An adaptive hydrological model for multiple time-steps: diagnostics and improvements based on fluxes consistency

Andrea Ficchí, Charles Perrin, Vazken Andréassian

An adaptive hydrological model for multiple time-steps

Diagnostics and improvements based on fluxes consistency

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4es Rencontres HydroGR 2021 - INRAE

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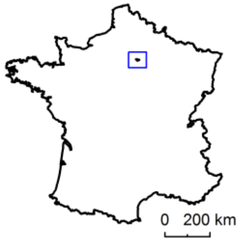
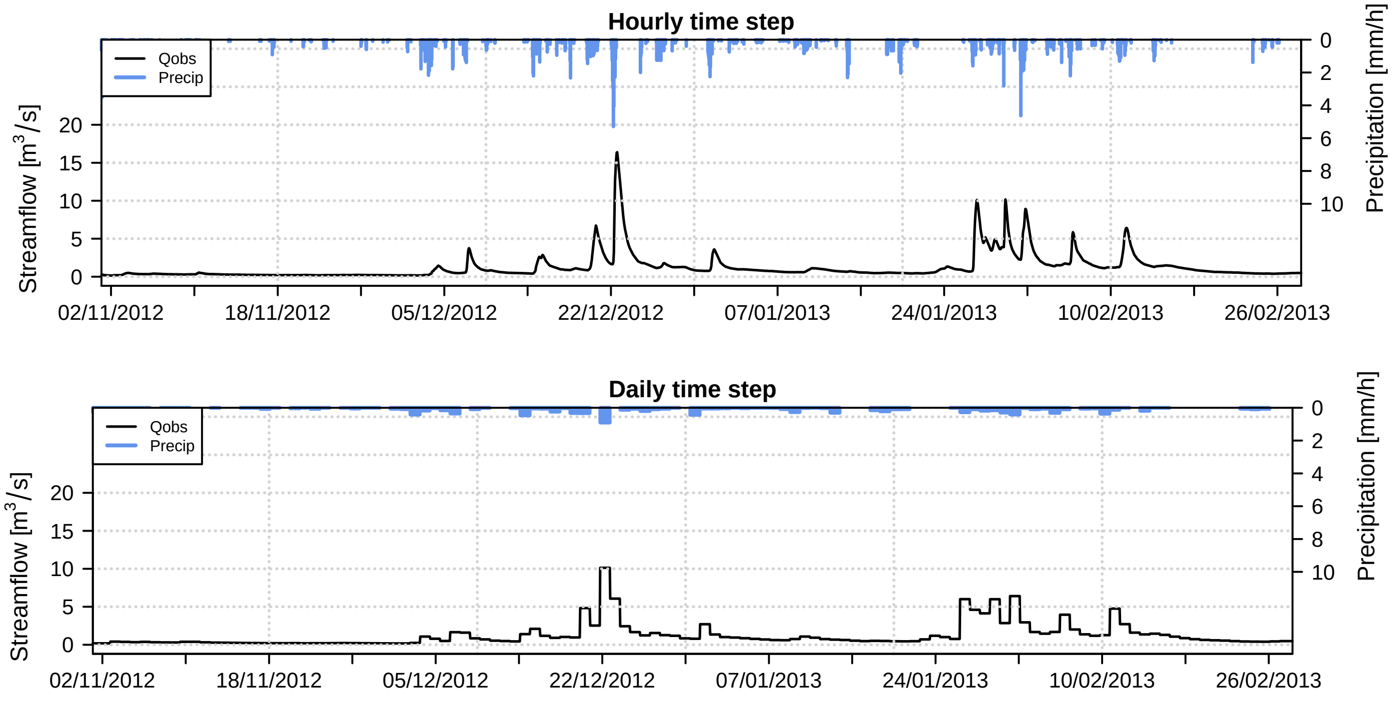
Importance of temporal variability

- Flood early warning requires forecasts at different time scales & resolutions (usually from daily to sub-hourly)
- Temporal averaging smooths peaks and masks variability

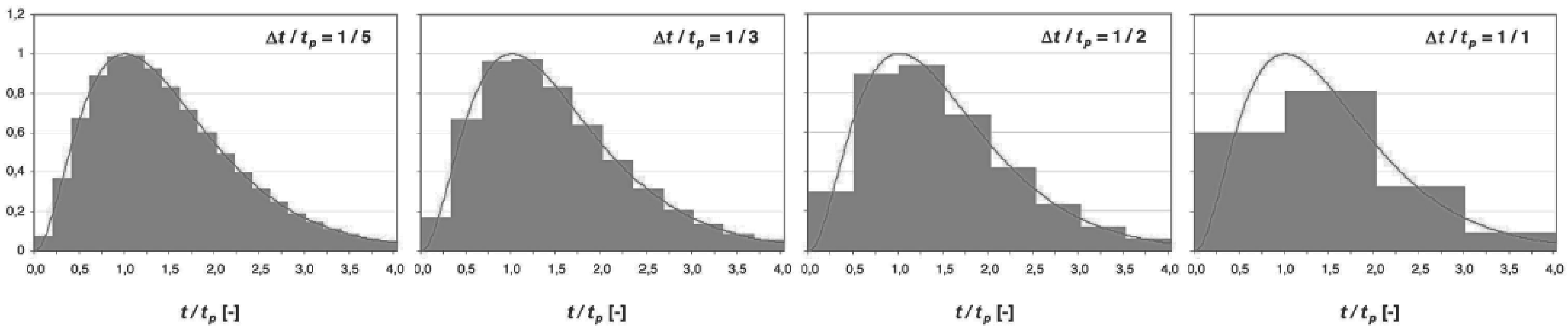




Example of data averaging effects for precipitation and streamflow of the Orgeval River basin at Boissy-le-Châtel (105 km^2)

