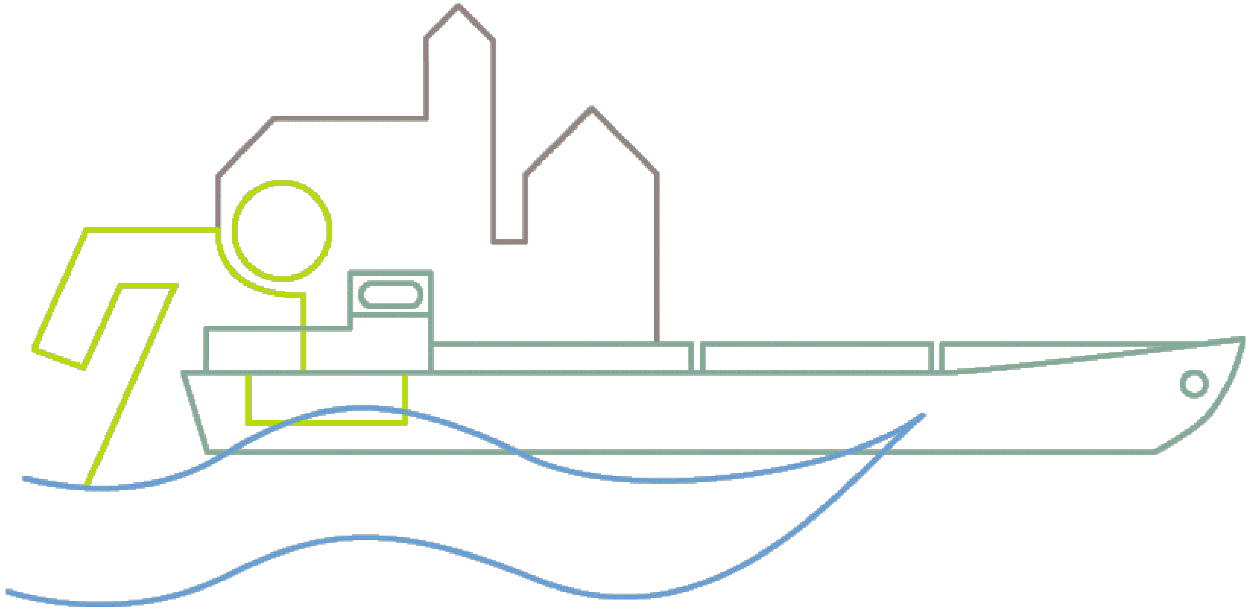

Impact of hydrological model uncertainty on predictability of seasonal streamflow forecasting in the River Rhine Basin

Bastian Klein, Dennis Meißner
Department M2 - Water Balance, Forecasting and Predictions
German Federal Institute of Hydrology, Koblenz

2018 HEPEX Workshop: "Breaking the barriers"
February 6-8, 2018 University of Melbourne, Melbourne, Australia

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Motivation

- Skillfull seasonal forecasts could be a valuable tool for decision making in the water sector
- There is a high demand on monthly to seasonal forecasting products in the navigation sector

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Motivation

- Skillfull seas … decision making in th…
- There is a hi… ting products in t…

	Required Lead-time of forecast product(s)			
	short-range (≤ 7 days)	medium-range (≤ 14 days)	monthly (≤ 1 month)	seasonal (≤ 3 months)
Transport / logistic companies (carrier)				
Optimization of current vessel load	x			
Shifting cargo from shipping to another mean of transportation in case of low flows		x	x	
Scheduling of a complete transport cycles (up- and downstream trip)		x		
Optimized deliverable of goods arriving via maritime vessels		x	(x)	
Scheduling of special transport (heavy / large load)		(x)	x	
Optimized timing of transports to avoid additional costs in case of low flows		(x)	x	x
Adaption of fleet / usable transport capacity			x	x
Industrial companies (consignor)				
Shifting cargo from shipping to another mean of transportation in case of low flows		x	x	
Building up stocks (e.g. coal power plants, refineries etc.)		x	x	
Hire additional storage space for industrial goods (interim storage facility)		x	x	
Guarantee security of energy supply (Redispach)		x	x	
Waterway management / Strategic IWT Management				
Planning / Timing of measurement projects	x	x	(x)	
Timing / suspending of dredge operations	x	x		
reduction of dredge operations	(x)	x	x	
Economic Outlook			(x)	x
Harbour Management /Delta Waterway management				
Timing / suspending of dredge operations		(x)	x	x
reduction of dredge operations		(x)	x	x

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Motivation

- Skillfull seasonal forecasts could be a valuable tool for decision making in the water sector
- There is a high demand on monthly to seasonal forecasting products in the navigation sector
- For Central Europe no (local) operational seasonal streamflow forecasting systems are available (low skill of meteorological seasonal forecasts in this region)
- Many studies only focus on meteorological forcings and neglect hydrological model uncertainty

➔ Analysis of seasonal forecast skill based on different hydrological models with different model structure and spatial resolution

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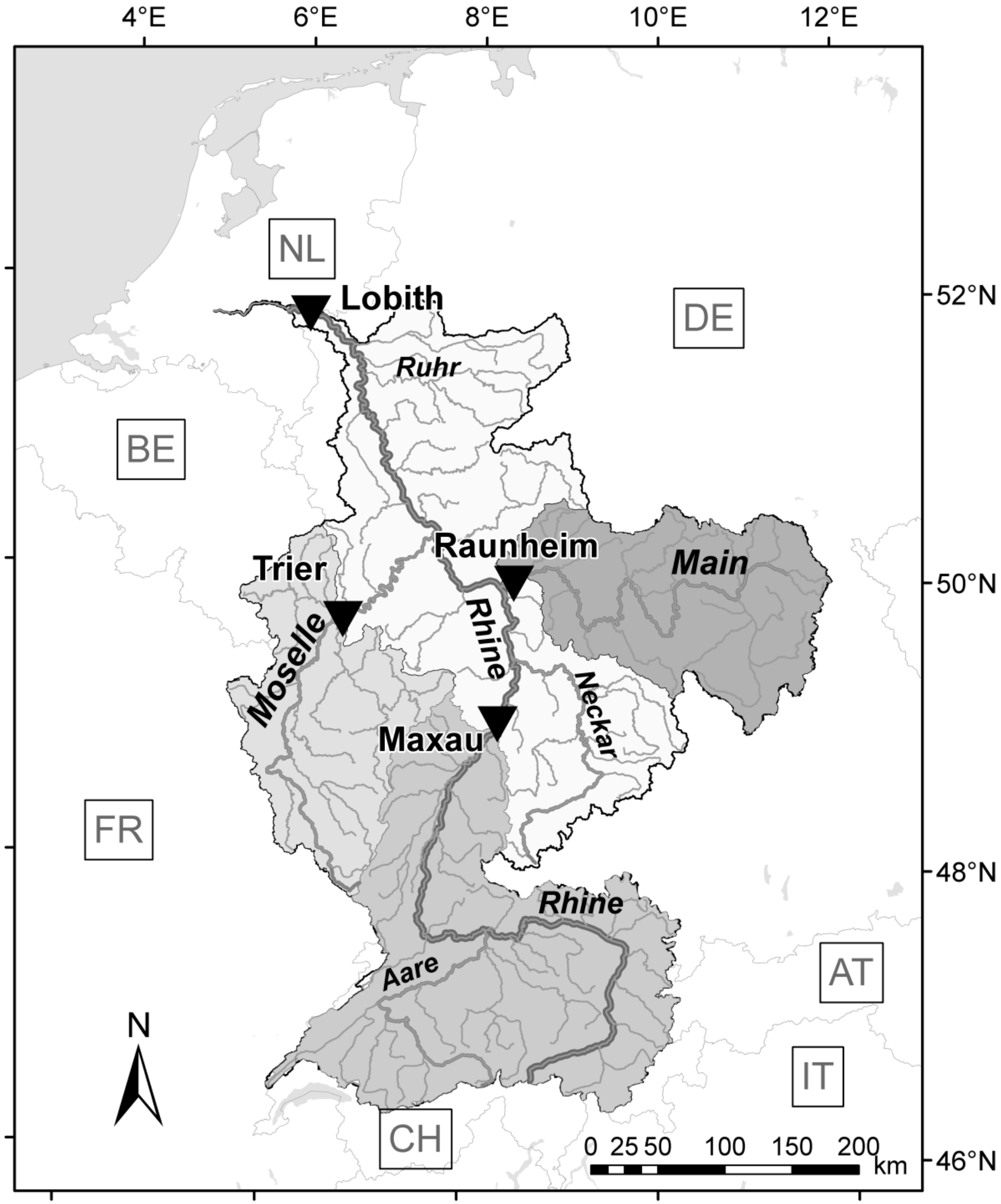
Study Area



- The waterway Rhine is one of the world's most frequented inland waterways
- Main tributaries of the free flowing waterway Rhine vulnerable to hydrological impacts: Upper Rhine (here up to gauge Maxau), Moselle and Main
  ~ 2/3 of the River Rhine catchment area
  ~ 80% of the flow
- Different flow regimes

Catchment	Area	MQ (1981-2010)
Upper Rhine (Maxau)	50 196 km²	1273 m³/s
Moselle (Trier)	23 857 km²	296 m³/s
Main (Raunheim)	27 142 km²	223 m³/s
Rhine (Lobith)	160 800 km²	2305 m³/s

