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Supplement of

Looking beyond general metrics for model comparison – lessons from an international model intercomparison study

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Supplement

This is a supplement accompanying the paper:

"Looking beyond general metrics for model comparison - lessons from an international model inter-comparison study"

by Tanja de Boer-Euser, Laurène Bouaziz, Jan De Niel, Claudia Brauer, Benjamin Dewals, Gilles Drogue, Fabrizio Fenicia, Benjamin Grelier, Jiri Nossent, Fernando Pereira, Hubert Savenije, Guillaume Thirel and Patrick Willems

The supplement contains graphs and tables with explanation. In each Section, graphs are shown for each catchment and where applicable for each model. Besides, the supplement also contains an analysis of the influence of Nisramont dam and reservoir on hydrological modelling in the Ourthe catchment (see Section 10).

1 Observations: discharge, precipitation and temperature

Figures 1 to 5 show the observed data for discharge, precipitation, potential evaporation and temperature for the five catchments.

Calibration was carried out for the Ourthe at Tabreux for the period 1 January 2004 to 31 December 2007, using 2003 as a spin-up year. Validation in time was carried out for the Ourthe at Tabreux for the period 1 January 2001 to 31 December 2003, using 2000 as a spin-up year. The period 1 January 2008 to 31 December 2010 was used as a blind validation period for the Ourthe at Tabreux.

The derived parameters for the Ourthe at Tabreux were used for a blind validation in the neighbouring Lesse (at Gendron) and Semois (at Membre) catchments and in the nested Ourthe Orientale (at Mabompré) and Ourthe Occidentale (at Ortho) catchments for the period 1 January 2001 to 31 December 2010, using 2000 as a spin-up year.