Scientific questions and state-of-the-art

- **The question of temporal scaling in hydrological modelling implies multiple issues**
  - Relationship between processes, observation and modelling scale (*Blöschl and Sivapalan, 1995; Obled et al. 2009*)



Representation of a flood hydrograph by different discrete time step size (*Obled et al. 2009*)

- **Two levels of model time-step dependency**
  - Time step-dependency of model parameters (e.g. *Littlewood and Croke, 2008*)
  - Dependency of model structures on time step (e.g. *Atkinson et al., 2002; Mouelhi, 2003*)

Objective: a GR multi-time step model

❑ The emblematic case of the GR models chain

- annual → monthly → daily ⟹ complexification (*Mouelhi, 2003*)
- daily → hourly ⟹ same complexity? (*Mathevet, 2005; Le Moine, 2008)*

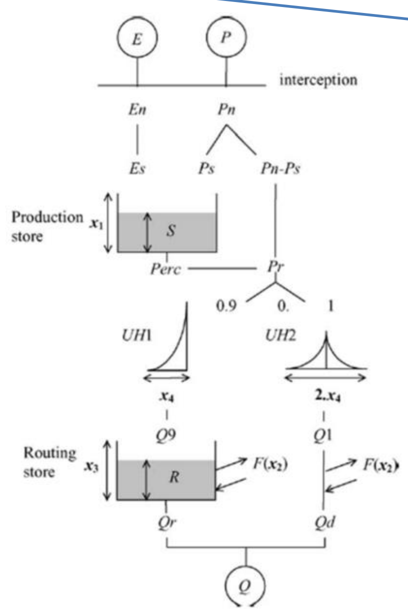
❑ Objectives

- Optimality of the structure at sub-daily time steps?
- Which **coherent multi-time step model** from daily to sub-hourly time step?

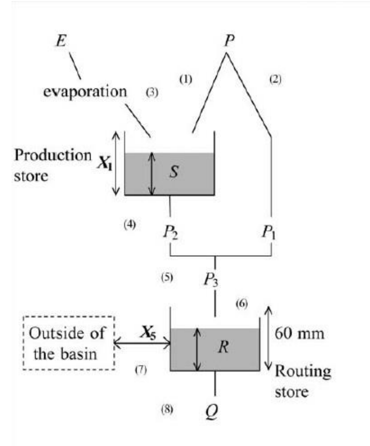
Complexification

?

Daily



Monthly



Annual

$$Q_k = P_k \left\{ 1 - \frac{1}{\left[1 + \left(\frac{0.7P_k + 0.3P_{k-1}}{X1.E_k} \right)^2 \right]^{0.5}} \right\}$$

Catchment data set

Multi-time step database

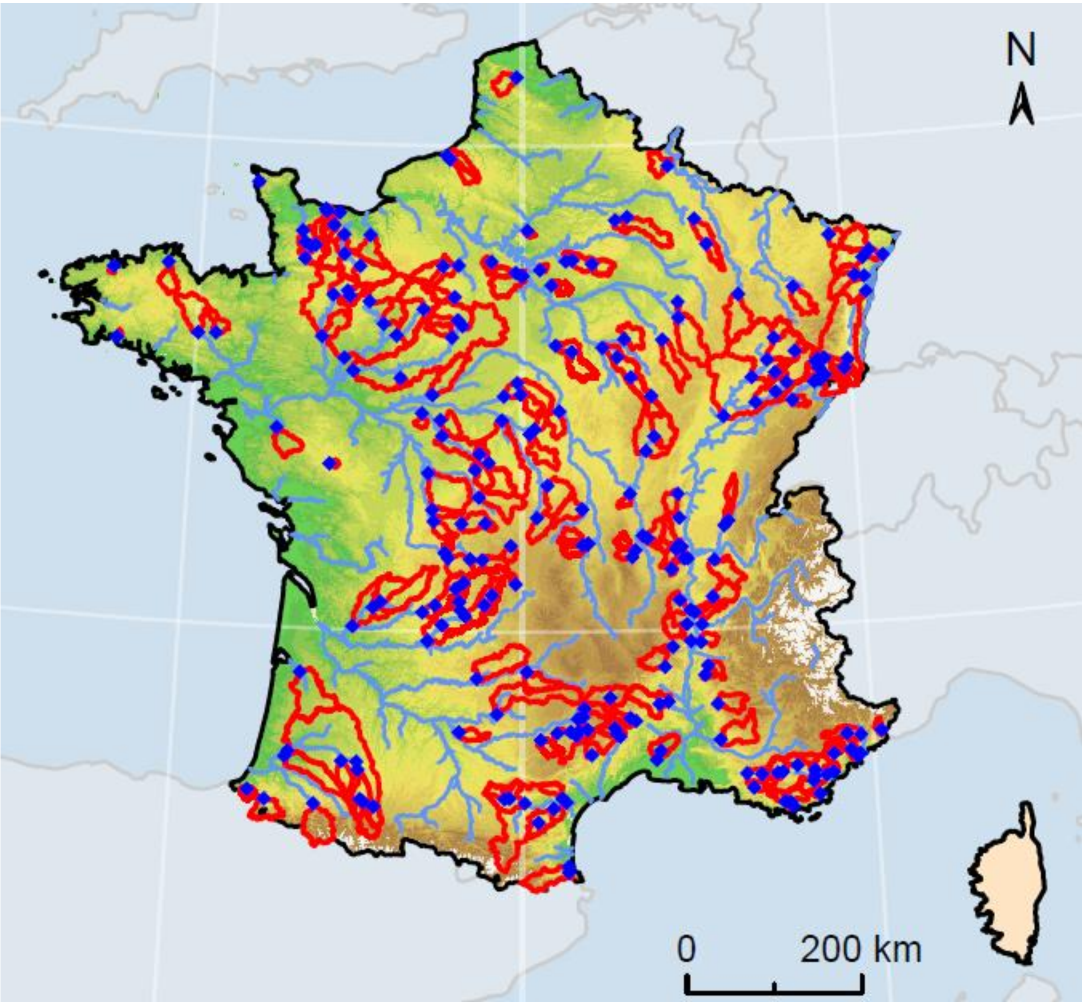
- Precipitation: disaggregation of daily reanalysis data by sub-hourly distribution of the 6-min data
- Streamflow: interpolation of the variable time-step series
- Potential evapotranspiration: daily temperature-based formula + sinusoidal sub-daily pattern

