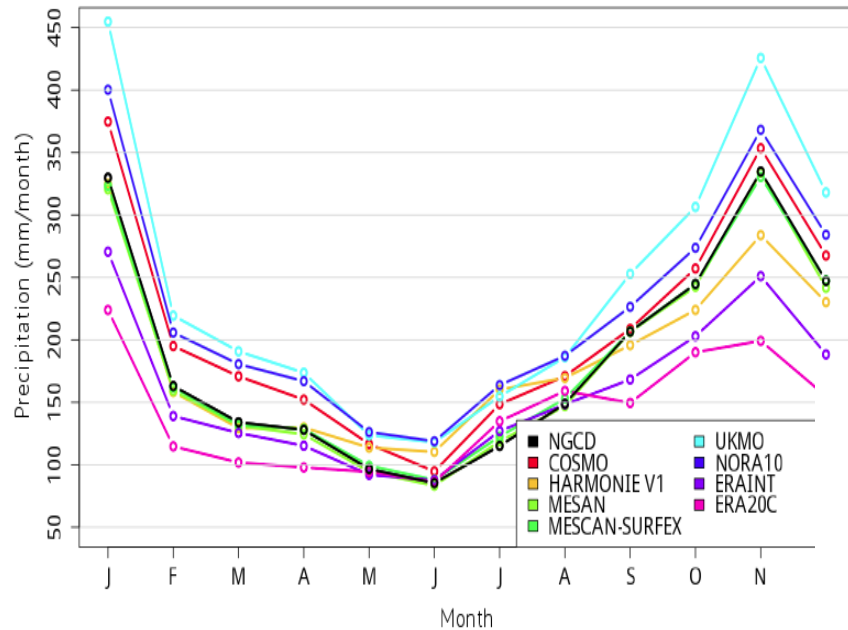
Norwegian  
Meteorological  
Institute

# Yearly cycle

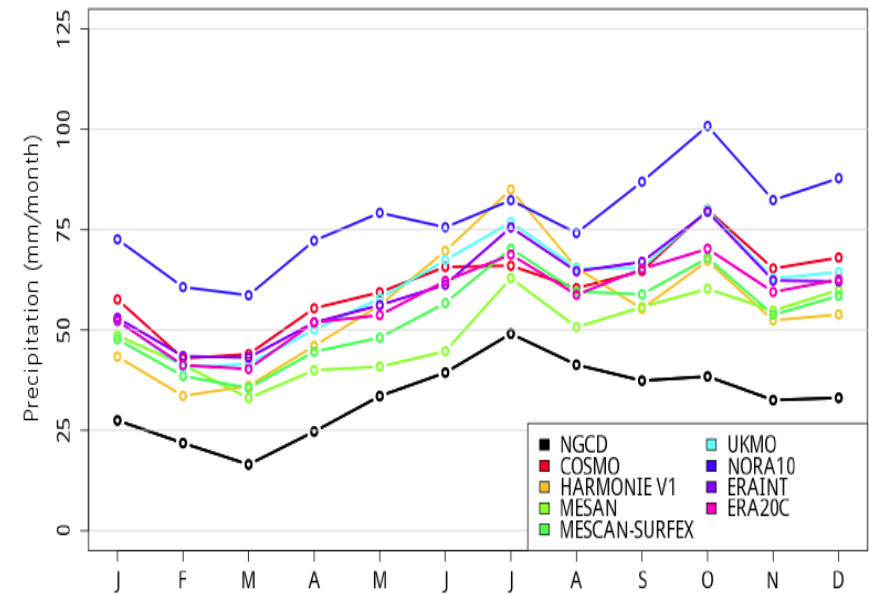
Monthly mean total precipitation  
2005-2008 (25 km grid)



## West coast



## Lapland



## Oslo Area