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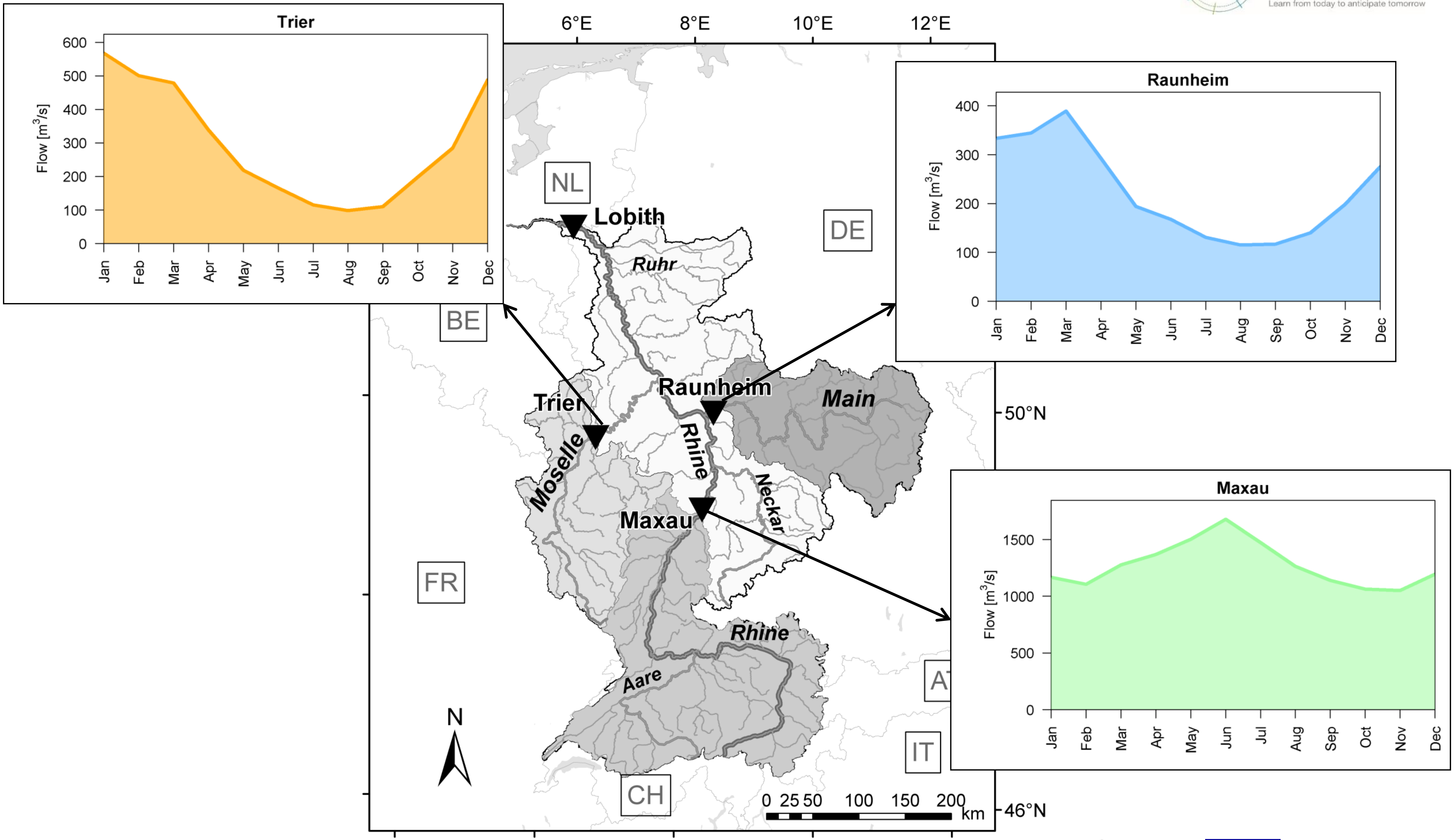
Study Area



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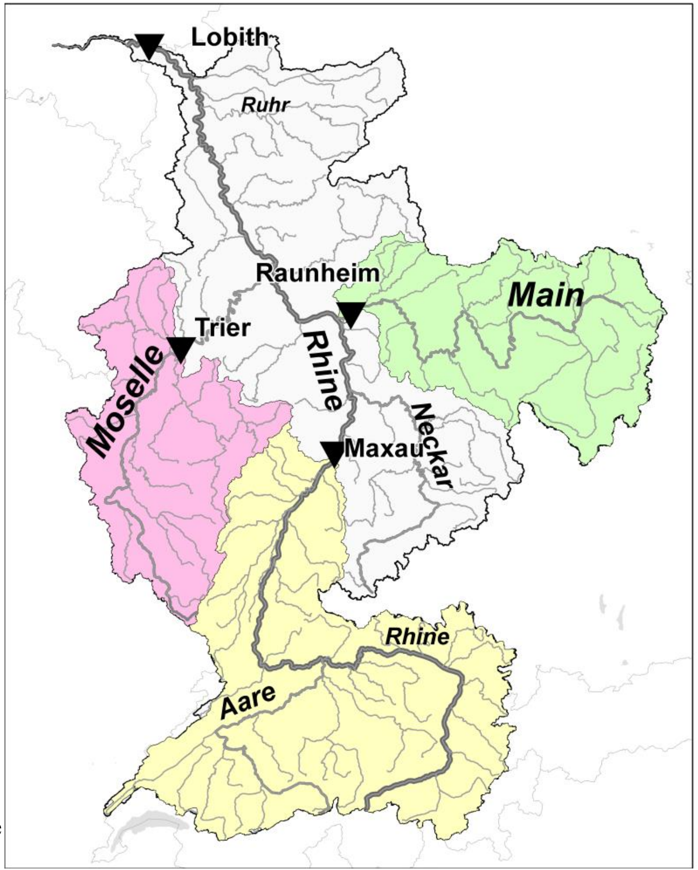
Hydrological models

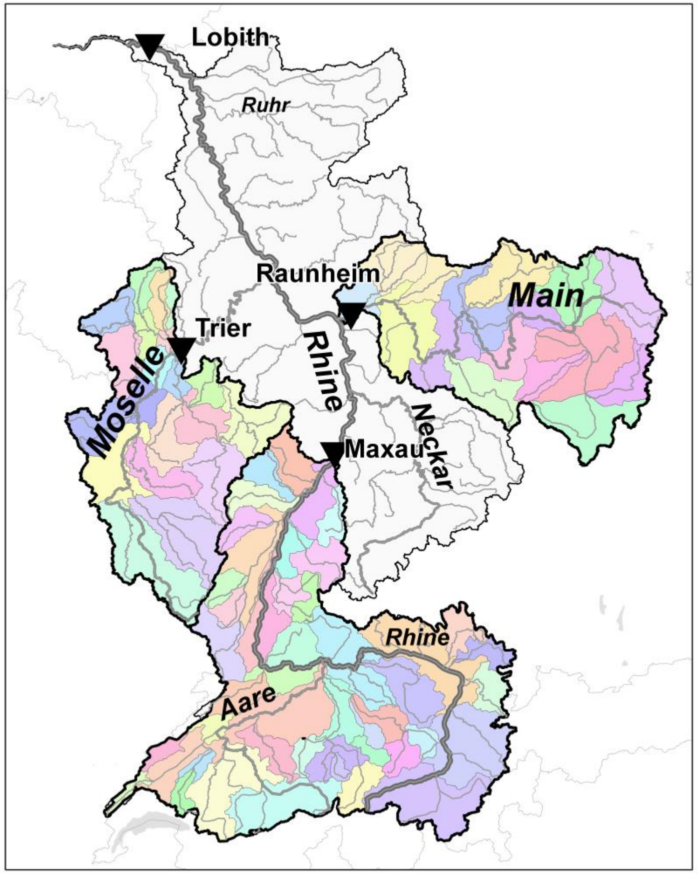
Model Complexity →

Spatial Resolution →

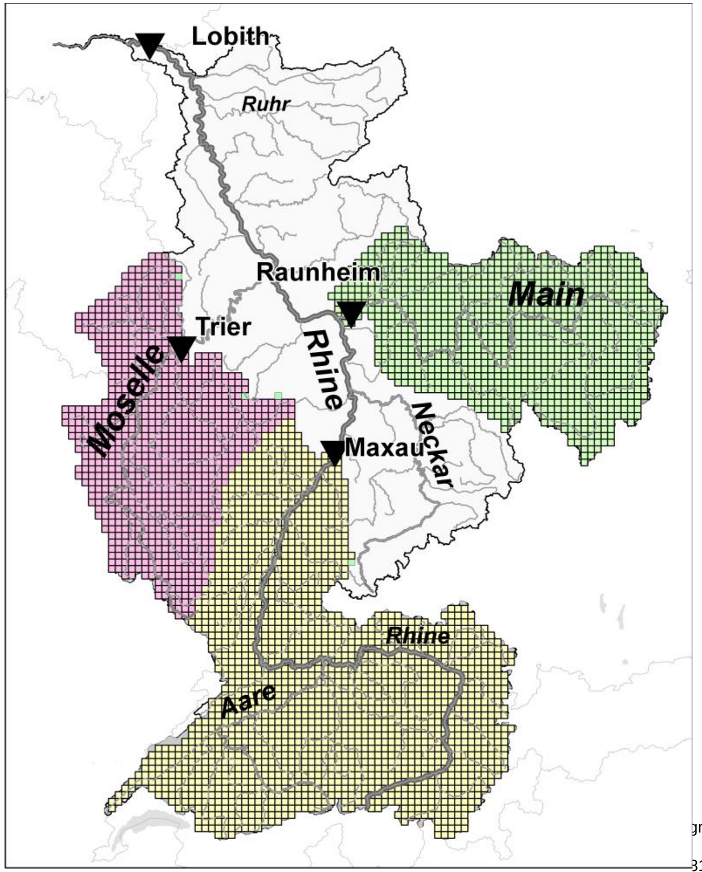
GRXJ-CemaNeige
lumped



HBV
semi-distributed
(200 – 3000 km²)



LARSIM
distributed
(5 km x 5 km)



Calibration

- meteo input precipitation, temperature, global radiation from HYRAS data set (Rauthe et al. 2013) 1951-2006
- Calibration period 1991-2006 / Validation period 1976-1990
- Automatic calibration SCE-UA (Duan et al. 1994) optimization criteria: Mean of NSE_{day}, $logNSE_{day}$, KGE'_{mon}

Gauge	NSEday 1991-2006	NSEday 1976-1990	KGEmon 1991-2006	KGEmon 1979-1990
Maxau (Rhine)	GR6J: 0.87 HBV: 0.92 LARSIM: 0.91	GR6J: 0.87 HBV: 0.92 LARSIM: 0.93	GR6J: 0.96 HBV: 0.93 LARSIM: 0.92	GR6J: 0.93 HBV: 0.94 LARSIM: 0.96
Raunheim (Main)	GR5J: 0.92 HBV: 0.93 LARSIM: 0.91	GR5J: 0.92 HBV: 0.94 LARSIM: 0.92	GR5J: 0.98 HBV: 0.94 LARSIM: 0.93	GR5J: 0.98 HBV: 0.94 LARSIM: 0.95
Trier (Moselle)	GR5J: 0.96 HBV: 0.96 LARSIM: 0.95	GR5J: 0.92 HBV: 0.94 LARSIM: 0.93	GR5J: 0.99 HBV: 0.99 LARSIM: 0.95	GR5J: 0.92 HBV: 0.93 LARSIM: 0.95