240 catchments

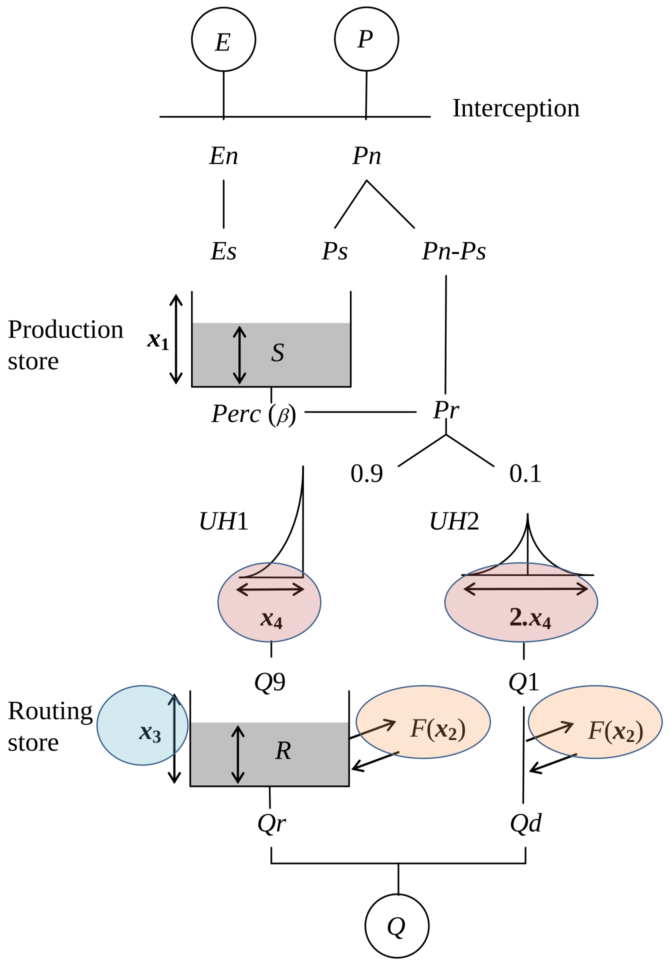
& 2400 flood events

Selection criteria

- Flow measurements
- Rain gauges density
- No snow influence
- No major regulation
- Surface: 3.5 to 8790 km^2
- Hydro-climatic variability



The rainfall-runoff model



GR4 model structure
(Perrin et al., 2003)

❑ Starting point: the daily GR4 model

❑ Time-step (TS) dependencies in parameters *(Le Moine, 2008)*

For 3 out of the 4 free parameters

- x_1 (mm): production store capacity
- x_2 (mm/*TS*): inter-catchment groundwater coefficient
- x_3 (mm): maximum reference capacity of the routing store
- x_4 (*TS*): time base of the UH

Testing methodology

- **"Split-Sample Test" (SST) on the 8-year period 2005-2013**

- **Calibration criterion**
  - Kling-Gupta Efficiency (KGE, *Gupta et al., 2009*) on streamflows (Q) over the whole calibration period

- **Evaluation criteria**
  - KGE and its three components:
    - relative variability, a
    - ratio of means, b
    - correlation, r

  - on the whole validation period
  - on flood events

- **8 time-steps tested:** 6-, 12-, 30-min, 1-, 3-, 6-, 12-h, and 1 day

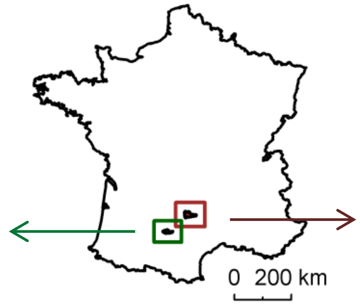
- **Evaluation of simulations at different time steps** at a common reference time step