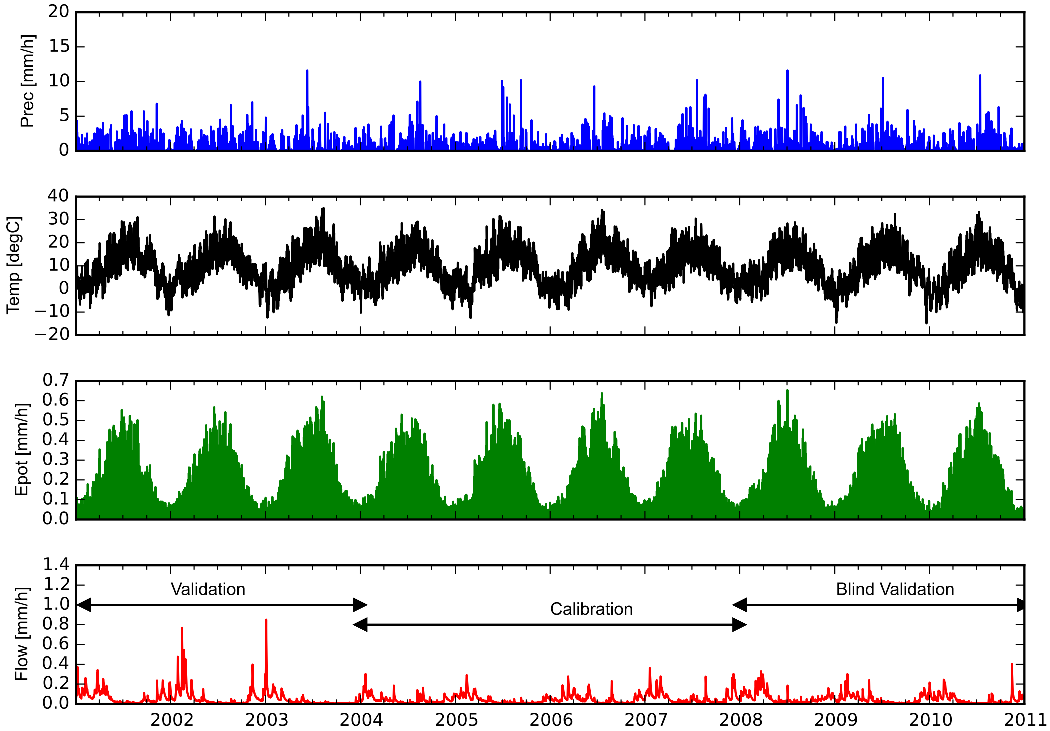

Figure 1: Ourthe at Tabreux

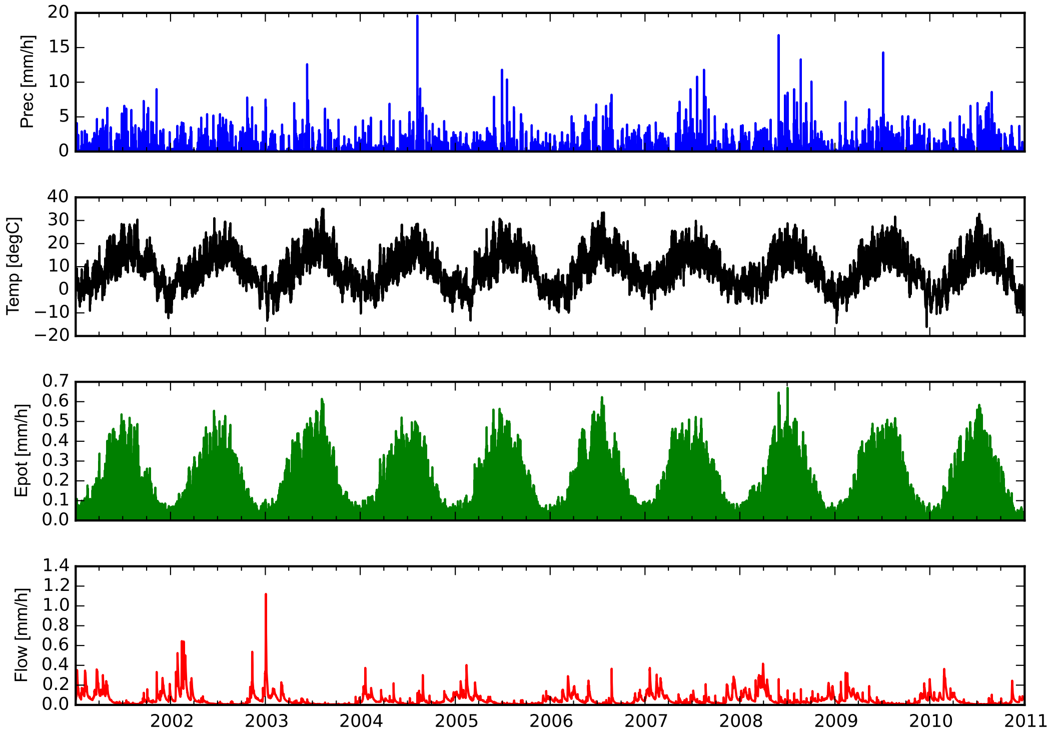

Figure 2: Ourthe Orientale at Mabompré

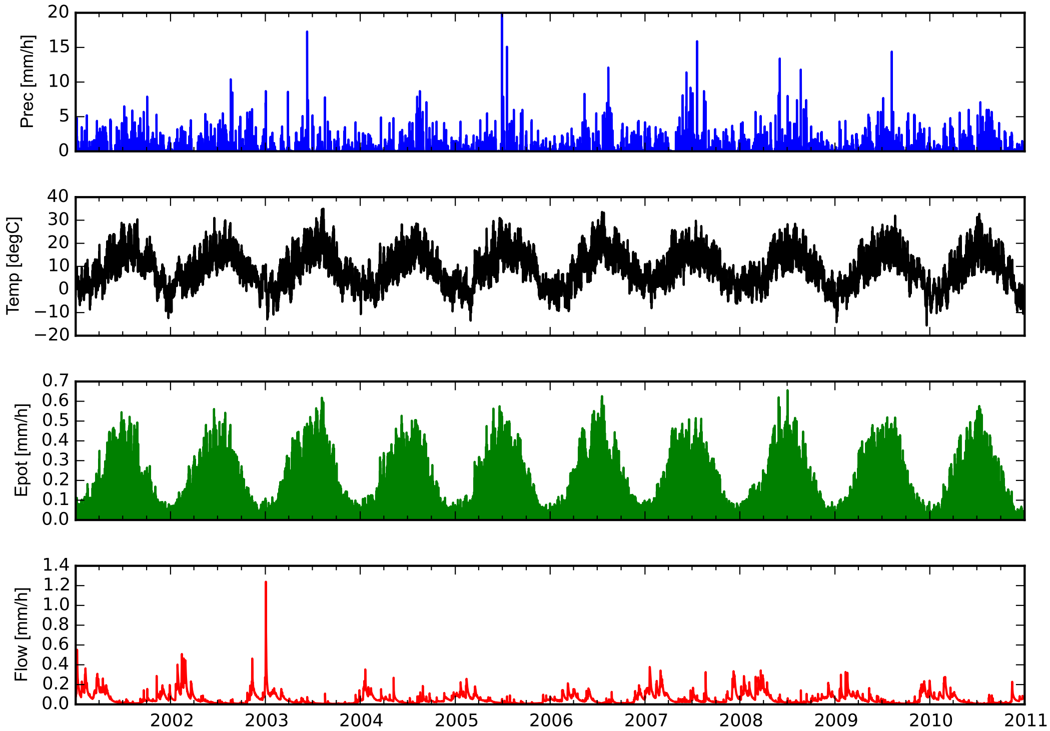

Figure 3: Ourthe Occidentale at Ortho

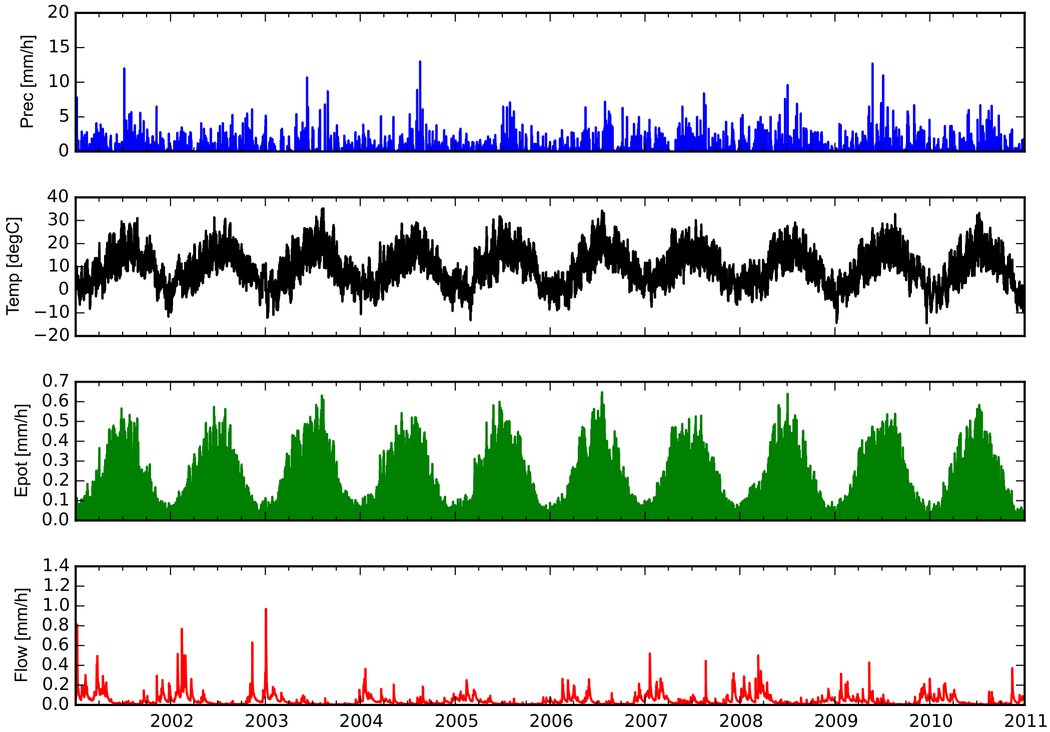

Figure 4: Lesse at Gendron

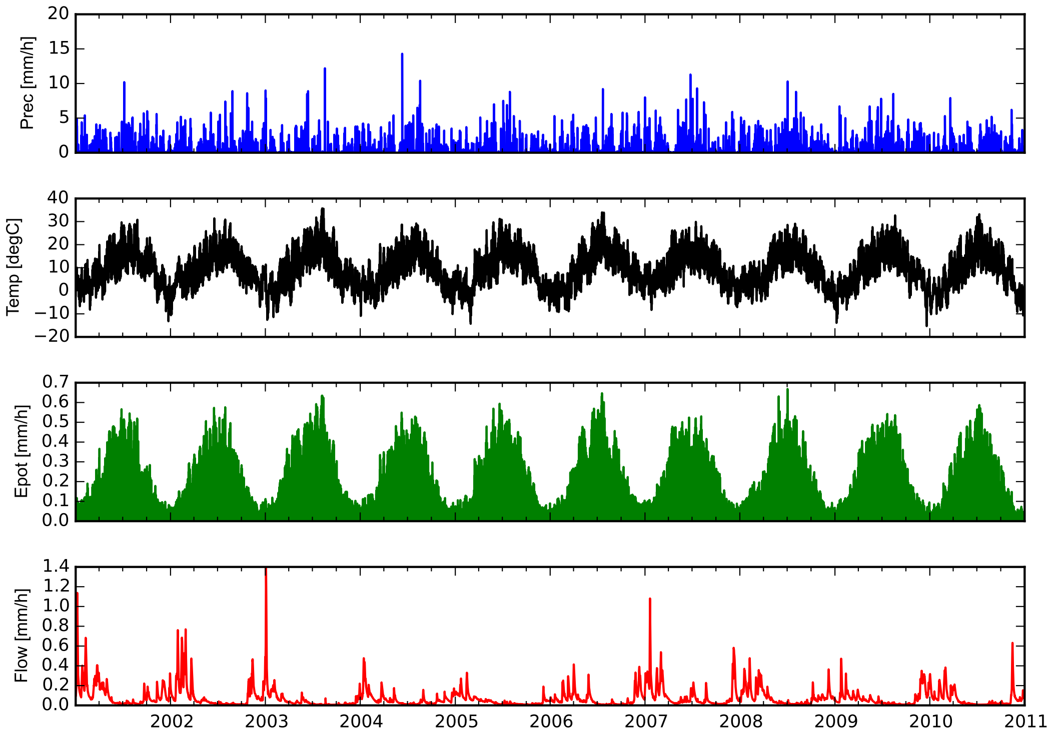

Figure 5: Semois at Membre

2 Evaluation metrics

The minimum and maximum scores for Nash-Sutcliffe Efficiency (NSE) and NSE calculated for the log of the discharge (NSElog) of the 20 realisations per model and for the five catchments are shown in the tables below. For each catchment the scores are shown for the calibration, validation and blind validation period in the Ourthe catchment.

Table 1: Minimum and maximum NSE scores for the Ourthe at Tabreux

	2001-2003 Validation	2004-2007 Calibration	2008-2010 Blind validation
GR4H-CemaNeige	0.93-0.93	0.89-0.89	0.88-0.88
PRESAGES	0.74-0.90	0.65-0.83	0.68-0.83
WALRUS	0.88-0.90	0.85-0.85	0.84-0.84
M2	0.90-0.91	0.86-0.87	0.85-0.87
M3	0.92-0.93	0.87-0.89	0.86-0.88
M4	0.92-0.93	0.88-0.90	0.86-0.88
M5	0.92-0.94	0.89-0.91	0.86-0.89
NAM	0.85-0.90	0.85-0.92	0.85-0.89
FLEX-Topo	0.86-0.90	0.82-0.87	0.78-0.82
VHM	0.87-0.90	0.87-0.88	0.87-0.88
wflow_hbv	0.89-0.92	0.86-0.88	0.83-0.85

Table 2: Minimum and maximum NSElog scores for the Ourthe at Tabreux

	2001-2003 Validation	2004-2007 Calibration	2008-2010 Blind validation
GR4H-CemaNeige	0.94-0.94	0.90-0.90	0.91-0.91
PRESAGES	0.86-0.89	0.77-0.83	0.82-0.85
WALRUS	0.61-0.66	0.40-0.47	0.21-0.58
M2	0.88-0.93	0.84-0.87	0.79-0.82
M3	0.88-0.93	0.85-0.87	0.79-0.82
M4	0.89-0.93	0.85-0.88	0.79-0.81
M5	0.91-0.93	0.88-0.89	0.82-0.87
NAM	0.51-0.89	0.62-0.91	0.23-0.90
FLEX-Topo	0.86-0.91	0.75-0.88	0.66-0.88
VHM	0.91-0.94	0.87-0.92	0.88-0.92
wflow_hbv	0.87-0.93	0.84-0.87	0.82-0.86

Table 3: Minimum and maximum NSE scores for the Ourthe Orientale at Mabompré

	2001-2003	2004-2007	2008-2010
GR4H-CemaNeige	0.82-0.82	0.77-0.78	0.72-0.72
PRESAGES	0.79-0.88	0.79-0.86	0.78-0.80
WALRUS	0.10-0.33	0.79-0.81	0.71-0.75
M2	0.87-0.89	0.79-0.83	0.75-0.77
M3	0.85-0.87	0.77-0.82	0.72-0.75
M4	0.86-0.88	0.77-0.82	0.77-0.79
M5	0.87-0.88	0.80-0.83	0.75-0.78
NAM	0.80-0.84	0.84-0.85	0.78-0.82
FLEX-Topo	0.73-0.84	0.61-0.80	0.54-0.70
VHM	0.84-0.86	0.82-0.85	0.77-0.81
wflow_hbv	0.74-0.78	0.65-0.70	0.47-0.56

Table 4: Minimum and maximum NSElog scores for the Ourthe Orientale at Mabompré

	2001-2003	2004-2007	2008-2010
GR4H-CemaNeige	0.88-0.88	0.85-0.85	0.79-0.79
PRESAGES	0.84-0.86	0.76-0.84	0.78-0.81
WALRUS	0.50-0.56	0.41-0.51	0.46-0.63
M2	0.86-0.90	0.81-0.85	0.72-0.76
M3	0.86-0.88	0.80-0.84	0.72-0.74
M4	0.86-0.89	0.80-0.84	0.72-0.75
M5	0.85-0.89	0.84-0.85	0.75-0.78
NAM	0.53-0.85	0.63-0.87	0.24-0.81
FLEX-Topo	0.80-0.87	0.72-0.84	0.62-0.78
VHM	0.88-0.91	0.85-0.91	0.80-0.85
wflow_hbv	0.75-0.85	0.68-0.75	0.66-0.72