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Calibration

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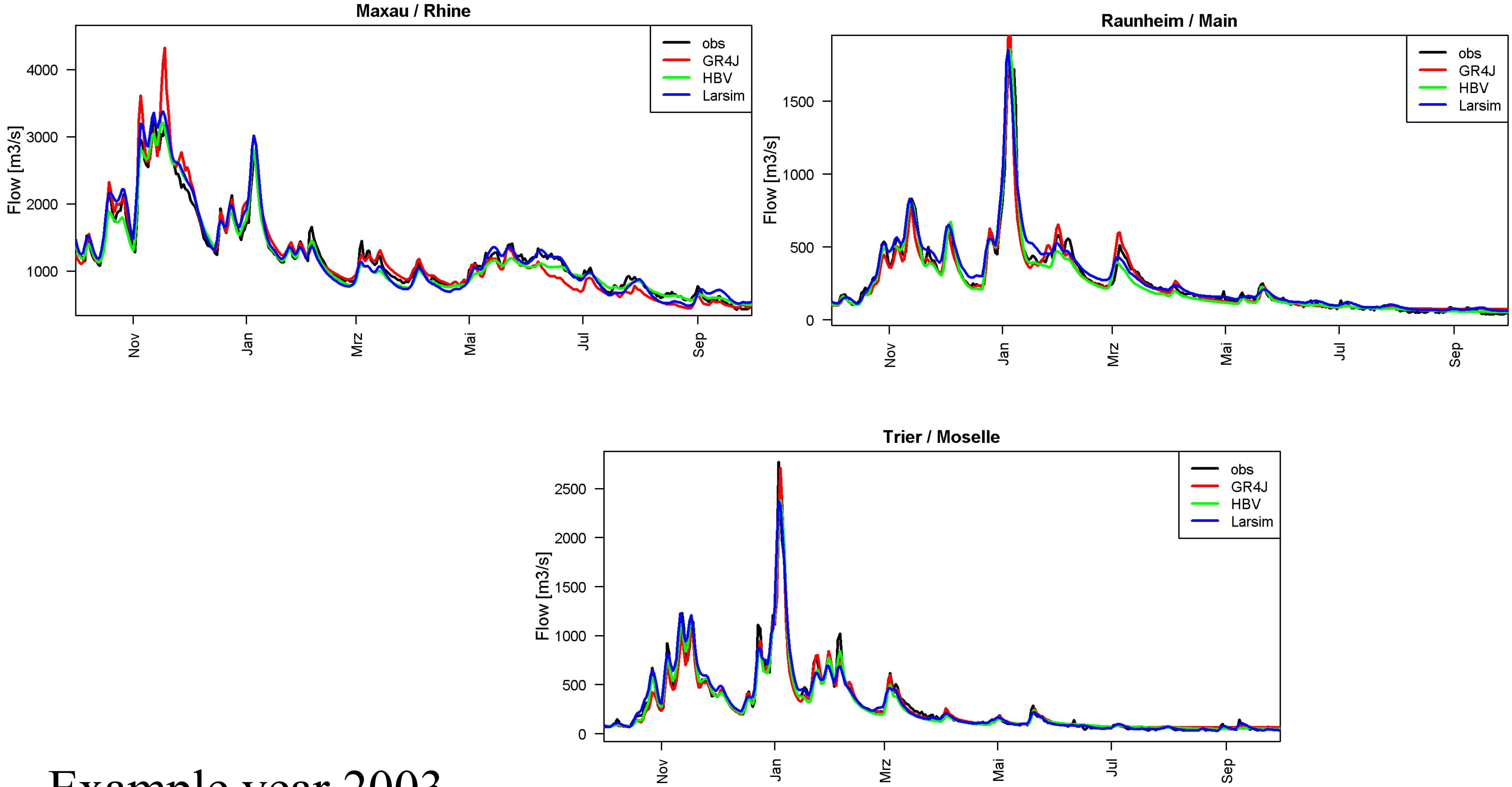
Learn from today to anticipate tomorrow



Example year 2003

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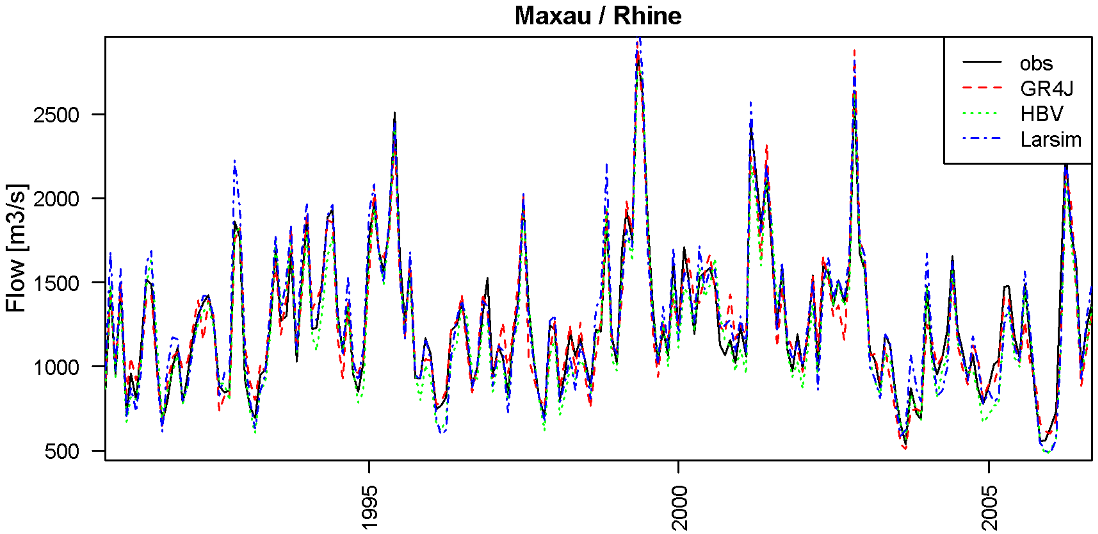
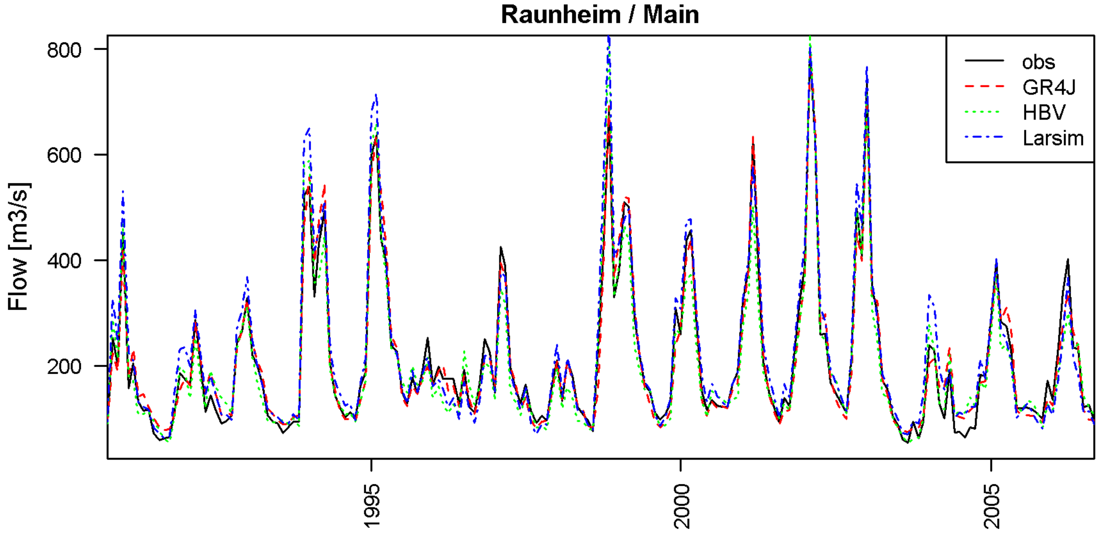
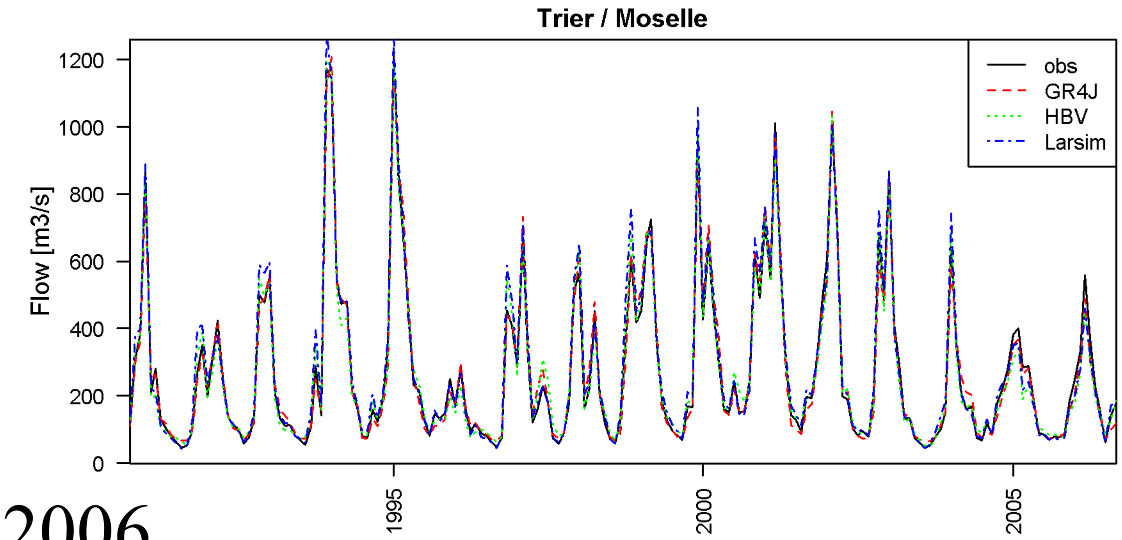
Calibration







Mean monthly values
validation period 1991 - 2006

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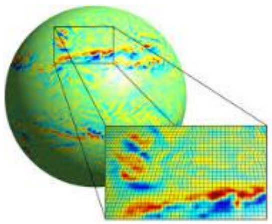
Methodology

Interpolation 50 x 50 km → **Bias/Drift Correction** → **Downscaling 5 x 5 km** →