Results: two examples

Daily vs. Hourly GR4 simulations

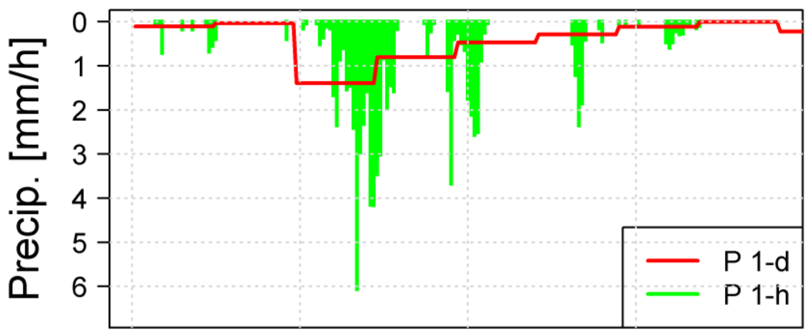
Tescou river at Saint–Nauphary (284 km²)

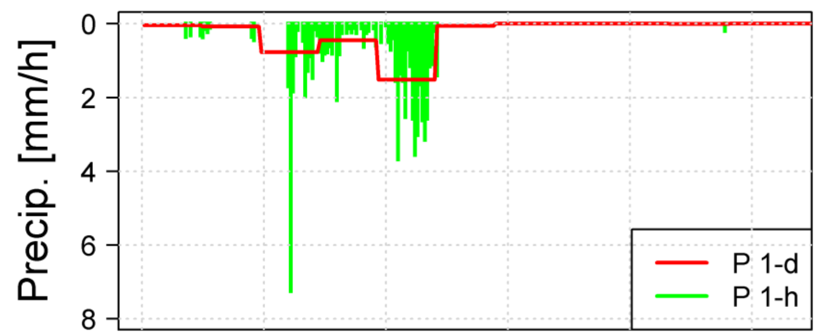
R_{KGE} = 0.3 (95th percentile)

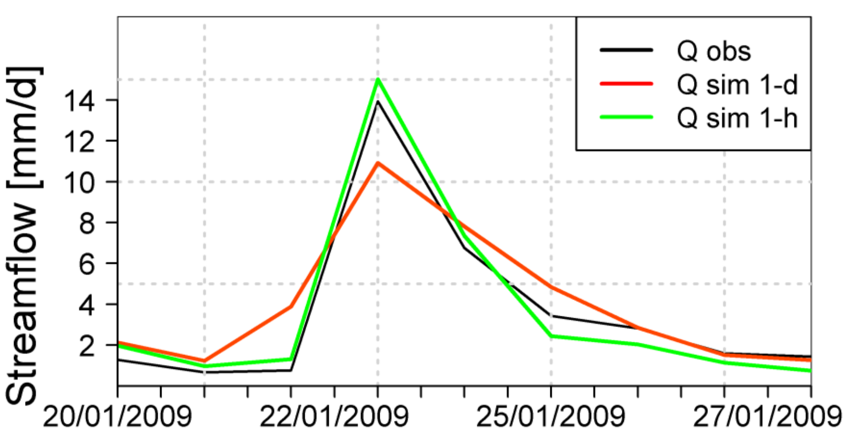


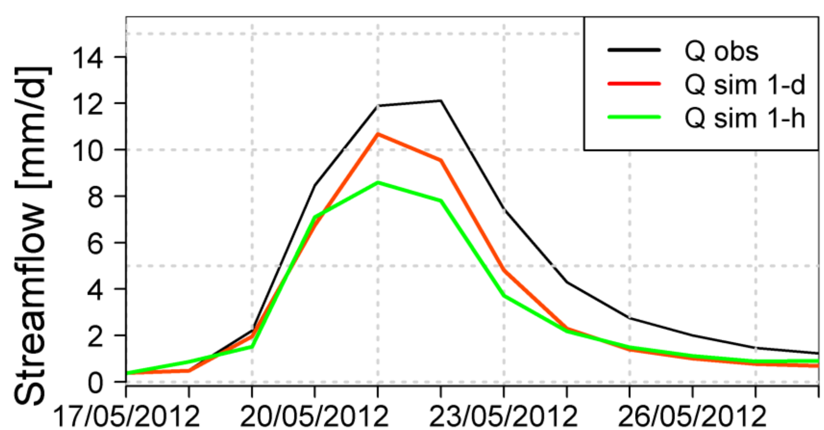
Dourdou river at Conques (545 km²)

R_{KGE} = -0.25 (5th percentile)







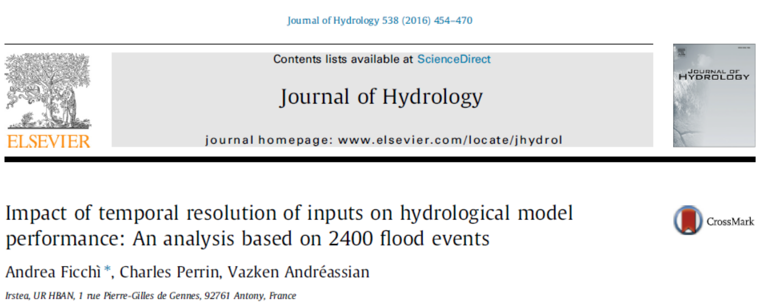


Model symptoms & suggested diagnosis

- **Comparison of two options to run the model:**
  1. Model run at short time step with inputs at the same time step and results aggregated at larger time step
  2. Model run at larger time step with inputs at the same time step
- Option 1 better than option 2 for only 30% of catchments (most reactive basins)
- Option 2 unexpectedly better than option 1 for 20% of catchments
- **Water balance degradation over flood events as the time step decreases**
  - **not linked to input data** because of the construction of the tests
  - **water balance better reproduced by the daily model** than the sub-daily versions

