A 20-year reforecast study combining high-resolution hydrological modelling, ensemble forecasting and data assimilation for the 12 largest tributaries of the Rhine

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08 May 2020
PhD thesis
Public defense LIVE STREAM:
12 May 2020, 16:00
https://weblectures.wur.nl
Methods and materials

Rhine basin

- ~160,000 km²
- Operational forecasting system for water levels and discharge at the Dutch border
- 12 subbasins (Moselle, Main, etc.) from which the discharge is fed into a hydrodynamic model of the Rhine
- The most upstream part (Rhine above Maxau) is characterized by the Alps and natural lakes
- Stations from which data is assimilated are in red dots.
- Assimilation / error correction is done for each subbasin separately
Why this study?

• Ongoing movement towards spatially distributed models on (very) high spatial and temporal resolutions
• Ongoing movement to implement ensemble forecasts
• Ongoing development to combine ensemble forecasts with state-updating data assimilation
• But only few studies that combine all three...
• And even less so over long time periods
Methods and materials

Data

- Hourly 1.2x1.2 km forcing data set (1998-2016)
- ECMWF hindcast data set for 20 years of forecasts every 3-4 days.


Methods and materials

Model: wflow_hbv

- Based on the well known HBV concept
- Discretized for each grid cell
- Flows are routed with kinematic wave
- Hourly time step
- 1.2x1.2 km
- Upper zone and Lower zone states are updated as well as the water level

Updated states

Adapted from Rakovec et al. 2015
Methods and materials
Data assimilation and Auto Regression

Asynchronous EnKF

• AEnKF in OpenDA (Ridler et al., 2014, see also Rakovec et al. 2015)

AR

• ARMASA algorithm in Delft-FEWS (Broersen and Weerts, 2005)

\[ X_t = c + e_t + \sum_{i=1}^{p} \varphi_i X_{t-i} + \sum_{i=1}^{q} \theta_i e_{t-i} \]

c: constant

e: white noise error

\(\varphi\): auto regressive parameters

\(\theta\): moving average parameters

Here: only AR part is used with maximum order 3

Results

Historic state estimation

- KGE of modelled discharge as proxy for correct state
- KGE improves greatly for each basin with AEnKF state updating
- Especially when initial model results were very poor
- Calculated over a 20 year simulation period on a daily time step

Results

Shown as hydrograph

- Effect of updating is shown in the hydrograph
- Correction is applied for whole biased periods

Results

Results in forecast mode

Forecast verification scores. MCRPS (left) and MCRP Skill Score against climatology (middle) or the open loop simulation (right)

Solid line: open loop simulation
Dotted line: AEnKF
Stripe-dot: AR correction
Results

Comparison AR and AEnKF

- Below zero line: EnKF has better results than AR
- Colors indicate the quality of the original (open loop) simulation (colorbar on the right)
- AR outperforms EnKF for the first ~2 days, EnKF outperforms for longer forecasts
- Exceptions are poorly modelled basins

MCRP Skill Score ARMA (vs EnKF)

- >Q75%
- <Q25%
Conclusions

• Large scale data assimilation experiment combining current trends in hydrological forecasting: high resolution spatial and temporal model, with ensembles and state-updating but for a long continuous time period

• AR correction strong for 2 day period

• AEnKF improves longer forecasts

• AR can give ‘odd’ results, while AEnKF results are always consistent with the model

Acknowledgement

IMPREX is a research project supported by the European Commission under the Horizon 2020 Framework Programme
Grant Agreement No 641811
Duration: 01/10/15 - 01/10/19

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