P, T, (RG)

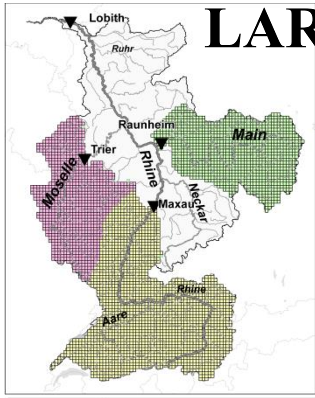


ECMWF S4
ERA-Interim

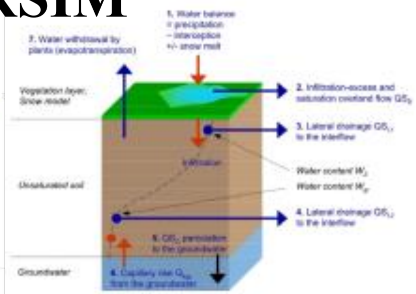
Interpolation subbasins → **Bias/Drift Correction** →

ECMWF
SEAS S4
Lead Time (months) 0 1 2 3 4 5 6 7

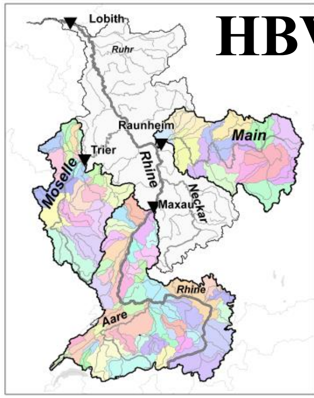
51 (15/51)



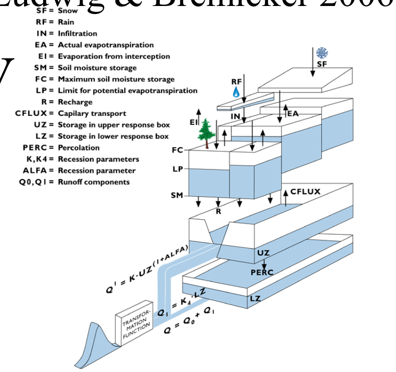
LARSIM



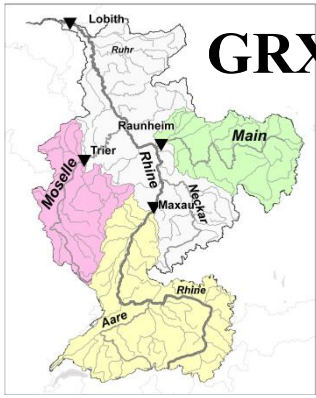
Ludwig & Bremicker 2006



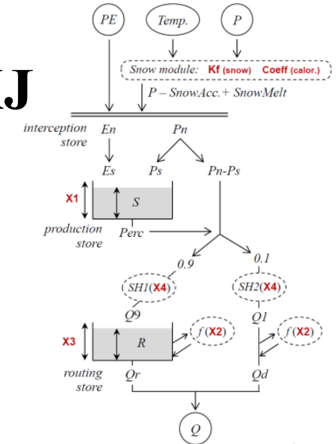
HBV



Lindström et al., 1997



GRXJ



Coron et al. 2014

Re-Forecast Period 1981-2016

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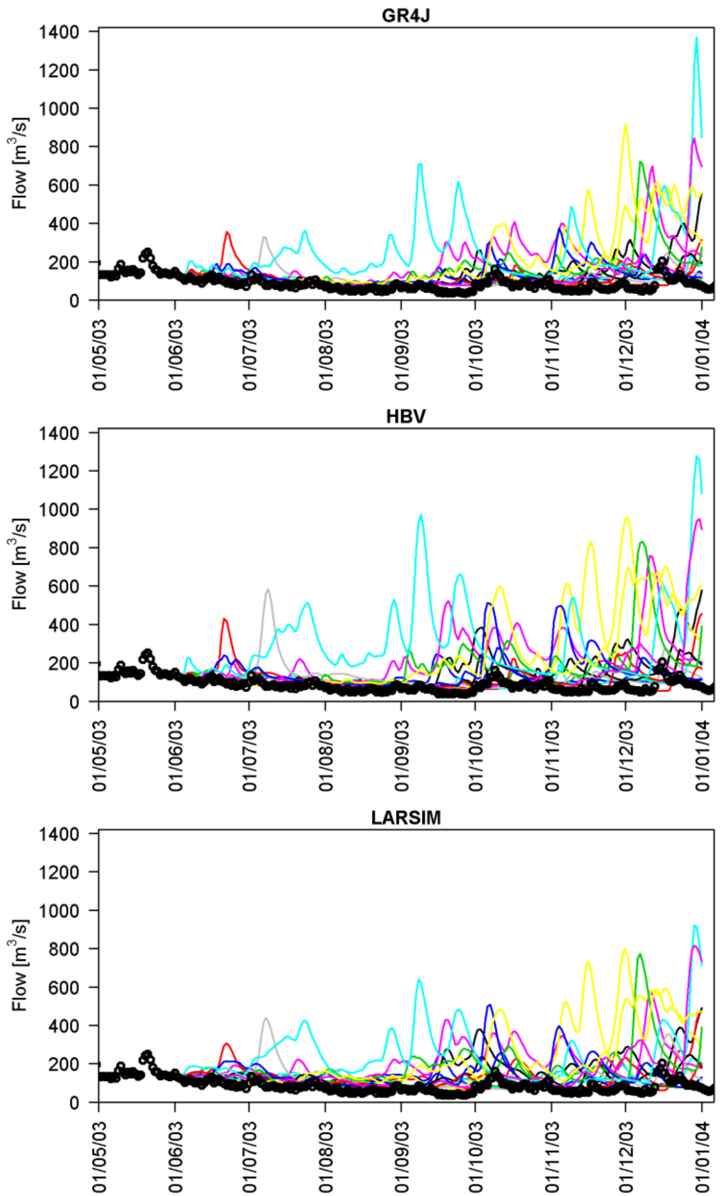
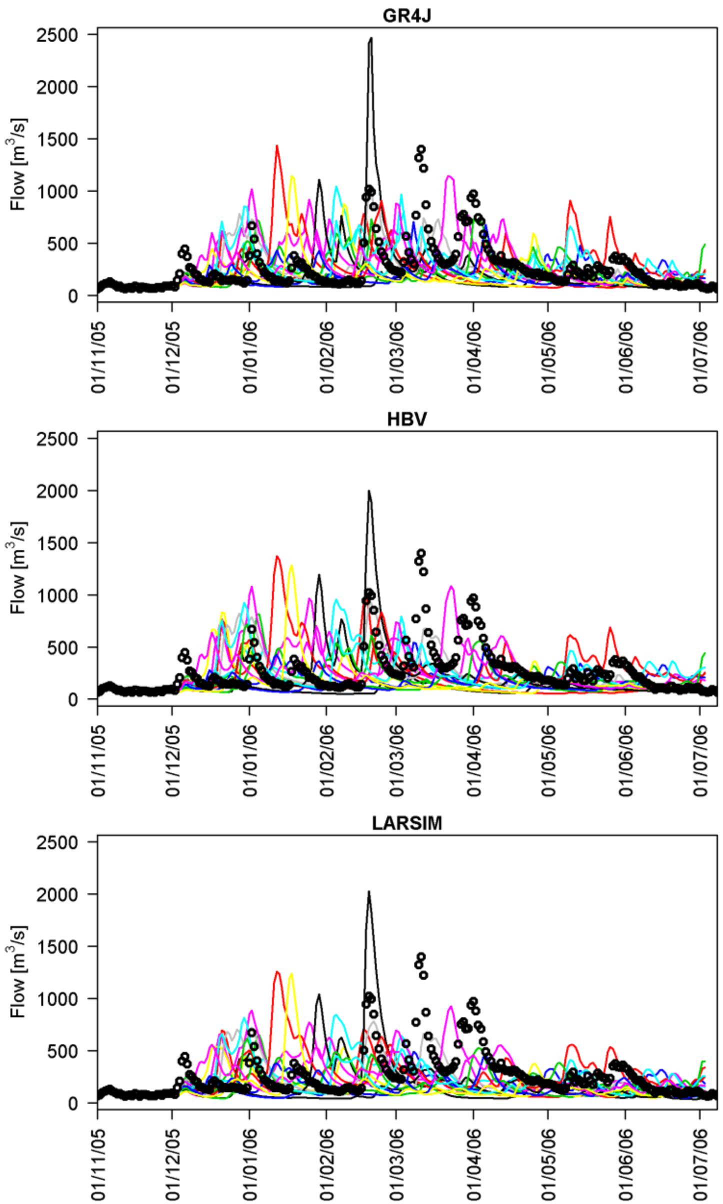
Example Forecasts