→ **Symptoms** of possible structural inadequacy

→ **Diagnosis**: analyse the consistency **of simulated fluxes across time steps**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Impact of temporal resolution of inputs on hydrological model performance: An analysis based on 2400 flood events
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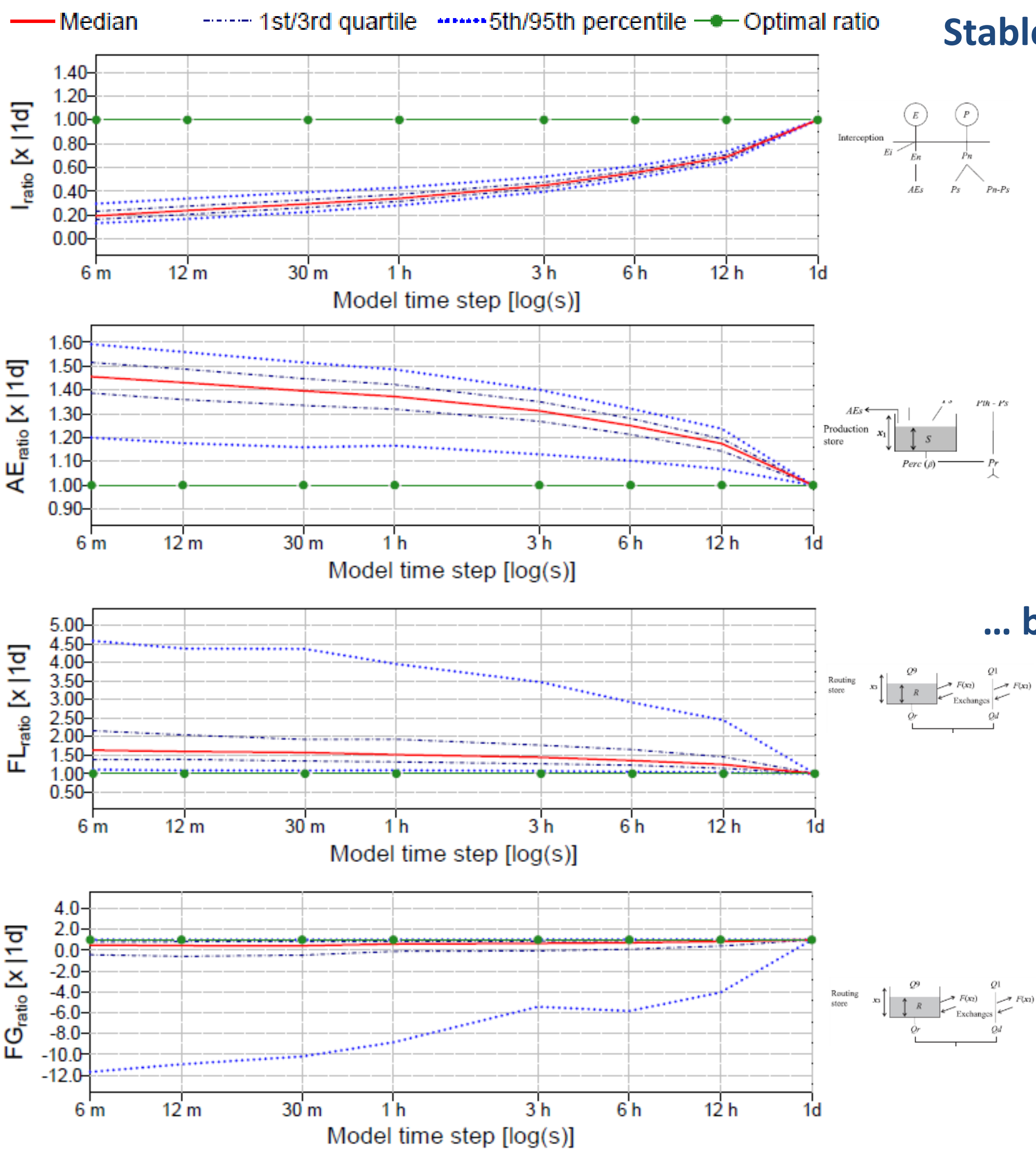
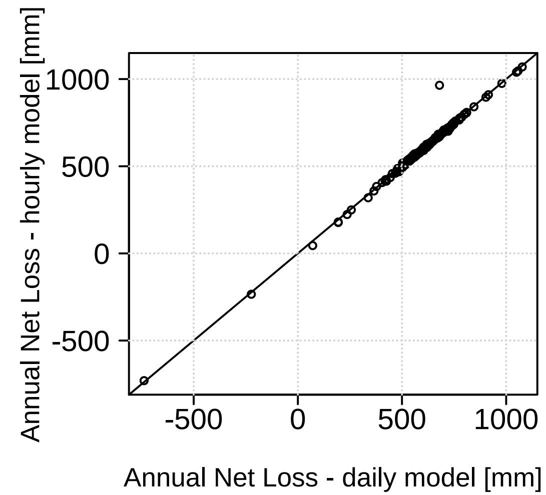
Ficchi, A., C. Perrin et V. Andréassian (2016). Journal of Hydrology 538: 454-470.