Table 5: Minimum and maximum NSE scores for the Ourthe Occidentale at Ortho

	2001-2003	2004-2007	2008-2010
GR4H-CemaNeige	0.82-0.83	0.80-0.81	0.75-0.76
PRESAGES	0.81-0.86	0.84-0.86	0.79-0.82
WALRUS	0.11-0.35	0.74-0.77	0.75-0.77
M2	0.91-0.92	0.82-0.85	0.80-0.82
M3	0.88-0.91	0.80-0.83	0.77-0.80
M4	0.88-0.92	0.82-0.84	0.78-0.80
M5	0.90-0.92	0.82-0.85	0.78-0.81
NAM	0.85-0.89	0.80-0.84	0.79-0.82
FLEX-Topo	0.77-0.87	0.61-0.76	0.58-0.71
VHM	0.88-0.90	0.85-0.86	0.82-0.84
wflow_hbv	0.82-0.85	0.75-0.81	0.72-0.78

Table 6: Minimum and maximum NSElog scores for the Ourthe Occidentale at Ortho

	2001-2003	2004-2007	2008-2010
GR4H-CemaNeige	0.90-0.90	0.79-0.79	0.83-0.83
PRESAGES	0.82-0.86	0.67-0.79	0.73-0.79
WALRUS	0.39-0.51	0.22-0.30	0.20-0.58
M2	0.86-0.90	0.74-0.77	0.75-0.79
M3	0.85-0.88	0.72-0.74	0.73-0.77
M4	0.86-0.89	0.72-0.75	0.73-0.77
M5	0.90-0.92	0.77-0.81	0.76-0.83
NAM	0.83-0.88	0.47-0.83	0.25-0.83
FLEX-Topo	0.70-0.91	0.24-0.69	0.38-0.76
VHM	0.90-0.94	0.73-0.83	0.81-0.88
wflow_hbv	0.80-0.87	0.52-0.71	0.59-0.72

Table 7: Minimum and maximum NSE scores for the Lesse at Gendron

	2001-2003	2004-2007	2008-2010
GR4H-CemaNeige	0.95-0.95	0.90-0.90	0.82-0.82
PRESAGES	0.71-0.81	0.73-0.78	0.71-0.75
WALRUS	0.04-0.28	0.84-0.85	0.81-0.83
M2	0.90-0.91	0.85-0.86	0.78-0.79
M3	0.93-0.94	0.87-0.88	0.80-0.82
M4	0.92-0.94	0.88-0.89	0.79-0.80
M5	0.90-0.93	0.88-0.91	0.79-0.84
NAM	0.78-0.86	0.83-0.89	0.80-0.83
FLEX-Topo	0.86-0.91	0.82-0.88	0.71-0.79
VHM	0.81-0.86	0.84-0.86	0.81-0.83
wflow_hbv	0.89-0.94	0.85-0.87	0.73-0.79

Table 8: Minimum and maximum NSElog scores for the Lesse at Gendron

	2001-2003	2004-2007	2008-2010
GR4H-CemaNeige	0.94-0.95	0.91-0.91	0.88-0.88
PRESAGES	0.80-0.82	0.64-0.70	0.69-0.72
WALRUS	0.55-0.62	0.29-0.41	0.22-0.54
M2	0.87-0.93	0.85-0.87	0.77-0.79
M3	0.88-0.93	0.86-0.87	0.78-0.80
M4	0.88-0.93	0.87-0.88	0.78-0.80
M5	0.92-0.93	0.89-0.91	0.81-0.85
NAM	0.49-0.92	0.44-0.90	0.34-0.87
FLEX-Topo	0.83-0.91	0.63-0.87	0.67-0.86
VHM	0.92-0.95	0.87-0.92	0.86-0.90
wflow_hbv	0.88-0.93	0.83-0.88	0.81-0.86

Table 9: Minimum and maximum NSE scores for the Semois at Membre

	2001-2003	2004-2007	2008-2010
GR4H-CemaNeige	0.82-0.83	0.78-0.79	0.77-0.78
PRESAGES	0.74-0.88	0.76-0.87	0.77-0.87
WALRUS	0.58-0.67	0.86-0.88	0.86-0.89
M2	0.87-0.89	0.83-0.86	0.82-0.85
M3	0.92-0.93	0.87-0.88	0.86-0.87
M4	0.91-0.93	0.87-0.89	0.85-0.87
M5	0.88-0.91	0.86-0.89	0.84-0.88
NAM	0.80-0.88	0.84-0.89	0.86-0.90
FLEX-Topo	0.86-0.89	0.87-0.91	0.85-0.92
VHM	0.82-0.85	0.85-0.87	0.85-0.88
wflow_hbv	0.93-0.94	0.86-0.91	0.84-0.92

Table 10: Minimum and maximum NSElog scores for the Semois at Membre

	2001-2003	2004-2007	2008-2010
GR4H-CemaNeige	0.92-0.92	0.89-0.89	0.89-0.89
PRESAGES	0.88-0.92	0.79-0.87	0.80-0.87
WALRUS	0.49-0.61	0.63-0.67	0.04-0.36
M2	0.84-0.89	0.85-0.87	0.83-0.85
M3	0.84-0.90	0.85-0.87	0.83-0.85
M4	0.85-0.90	0.86-0.88	0.83-0.85
M5	0.91-0.93	0.88-0.88	0.87-0.89
NAM	0.44-0.90	0.67-0.89	0.49-0.90
FLEX-Topo	0.86-0.91	0.76-0.88	0.84-0.89
VHM	0.89-0.94	0.82-0.90	0.85-0.92
wflow_hbv	0.90-0.93	0.84-0.90	0.85-0.90

3 Cumulative discharges

The graphs illustrate for each model observed (red) and modelled (blue) cumulative discharges for the total modelled period (2002-2010) for each studied catchment. The total modelled discharge was used as signature, this was evaluated by computing the relative error for each model realisation for each model and catchment. The smallest relative error for each model and catchment is presented with the graphs.