Maxau 2003-06-01



Trier 2005-12-01

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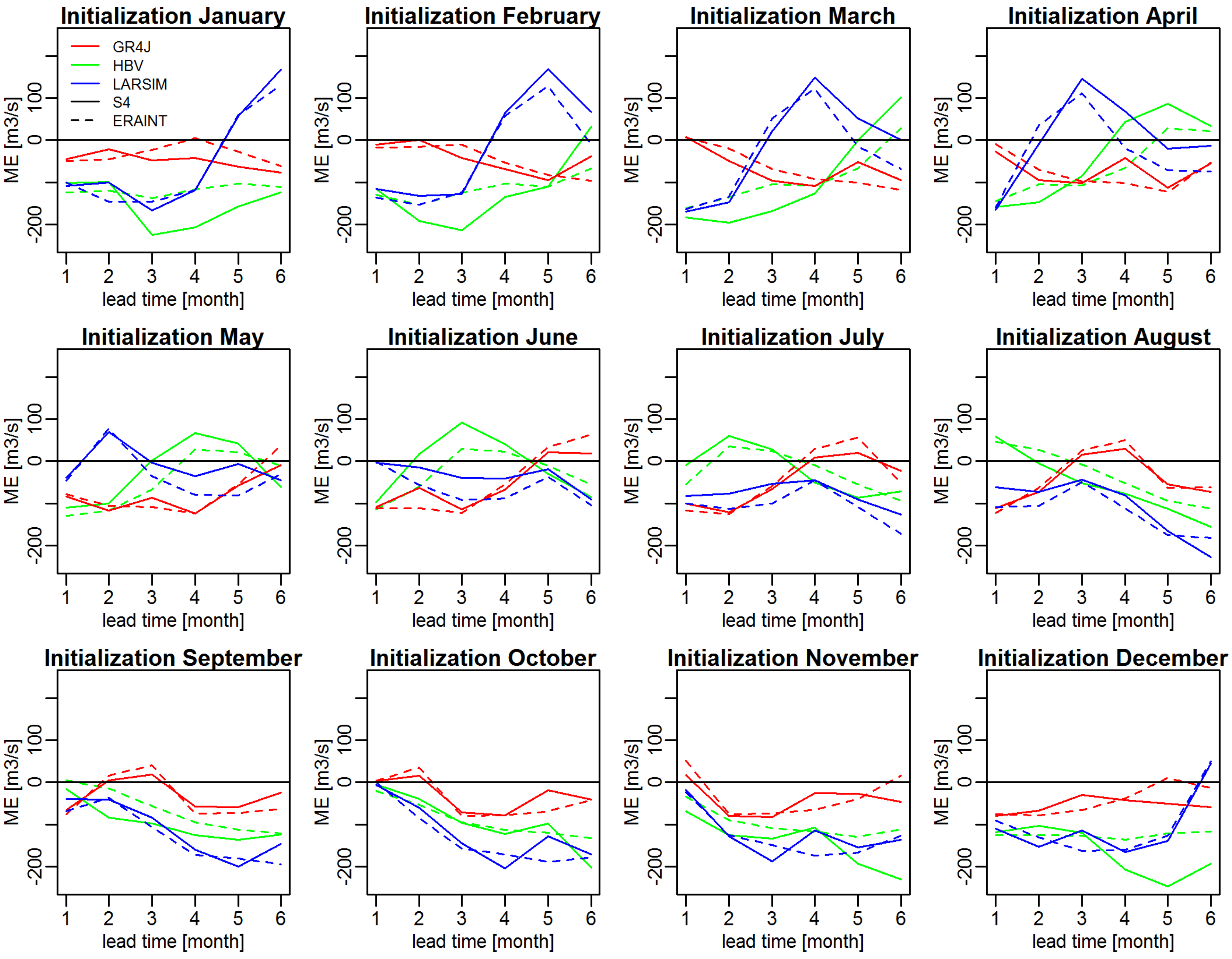
Verification ME (monthly means)



Gauge Maxau

Rhine

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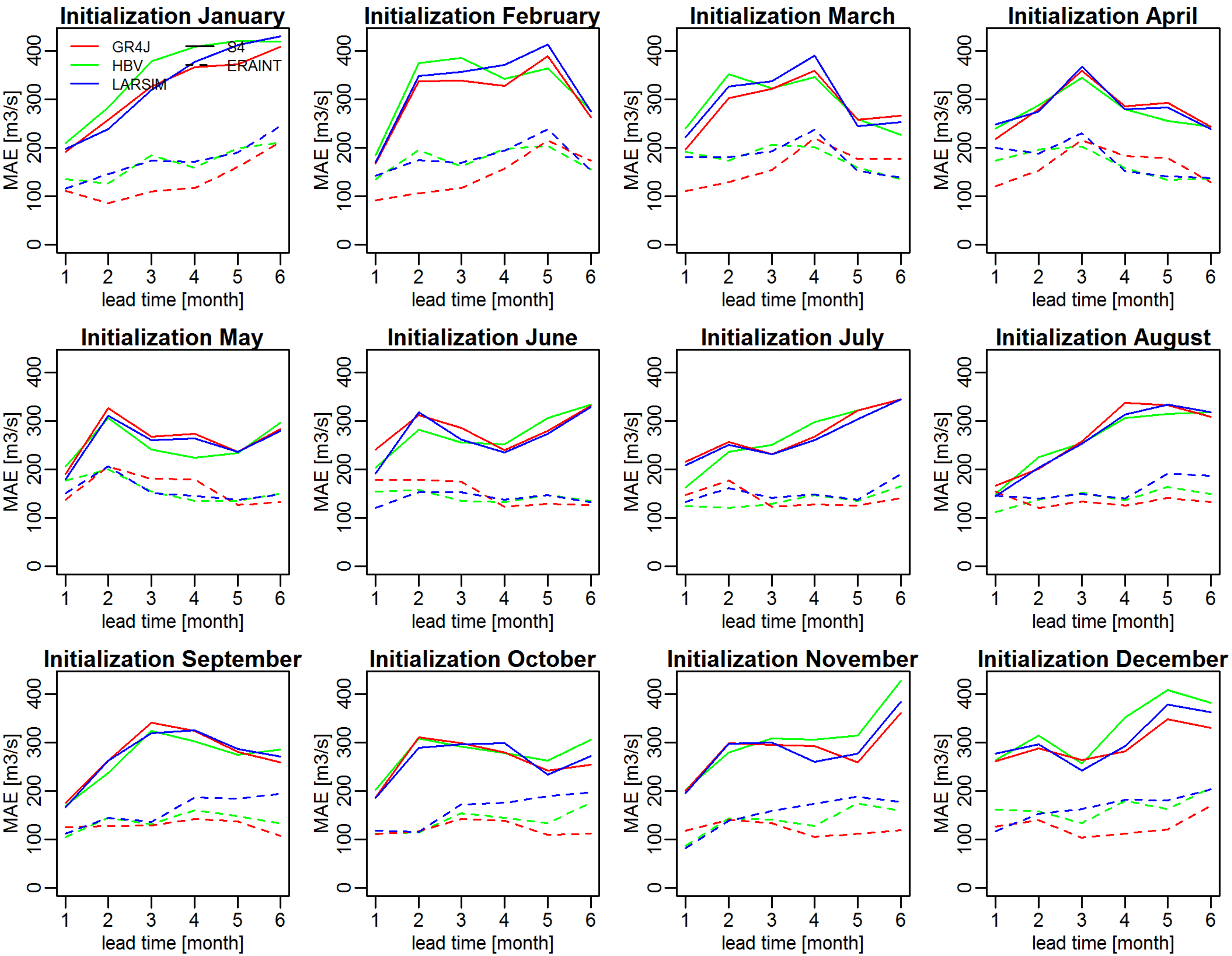
Verification MAE (monthly means)



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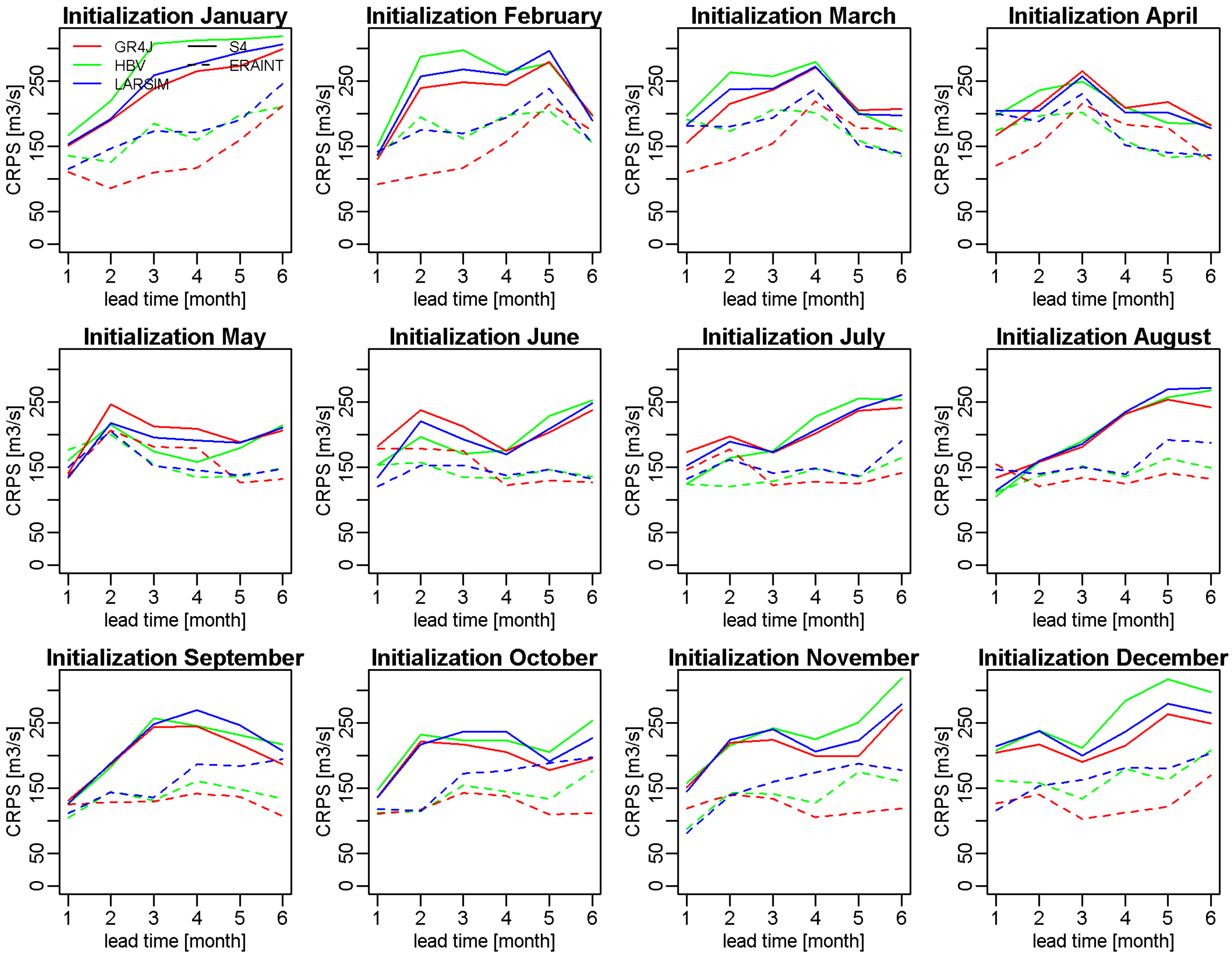
Verification CRPS (monthly means)