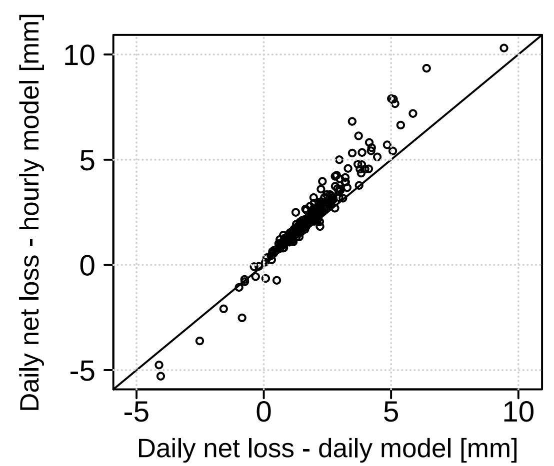
Consistency of fluxes of GR4



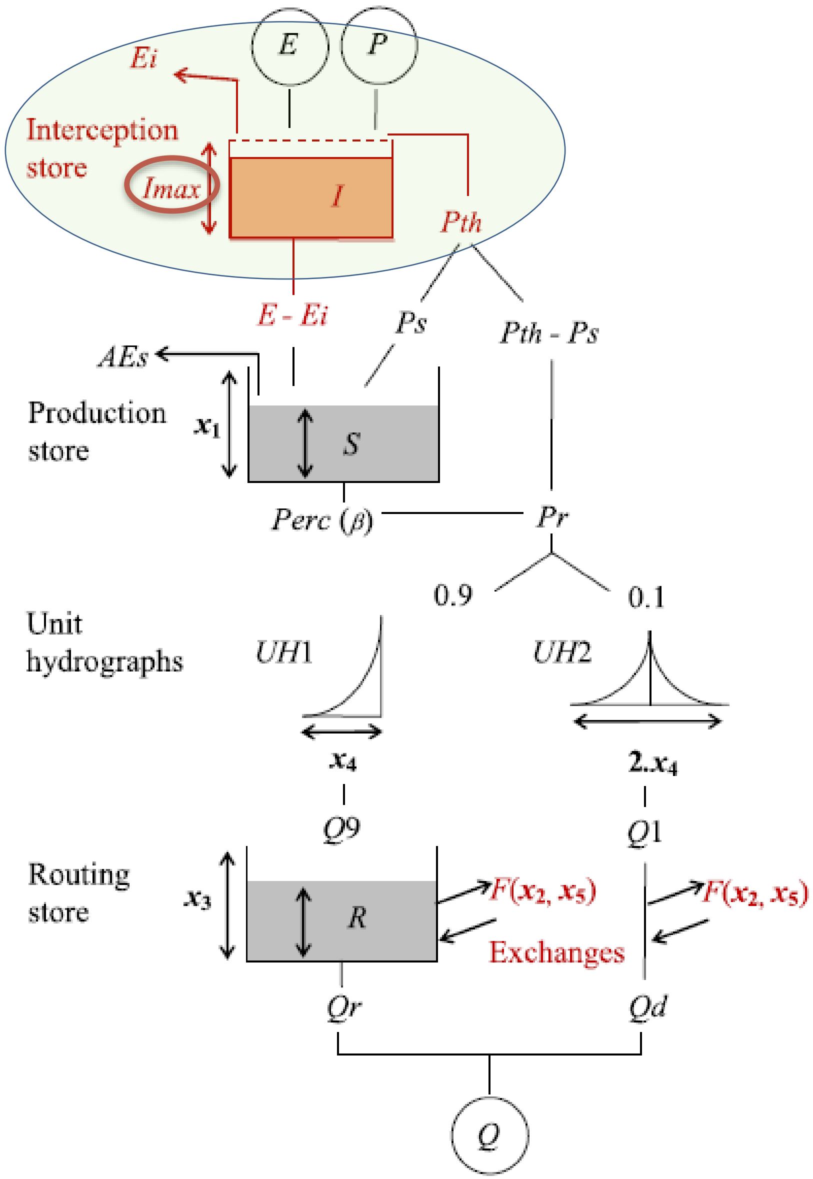
Stable net losses (I+AE+F) on the whole period…



… but increasing net losses (I+AE+F) at shorter time steps on flood events!