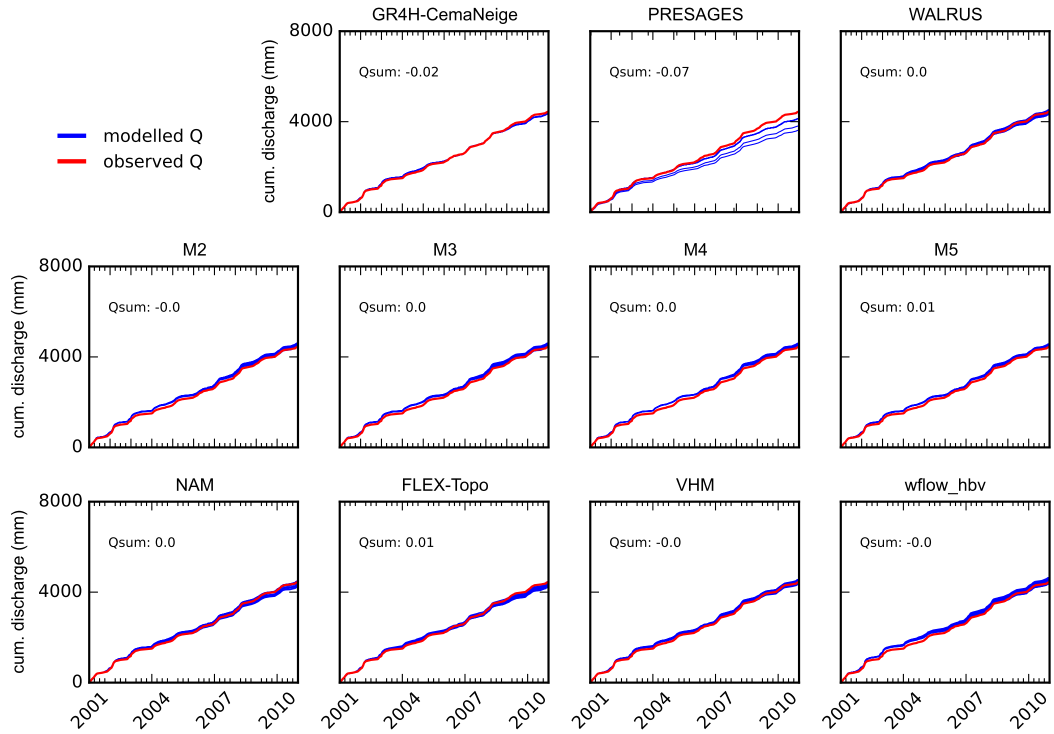

Figure 6: Ourthe at Tabreux

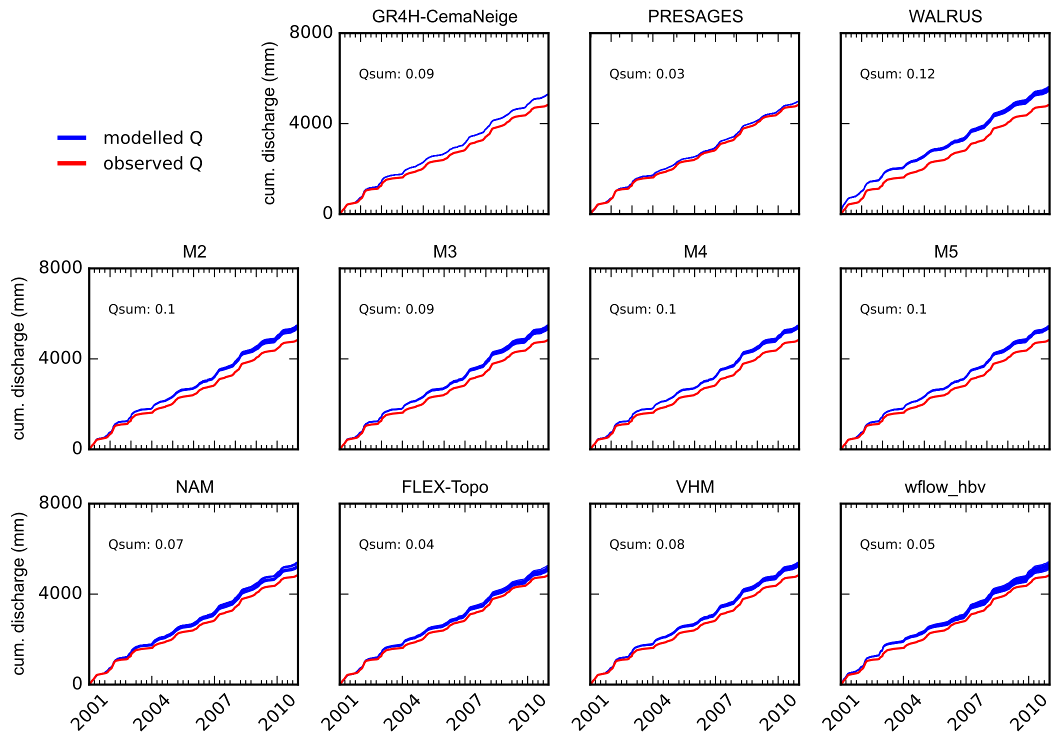

Figure 7: Ourthe Orientale at Mabompré

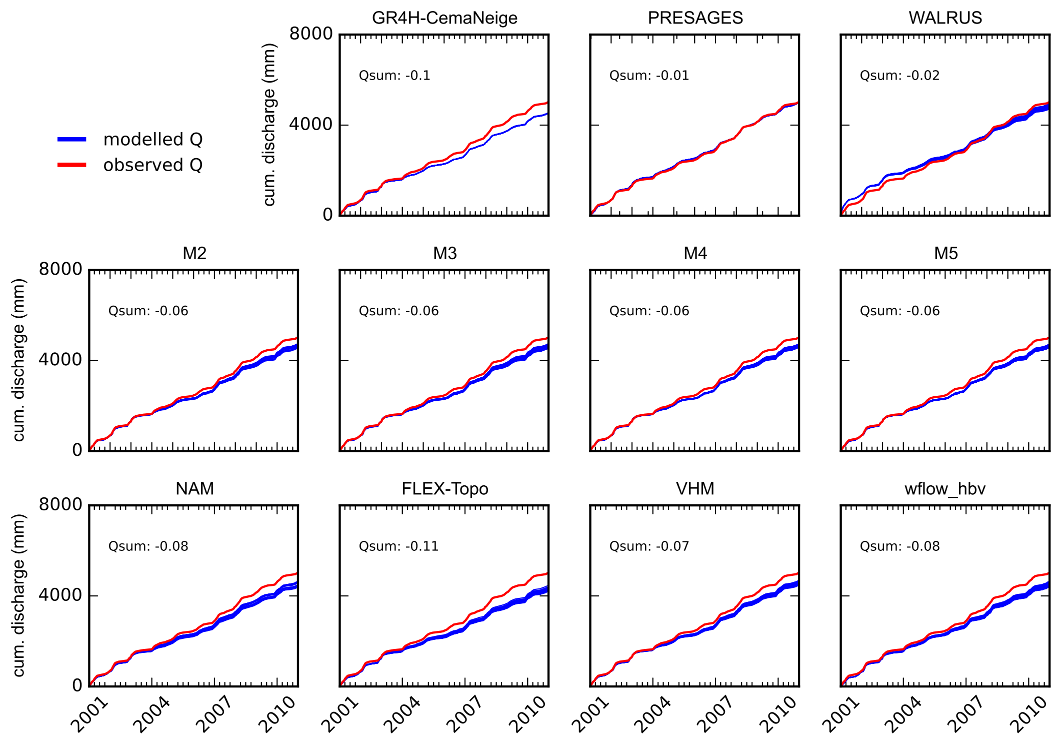

Figure 8: Ourthe Occidentale at Ortho

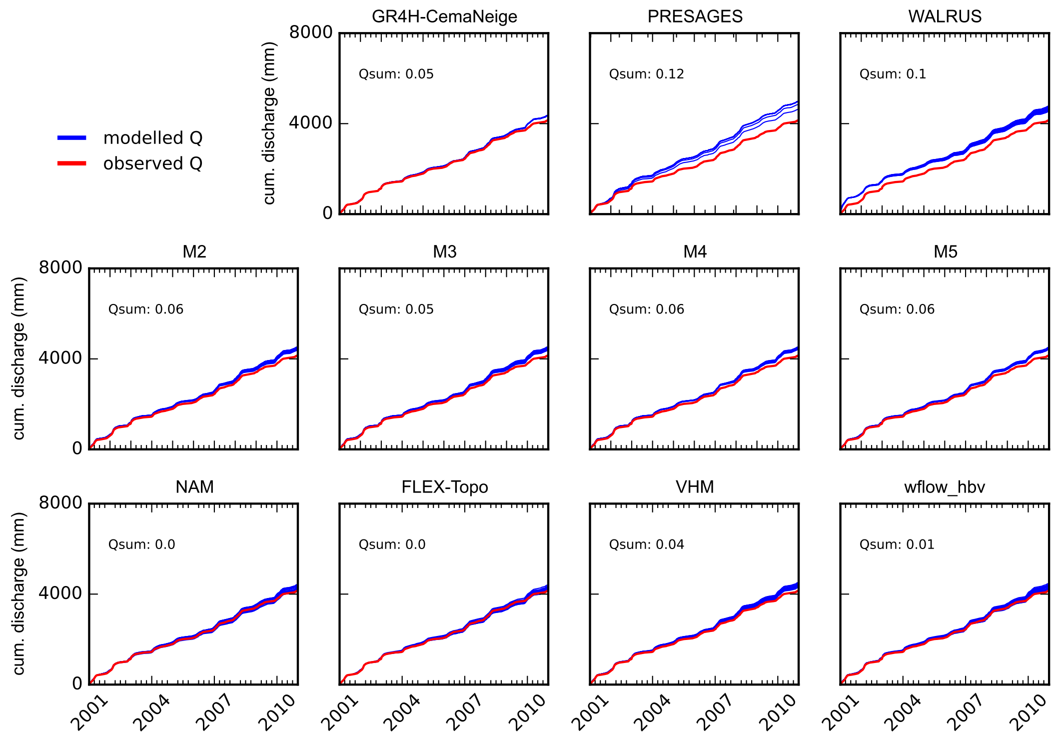

Figure 9: Lesse at Gendron

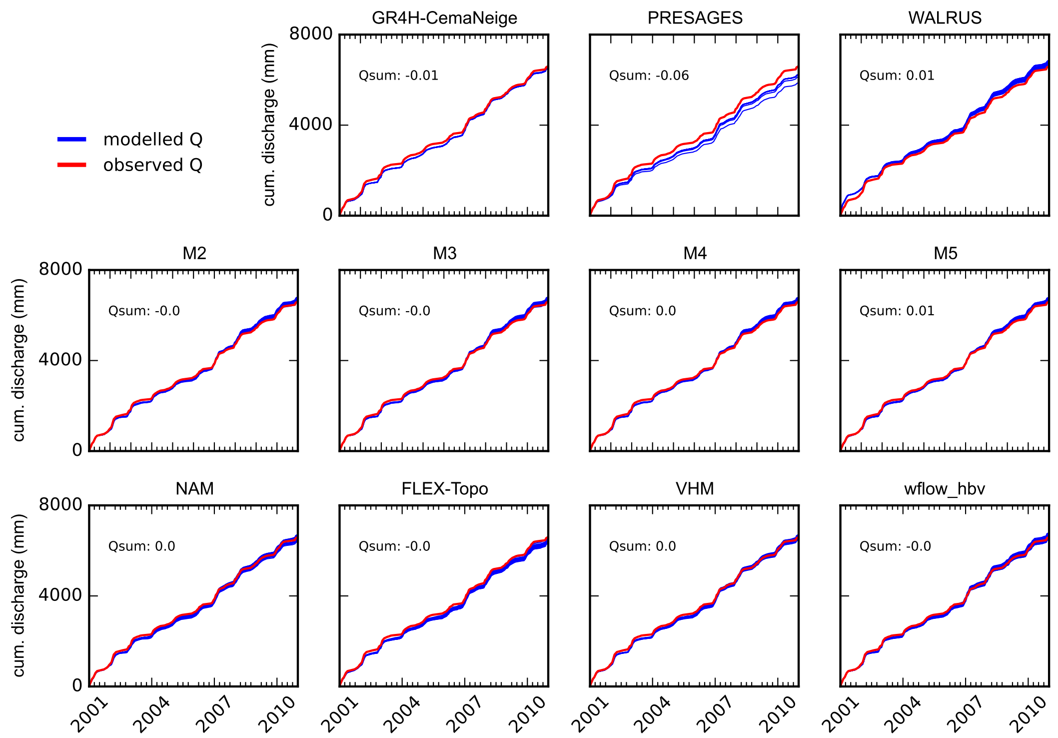

Figure 10: Semois at Membre

4 Empirical frequency distributions of peak flows

The graphs illustrate for each model observed (red) and modelled (blue) empirical frequency distributions of peak flows for the total modelled period (2002-2010) for each studied catchment. The upper and lower slopes of the distribution were used as signature, with the divider being located at a return period of 1.5 years. These slopes were evaluated by computing the relative error for each model realisation for each model and catchment. The smallest relative error for each model and catchment is presented with the graphs.