Gauge Maxau

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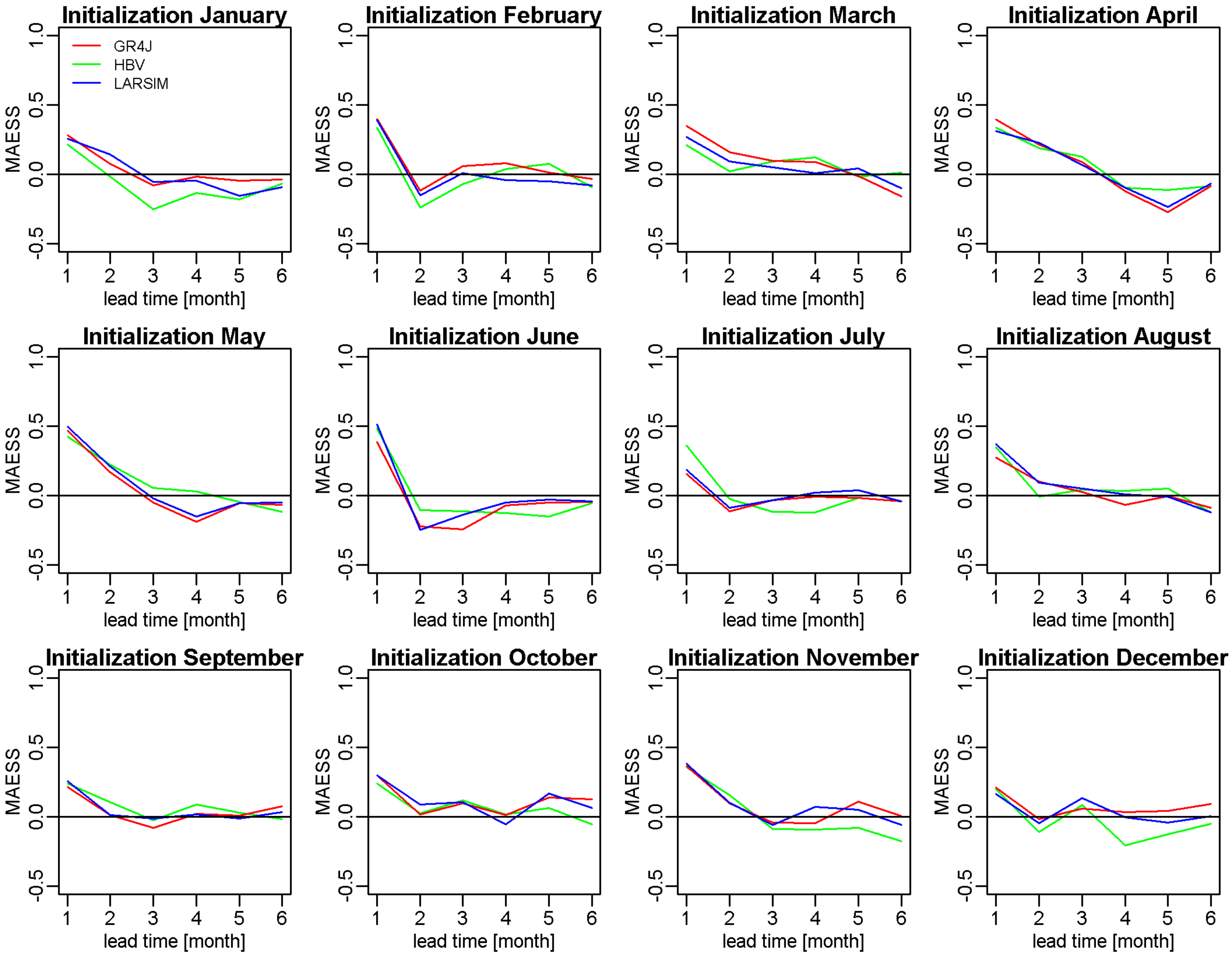
Verification MAESS (monthly means)



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Verification CRPSS (weekly means)

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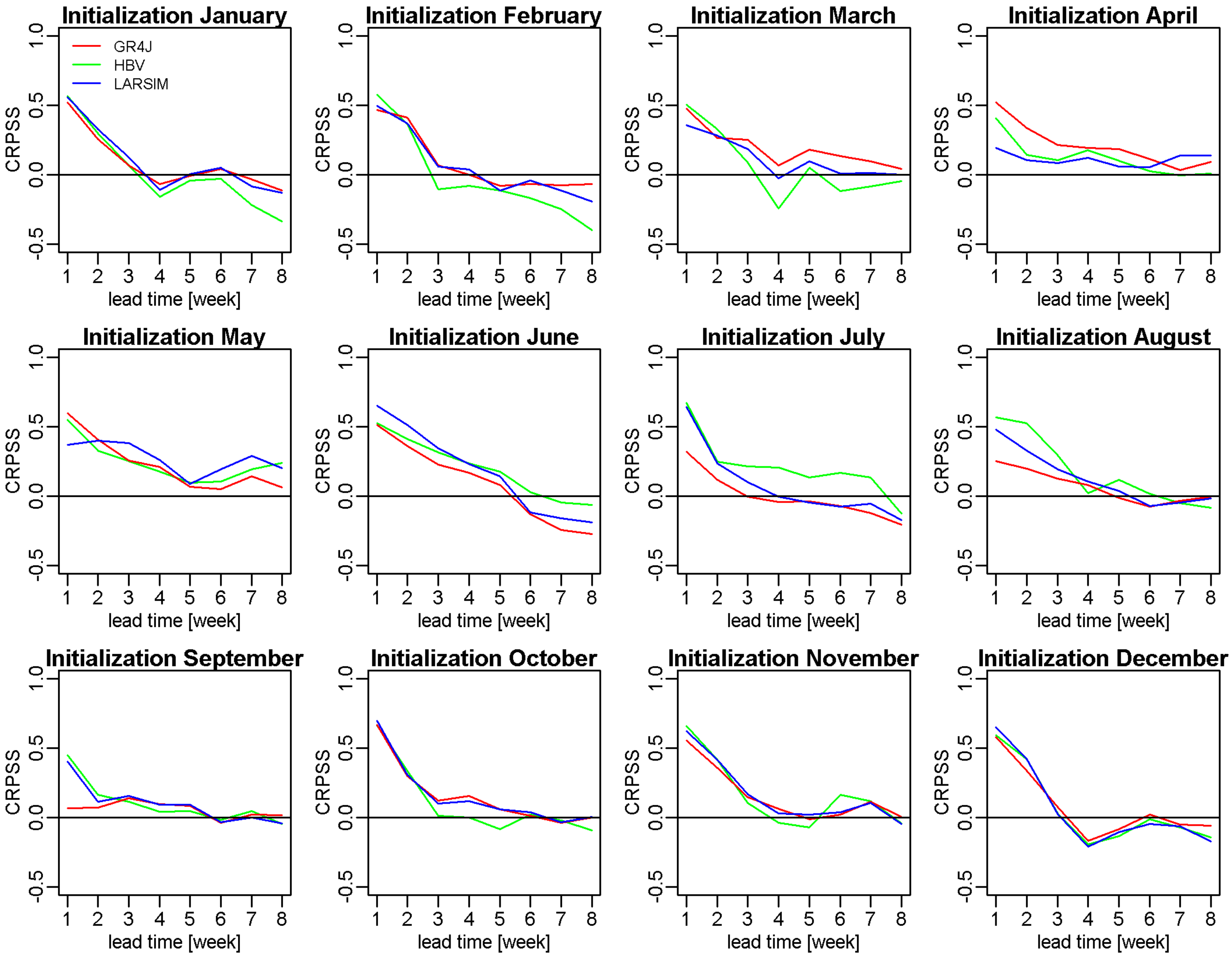

Gauge Maxau
Rhine

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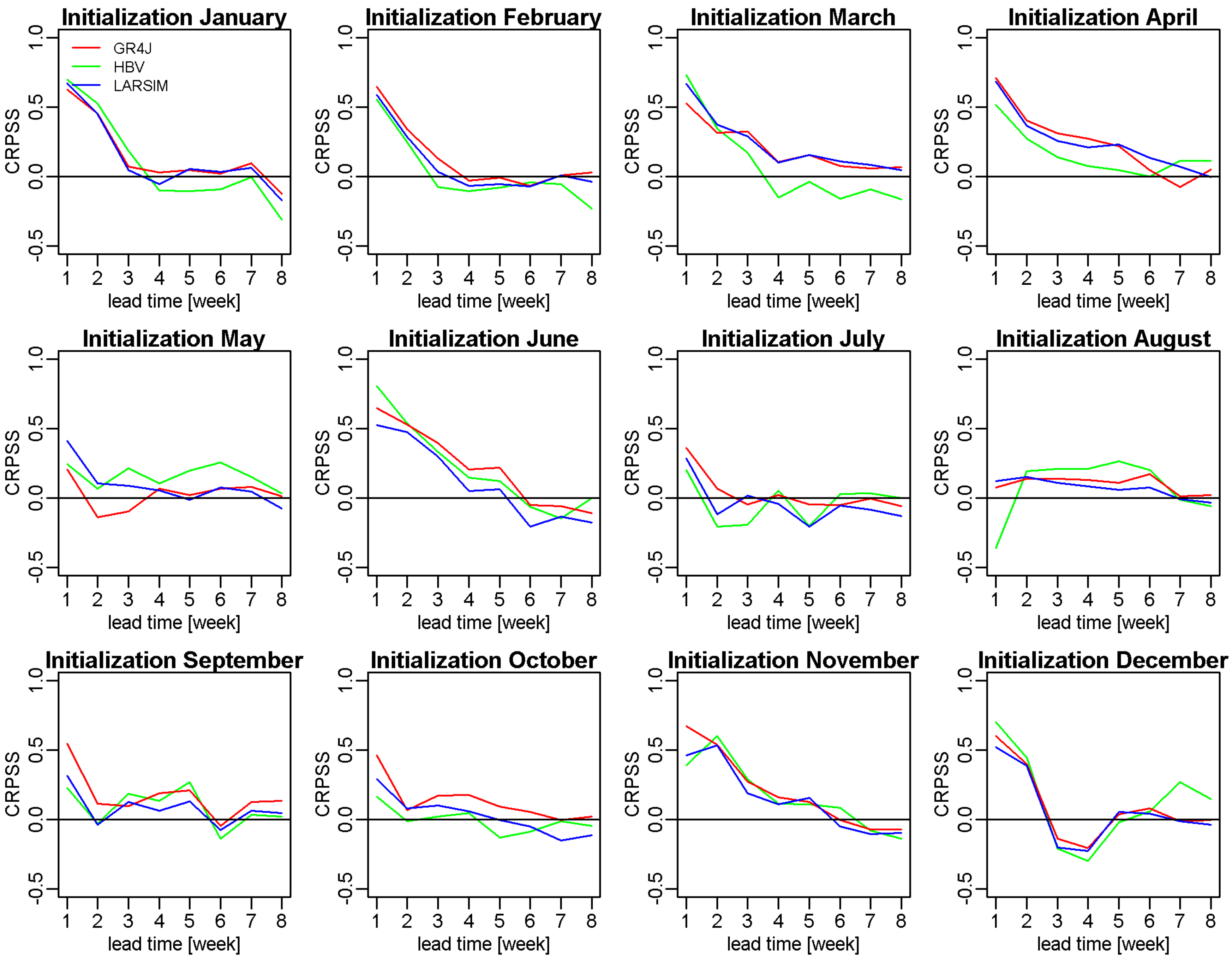
Verification CRPSS (weekly means)