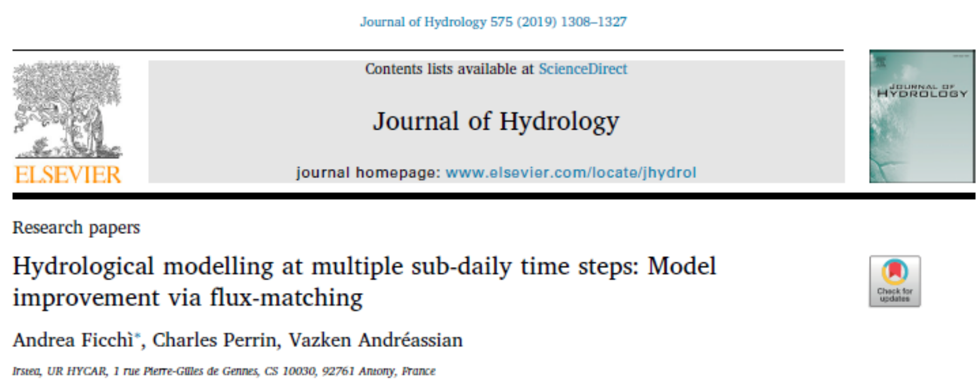


A new structure with interception store (GR4-I & GR5-I)



- ❑ **Daily neutralization (P-E_p) chosen as reference for the interception flux**
  - Model performance
  - Consistent order of magnitude and daily scale with literature (*Savenije, 2004; Gerrits, 2010*)

- ❑ **Capacity I_{max} fixed by ensuring the temporal consistency of the flux at different time steps**
  - Catchment-dependent
  - Based on climatic inputs only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Research papers

Hydrological modelling at multiple sub-daily time steps: Model improvement via flux-matching

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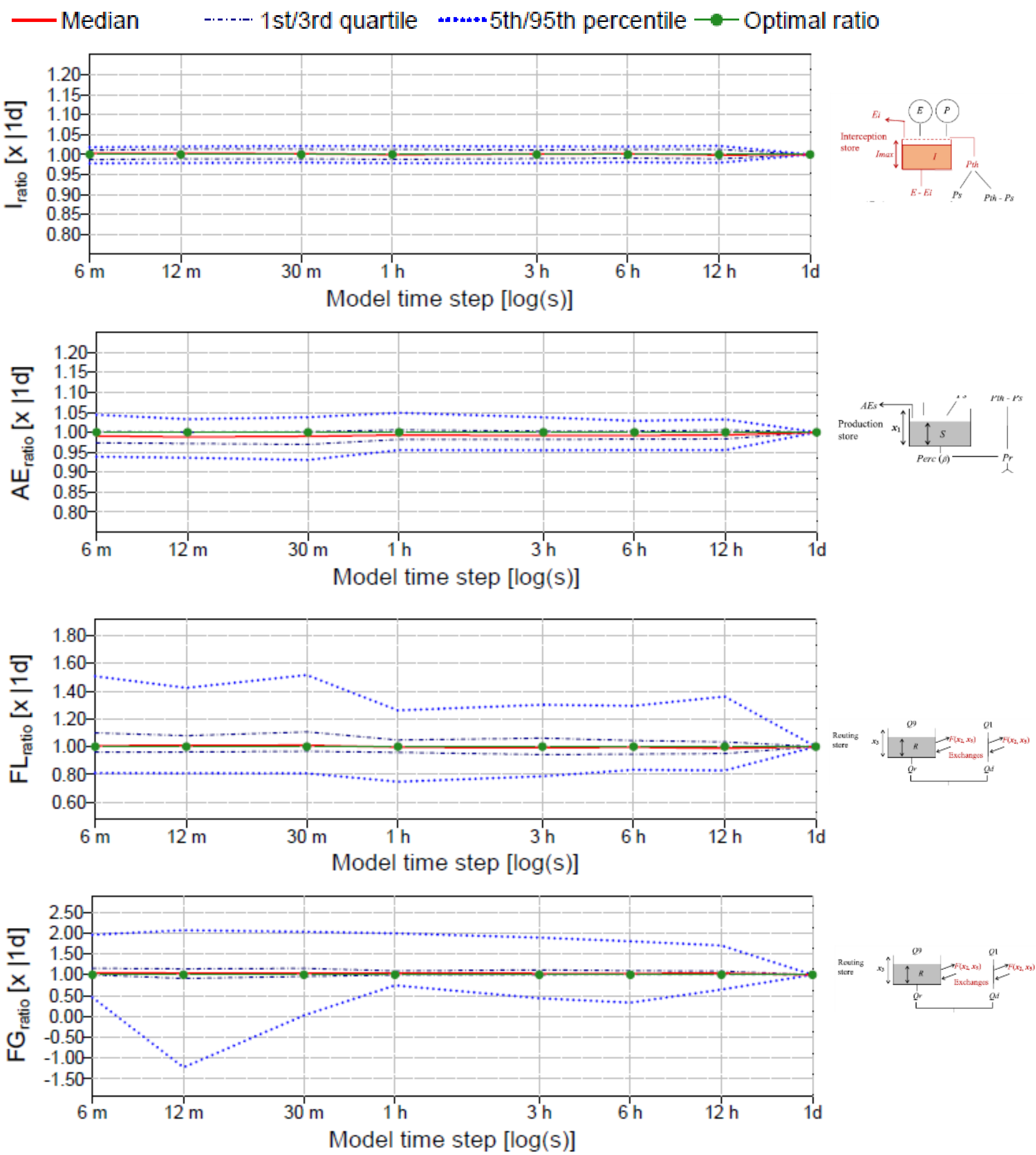
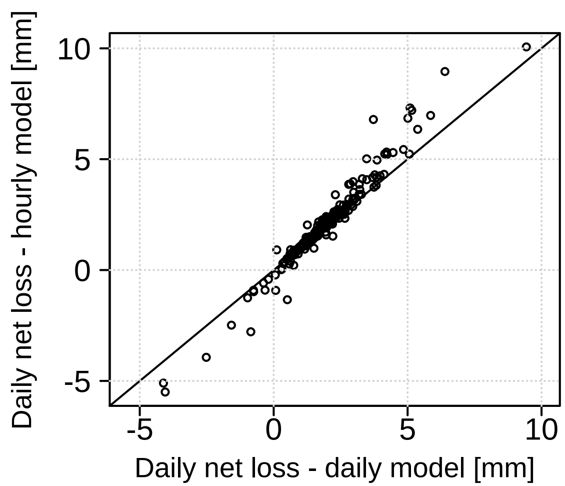
Ficchi, A., C. Perrin et V. Andréassian (2019). Journal of Hydrology.