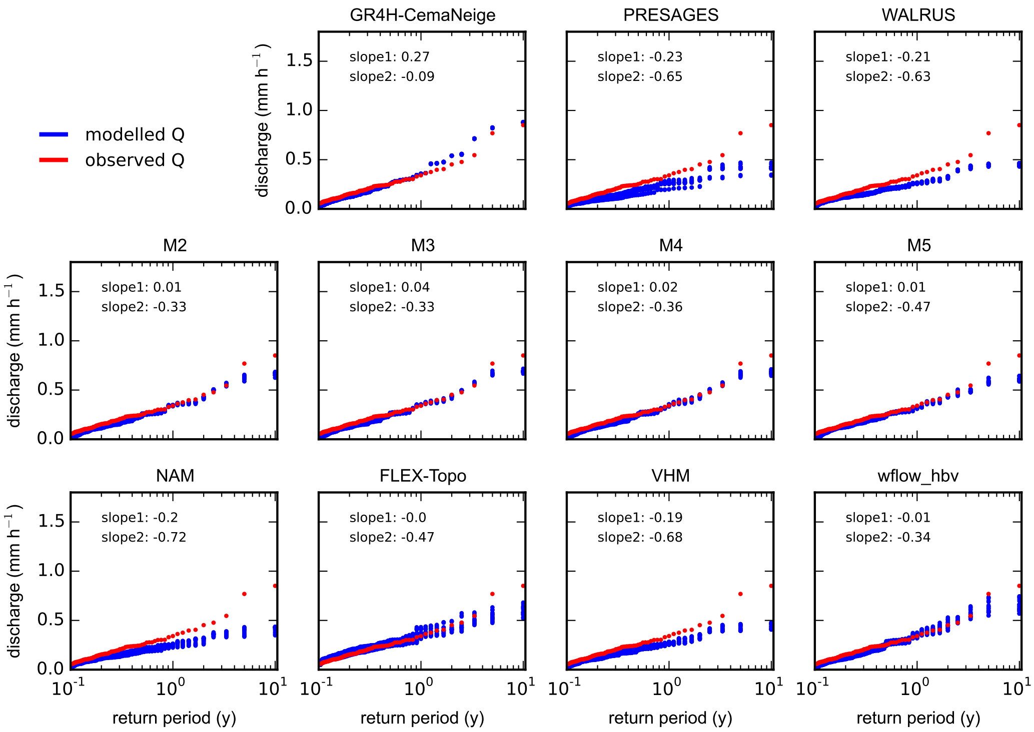

Figure 11: Ourthe at Tabreux

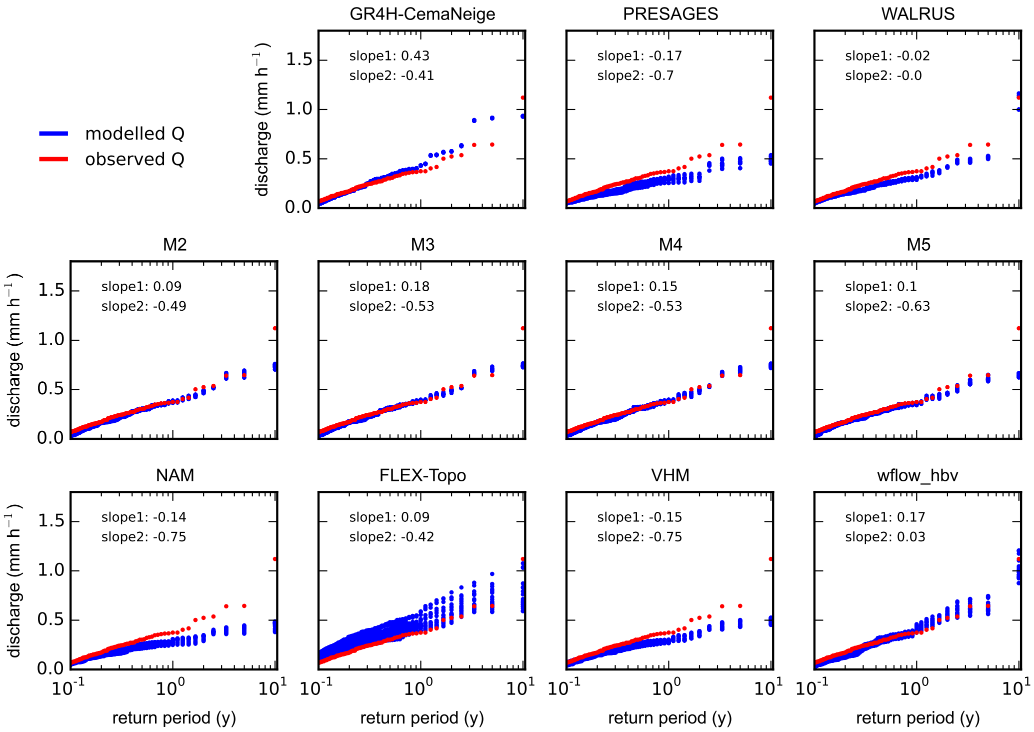

Figure 12: Ourthe Orientale at Mabompré

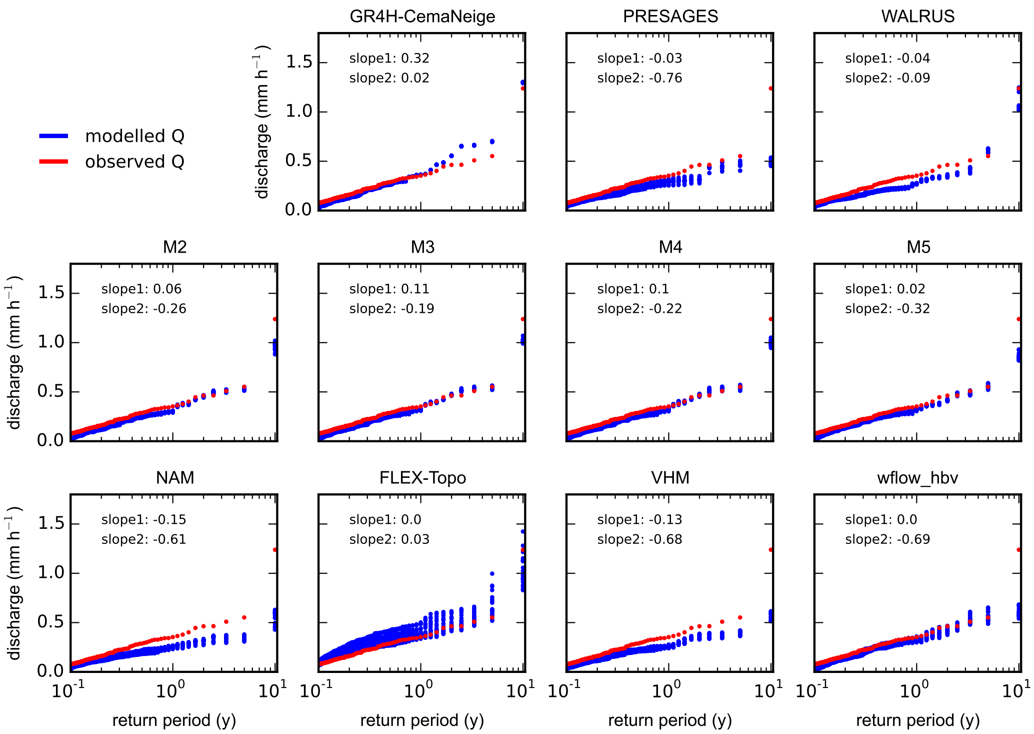

Figure 13: Ourthe Occidentale at Ortho

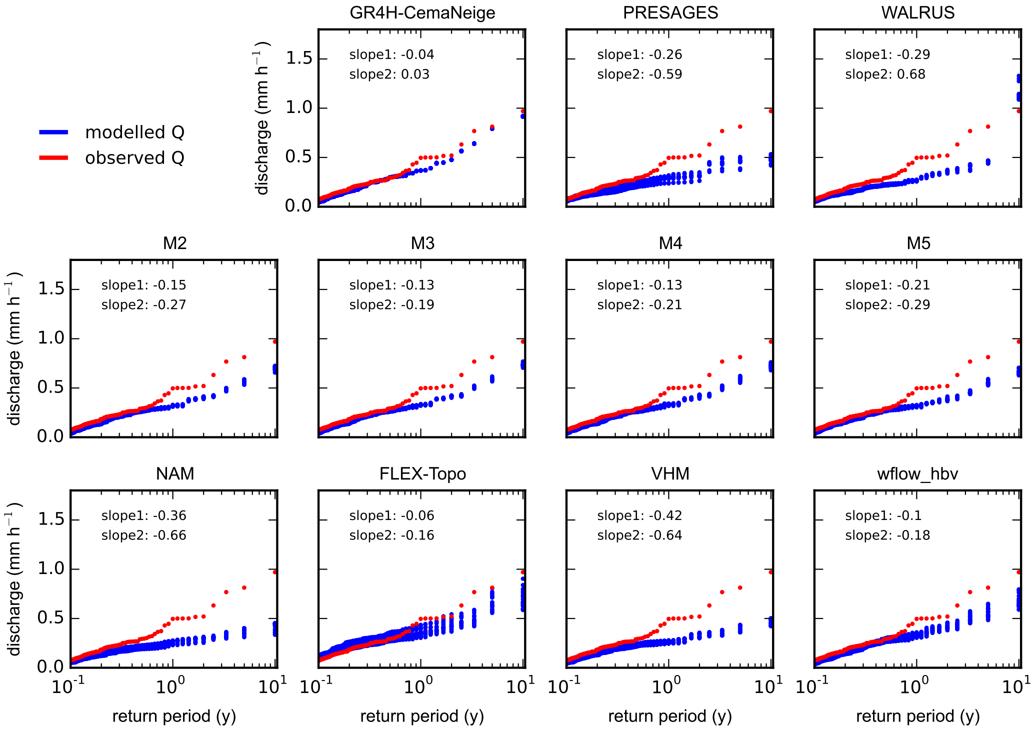

Figure 14: Lesse at Gendron; note that the y-axis deviate from the figure in the paper, to make it similar to the other plots in this section