Gauge Raunheim Main

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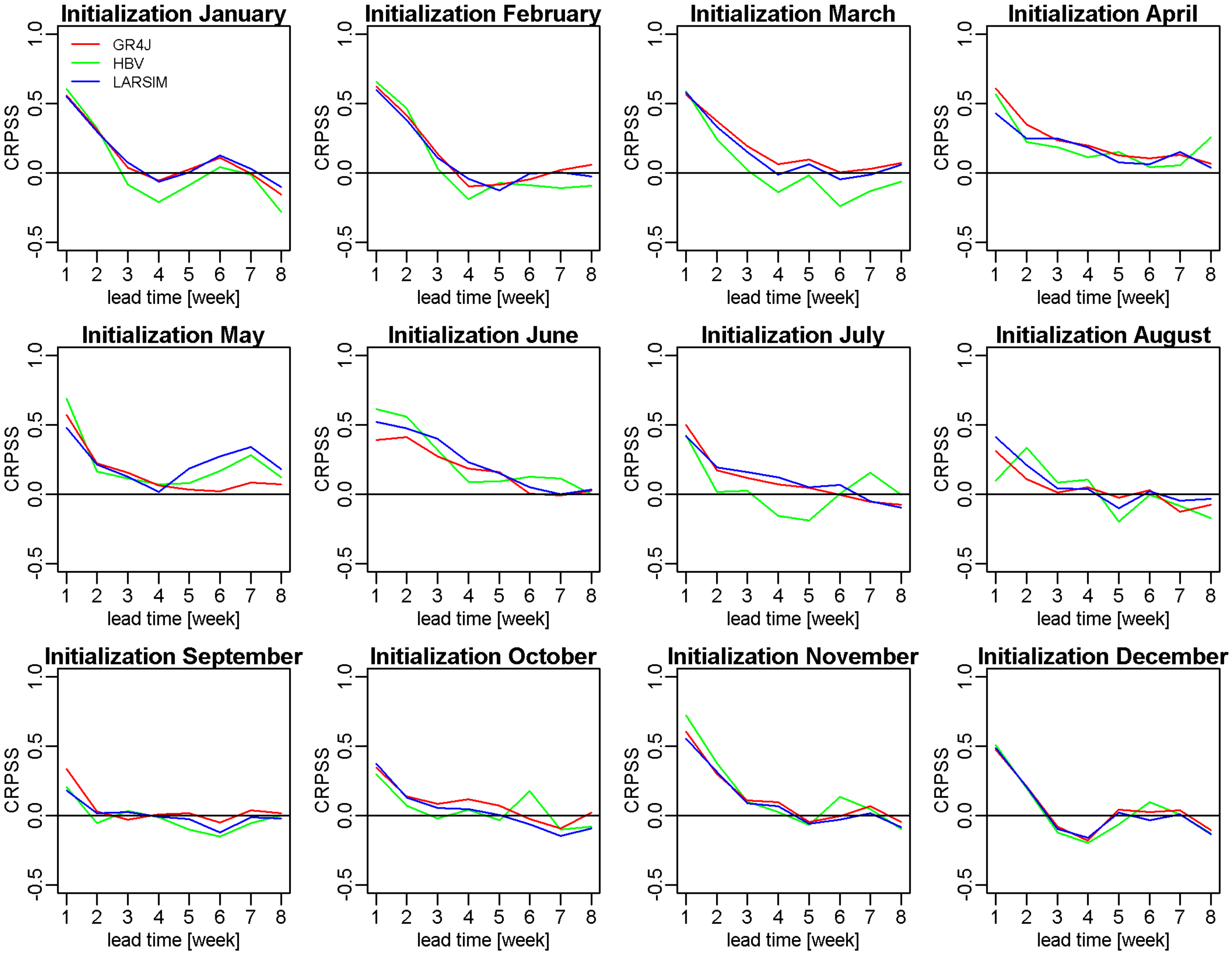
Verification CRPSS (weekly means)



Gauge Trier
Moselle

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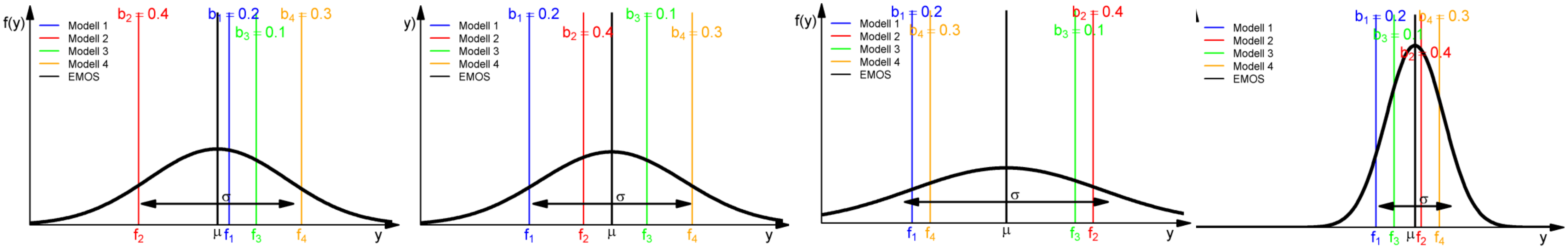
Multi-Model Combination

- Statistical Post-Processing of weekly mean flows with Method Ensemble Model Output Statistics EMOS (Gneiting et al. 2005)
- log-Transformation of forecasts and observations



Predictive normal distribution $f\left(y \mid \hat{y}_1,\ldots,\hat{y}_M\right) = N\left(\mu,\sigma^2\right)$

Mean is weighted mean of ensemble group means $\mu = a + b_1 \cdot \hat{y}_1 + b_2 \cdot \hat{y}_2 + \ldots + b_M \cdot \hat{y}_M$

Variance function of the ensemble variance $\sigma^2 = c + d \cdot S^2$

➔Estimate parameters by minimizing CRPS

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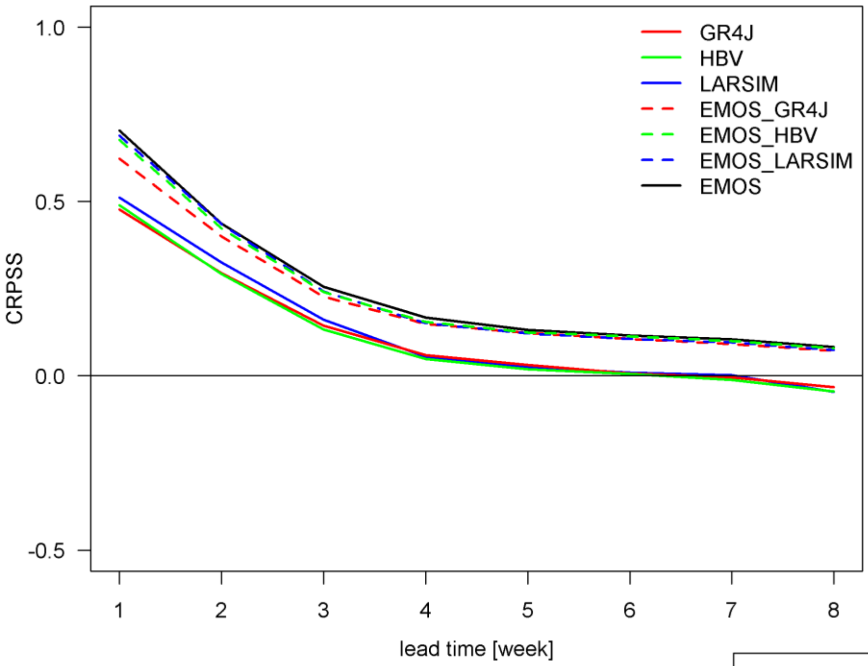
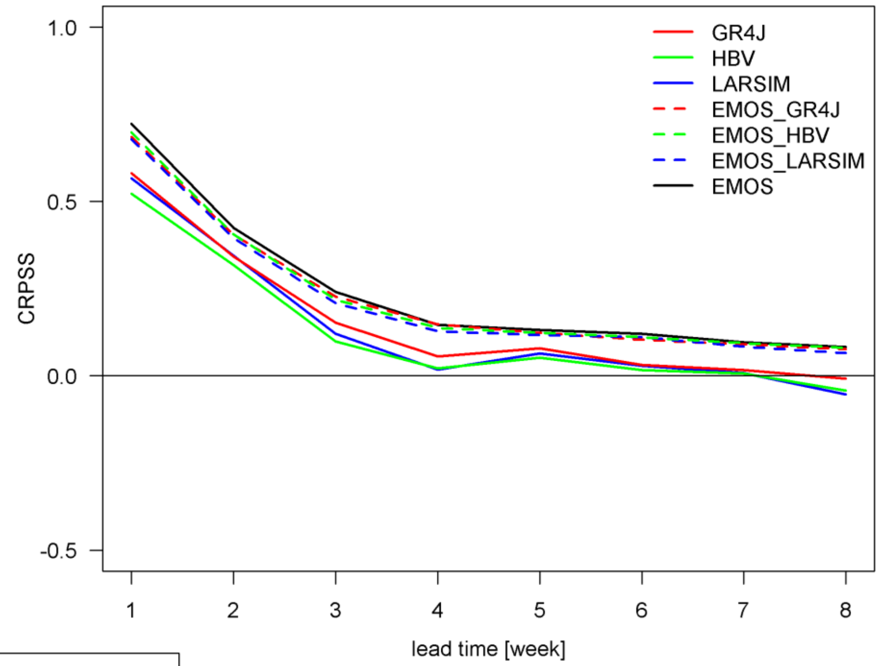
EMOS Results