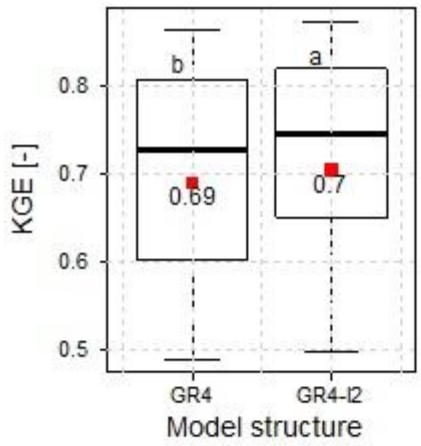
Consistency of fluxes of GR4-I (& GR5-I)

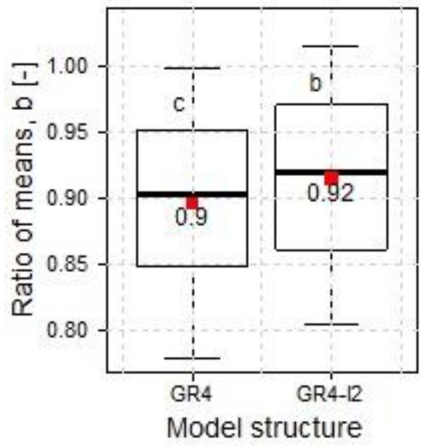


- ❑ **Perfect compensation of evaporative losses (I+AE) over flood events**
- ❑ **Reduced spurious increase in net losses on floods at shorter T.S.**
  - the median net losses increase at shorter time steps of about 8 % (4 times less than GR4)



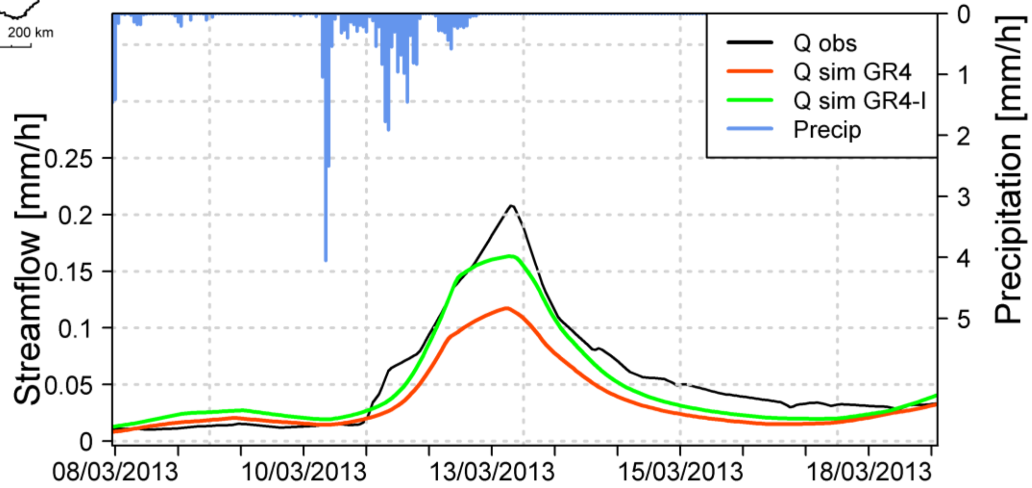
Performance of GR4-I with interception store





Example of improvement in flood conditions

Loir at Saint-Maur-sur-le-Loir (1081 km2)



→ **General positive effects of the reduction of exchange losses at sub-daily time step**

Conclusions & Perspectives

❑ **An original pathway for model diagnosis**

Three-step approach: symptoms/diagnosis/treatment

- Symptoms: Multi-time scale evaluation of model performance
- Diagnosis: Analysis of fluxes consistency at different time steps
- Treatment: Solving the structural inconsistencies

❑ **Improvement of GR4 at sub-daily T.S. by adding an interception store**

- Interception store effective to stabilize the fluxes at different T.S.
- Reduction of spurious time-step dependencies of parameters
- Performance improvement over flood events at shorter T.S.
- Essential role of the exchange function to be further investigated: tested functions saturating on floods unsuccessful; a linear function *(Le Moine, 2008)* proved the best option

❑ **Perspectives: Transfer to operational flood forecasting context & Semi-distributed models**

- Introduction of an interception store in the GRP forecasting model
- Adaptative multi-time step structure with data-assimilation schemes
- First results on three basins indicate a possible synergy of the combined refinement of temporal and spatial resolutions to improve model performance

Thank you for your attention!

(Alain Longuet)

The Herault at Laroque, 17th April 2006

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