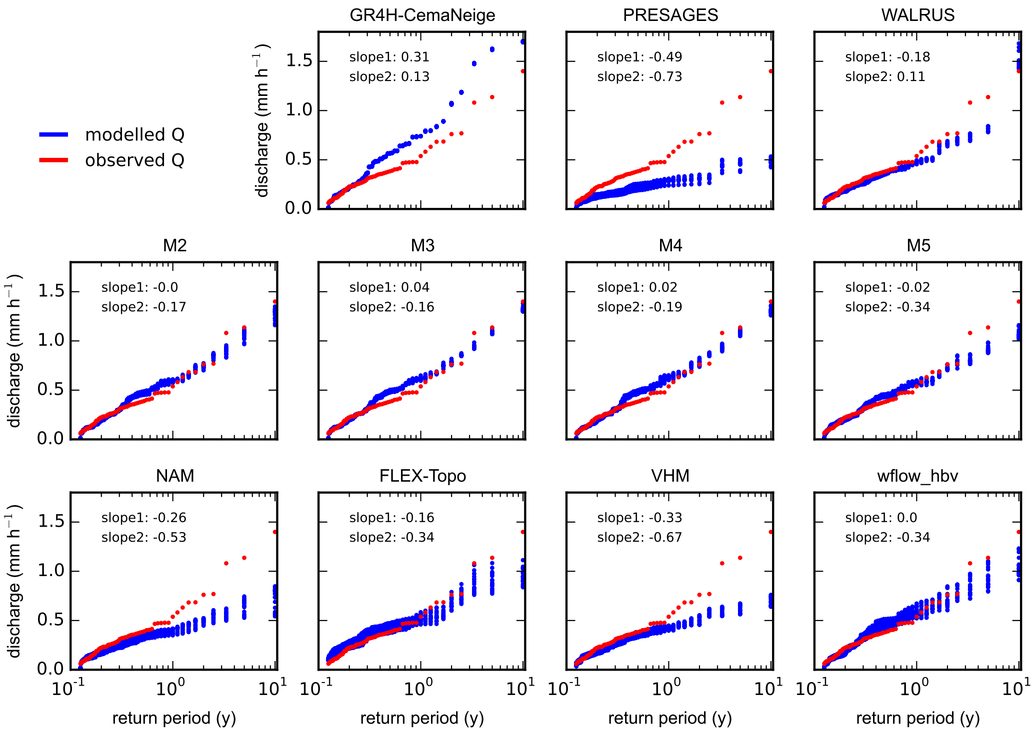

Figure 15: Semois

5 Lowest 20% of Flow Duration Curves

The graphs show the observed (red) and modelled (blue) flow duration curves for the lowest 20% of discharges for each model for the total modelled period (2002-2010) for each studied catchment. The slope and mean of this part of the flow duration curve were used as signature, these were evaluated by computing the relative error for each model realisation for each model and catchment. The smallest relative error for each model and catchment is presented with the graphs.