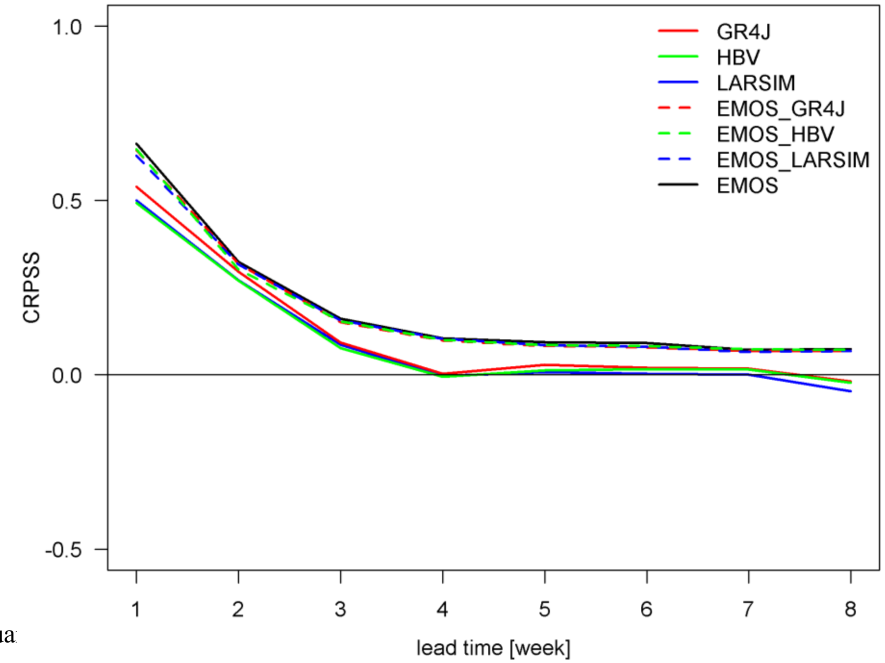


Gauge Maxau



Gauge Raunheim

Gauge Trier



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EMOS Results

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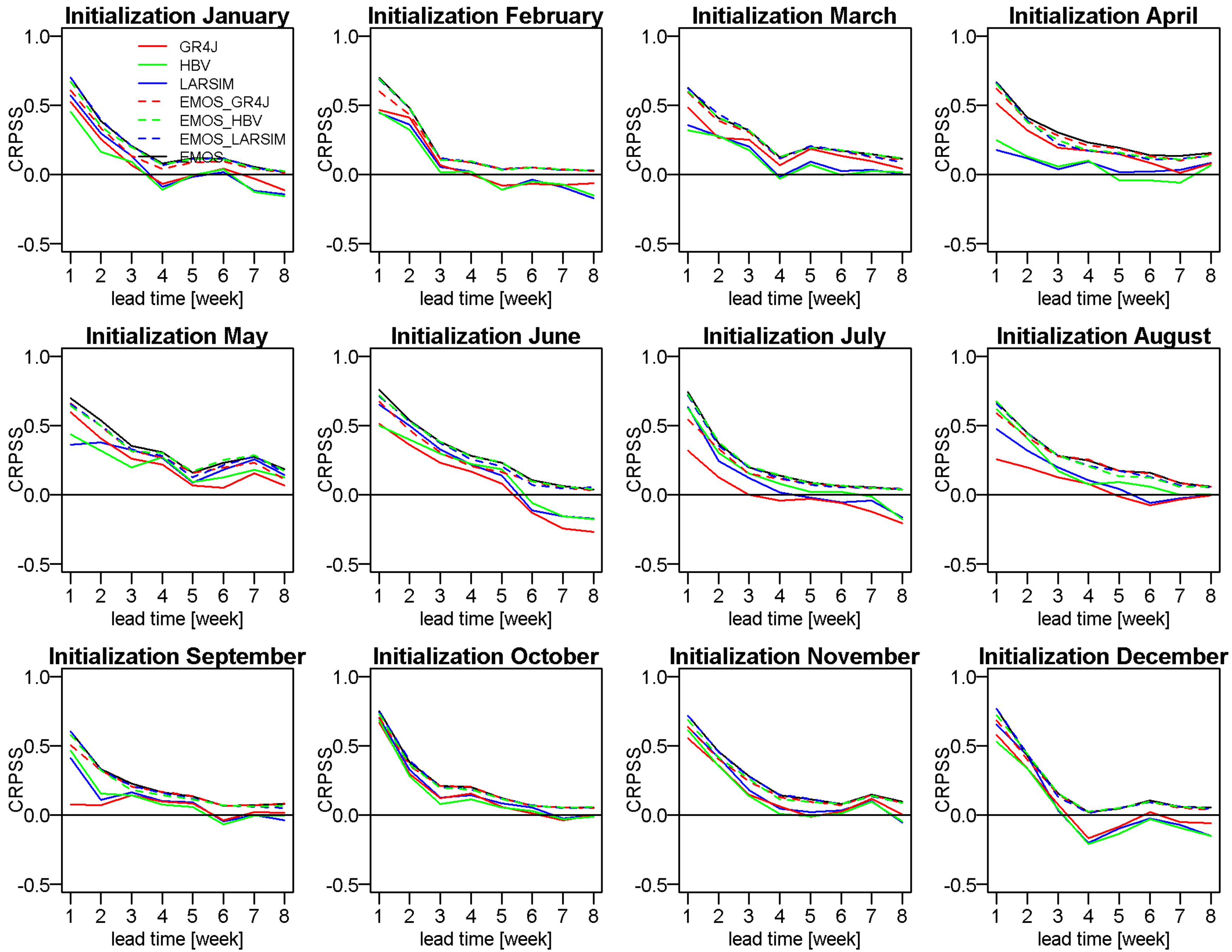

Gauge Maxau

Rhine

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Conclusion & Outlook

- Post-Processing with EMOS improves seasonal forcast skill
- Meteorological uncertainty (or probably downscaling / drift correction procedure?) dominates hydrological uncertainty

➔ no significant added benefit by using a hydrological multi-model ensemble

- Further in depth analysis of the results of the presented hydrological multi-model experiment
- Combination of seasonal hydrological forecasts from different institutes (different concepts / methodologies in data processing!) in the context of EU-Horizon2020 IMPREX
- Analysis of different bias / drift correction methods

➔ Meißner et al. EGU 2018

- Combination of model outputs using several meteorological seasonal forecast systems (ECMWF SEAS5, MetOffice GloSea5, ESP) as forcing

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Literature

Coron, L., V. Andréassian, C. Perrin, M. Bourqui & F. Hendrickx (2014): On the lack of robustness of hydrologic models regarding water balance simulation: a diagnostic approach applied to three models of increasing complexity on 20 mountainous catchments. Hydrol. Earth Syst. Sci. 18(2), 727-746

Duan, Q., S. Sorooshian & V. K. Gupta (1994): Optimal use of the SCE-UA global optimization method for calibrating watershed models. Journal of Hydrology 158(3–4), 265-284

Gneiting, T., A. E. Raftery, A. H. Westveld & T. Goldman (2005): Calibrated probabilistic forecasting using ensemble model output statistics and minimum CRPS estimation. Monthly Weather Review 133(5), 1098-1118

Lindström, G., B. Johansson, M. Persson, M. Gardelin & S. Bergström (1997): Development and test of the distributed HBV-96 hydrological model. Journal of Hydrology 201(1), 272-288

Ludwig, K. & M. Bremicker (2006): The Water Balance Model LARSIM –Design, Content and Applications. 22. C. Leibundgut, S. Demuth and J. Lange (Eds), Freiburger Schriften zur Hydrologie, Institut für Hydrologie, Universität Freiburg im Breisgau, Freiburg, 141 pp.

Rauthe, M., H. Steiner, U. Riediger, A. Mazurkiewicz & A. Gratzki (2013): A Central European precipitation climatology - Part I: Generation and validation of a high-resolution gridded daily data set (HYRAS). Meteorologische Zeitschrift 22(3), 235-256

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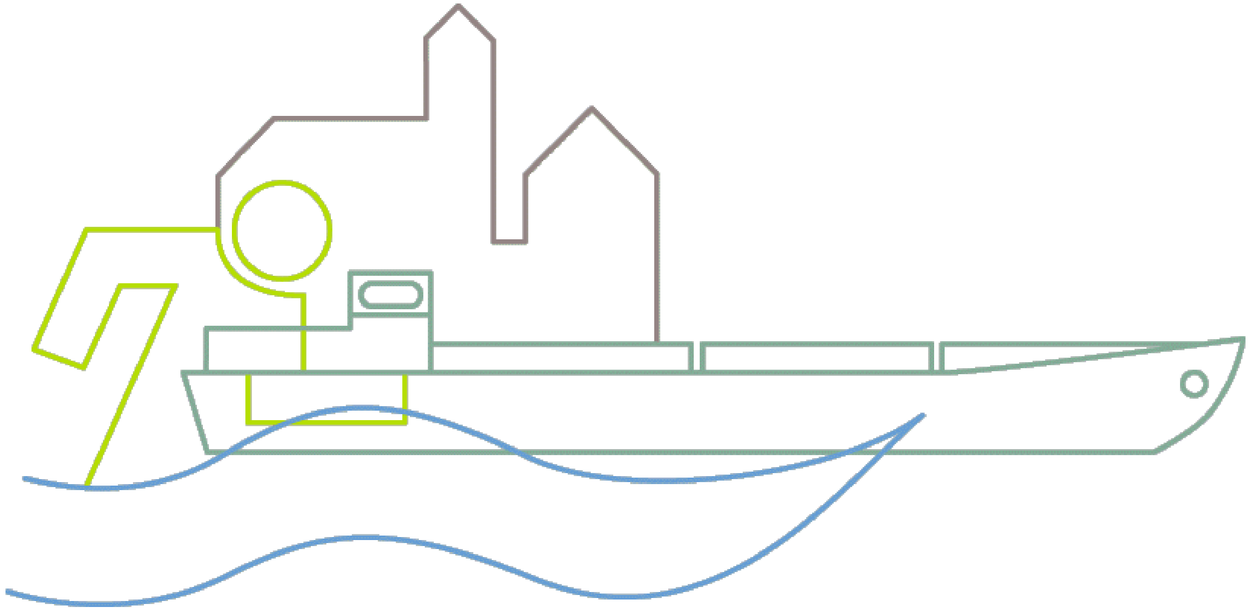

Thank you very much for your attention!

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