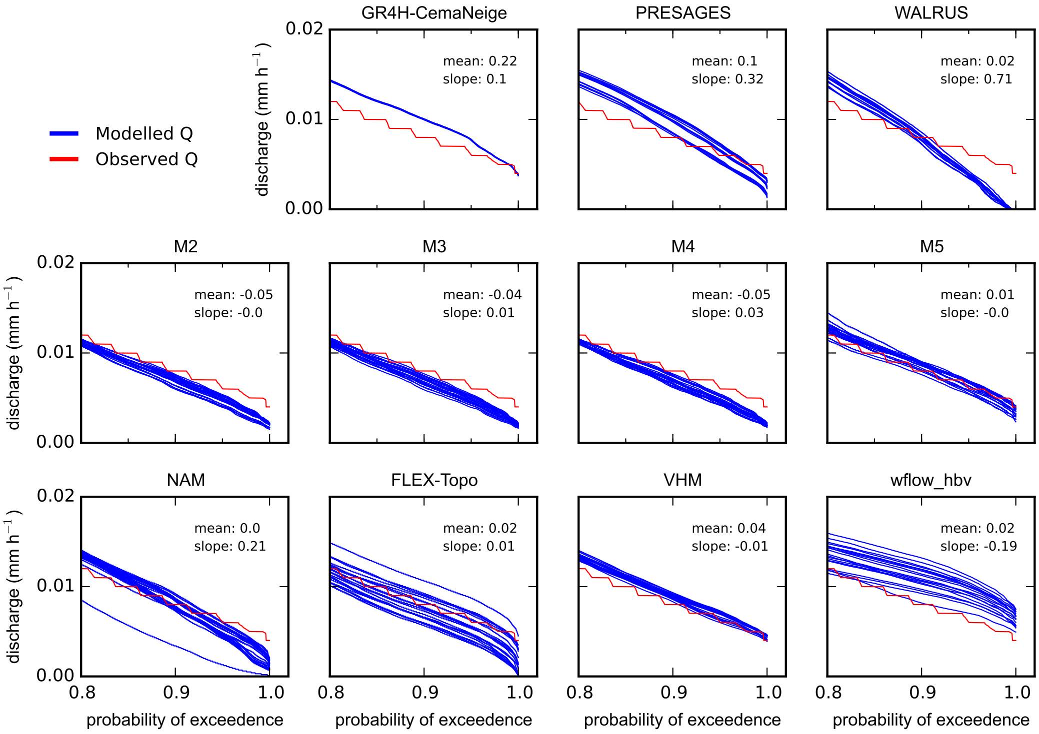

Figure 16: Ourthe at Tabreux

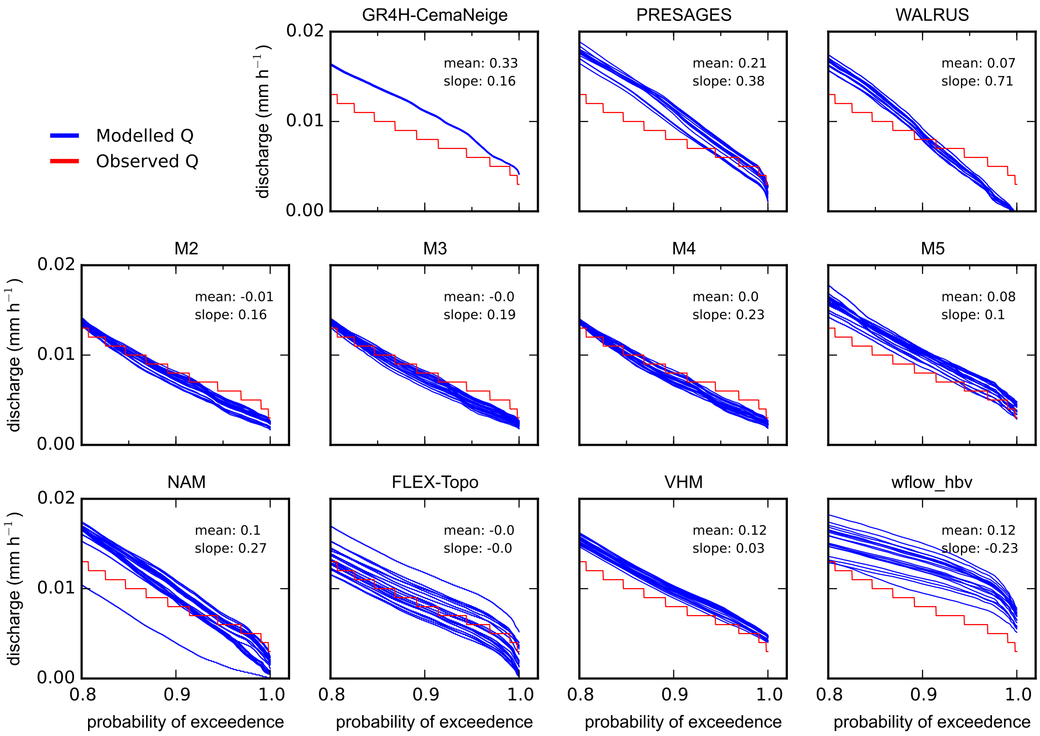

Figure 17: Ourthe Orientale at Mabompré

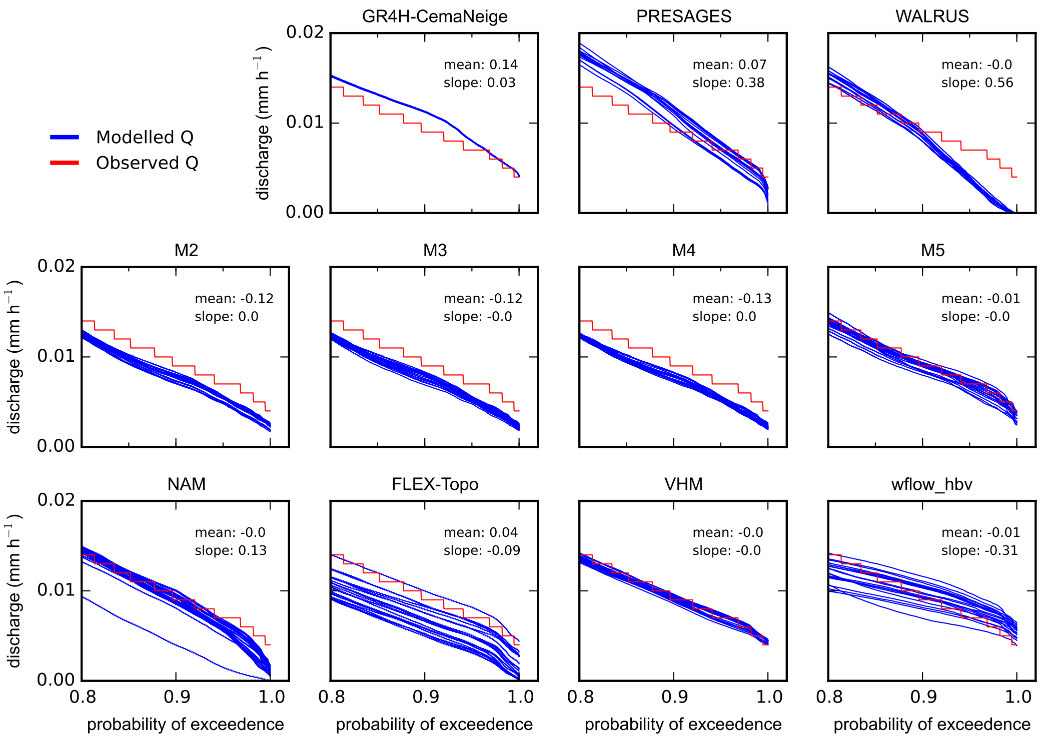

Figure 18: Ourthe Occidentale at Ortho

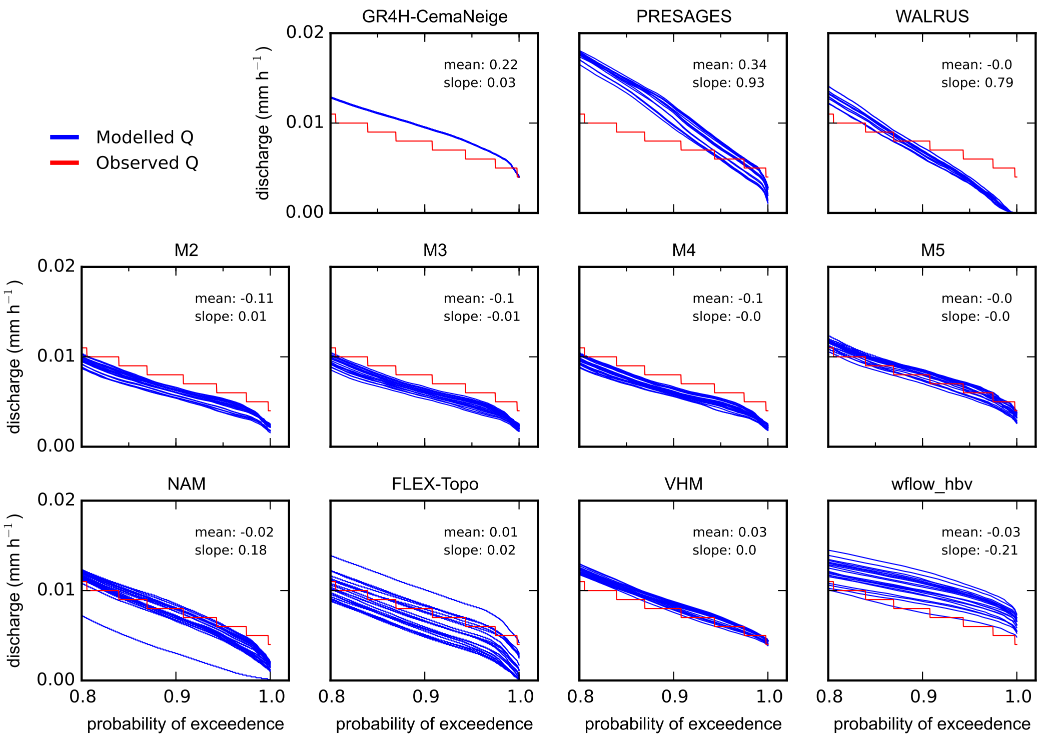

Figure 19: Lesse at Gendron

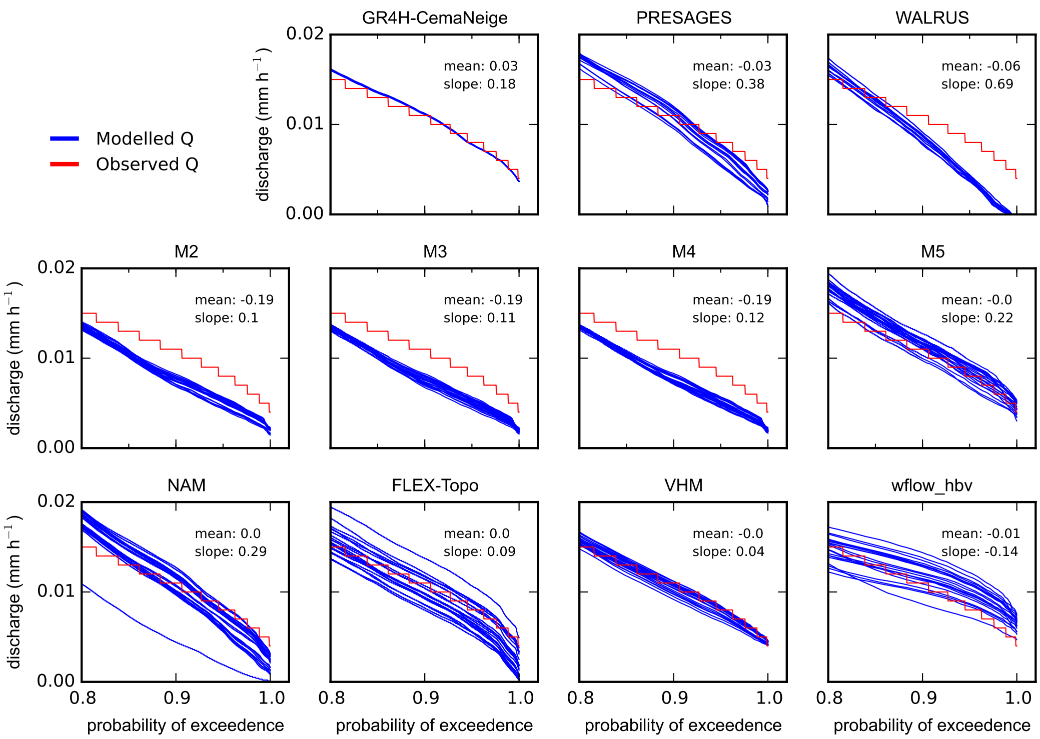

Figure 20: Semois at Membre

6 Hydrographs for a low flow period (Jul - Nov 2008)

The figures below show the modelled (blue) and observed (red) hydrographs for the relatively wet summer of 2008 (July-November) for the five studied catchments. Actual evaporation simulated by the models is shown in green. Precipitation and temperature are shown in the first row. Note: the four graphs with precipitation and temperature on top are the same. The averaged slope of the declining limbs and the total modelled discharge were used as signature, these were evaluated by computing the relative error for each model realisation for each model and catchment. The smallest relative error for each model and catchment is presented with the graphs.

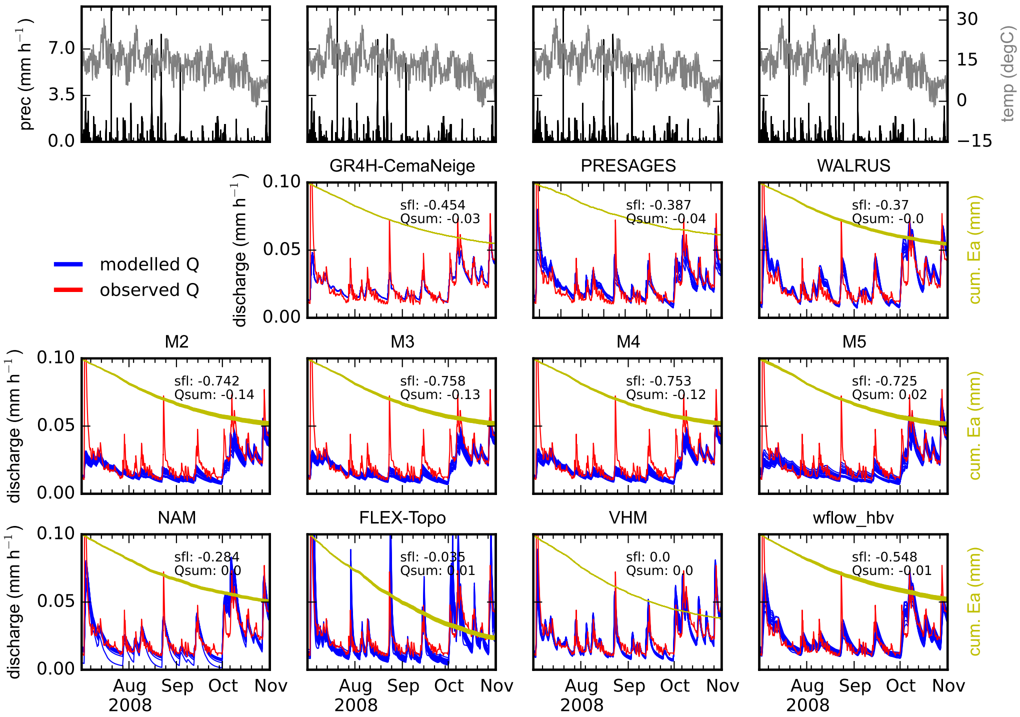

Figure 21: Ourthe at Tabreux

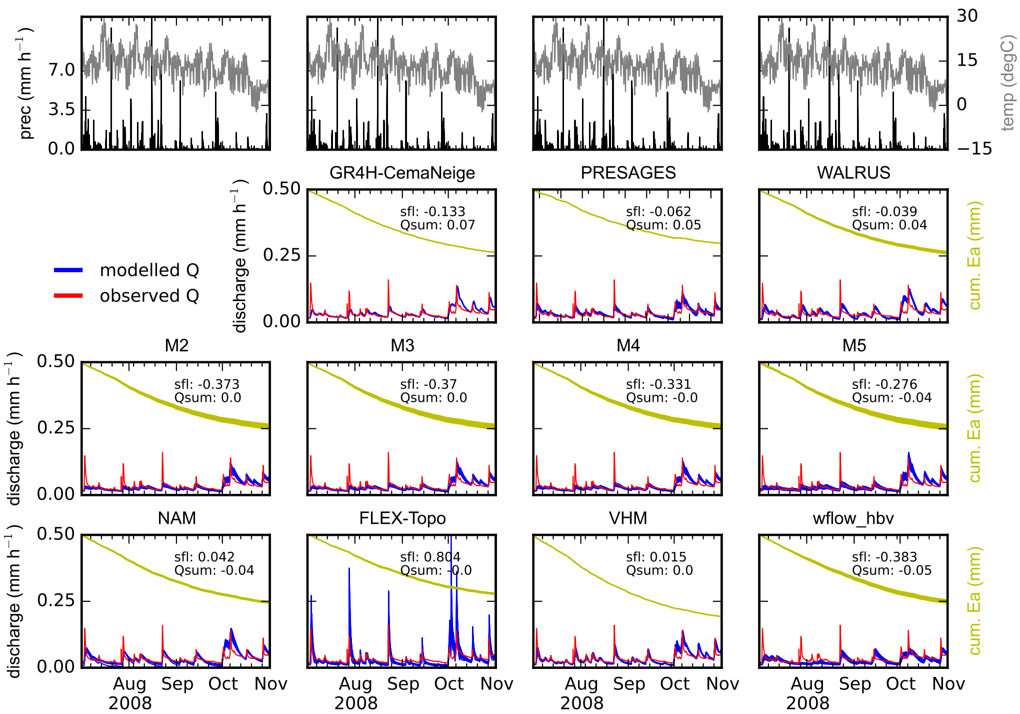

Figure 22: Ourthe Orientale at Mabompré

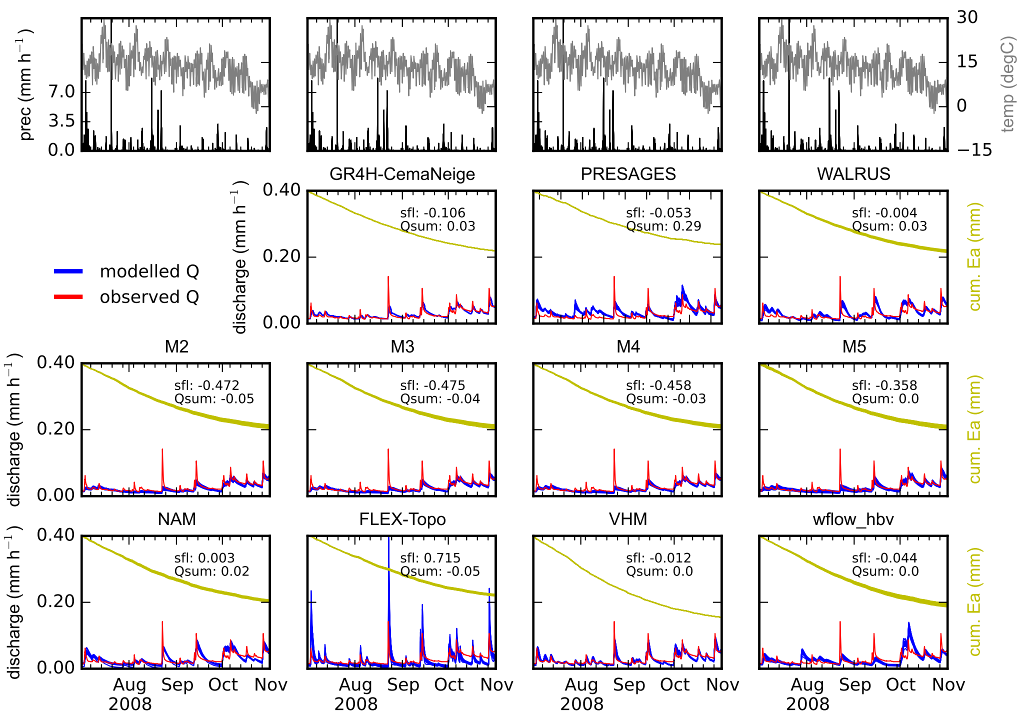

Figure 23: Ourthe Occidentale at Ortho

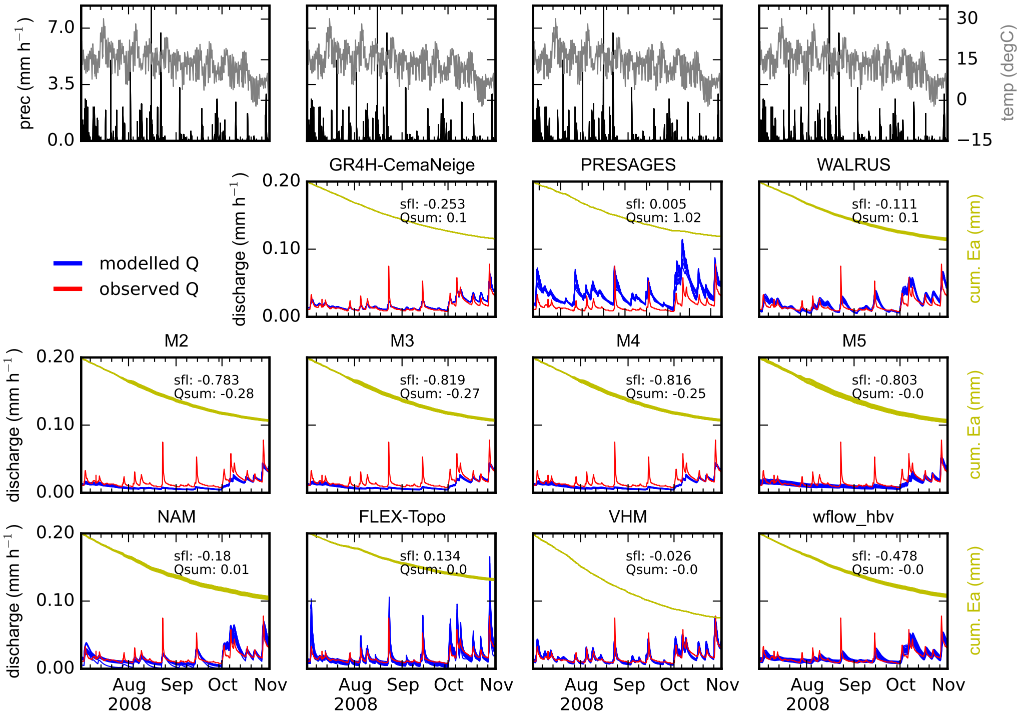

Figure 24: Lesse at Gendron

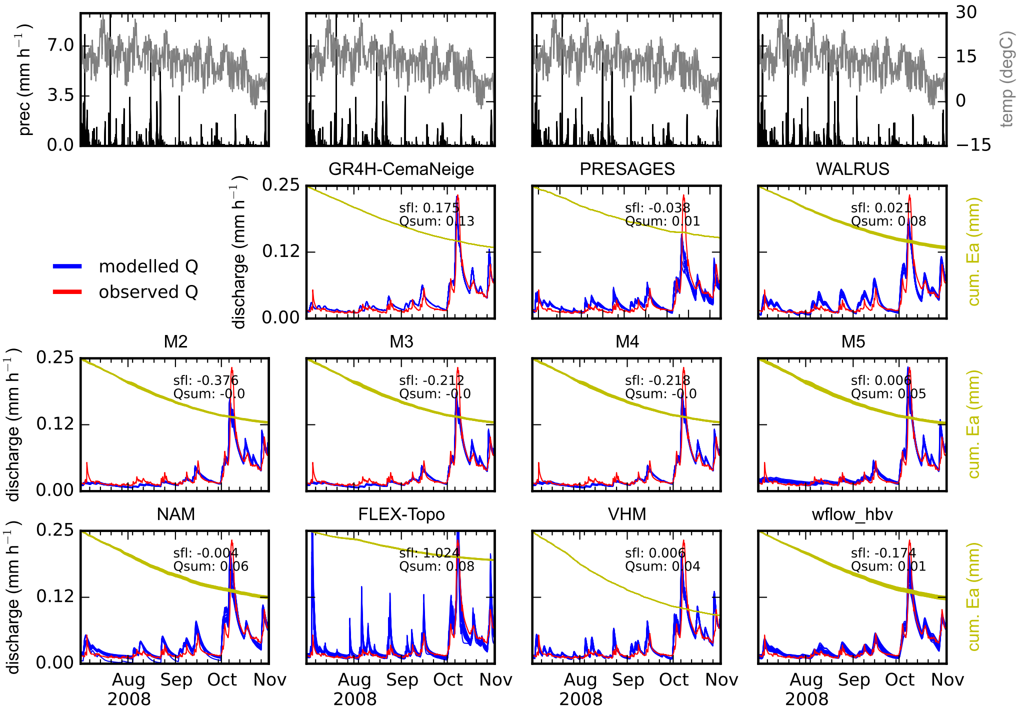

Figure 25: Semois at Membre

7 Hydrographs for a transition between low and high flow (Oct 2003 - Feb 2004)

The figures below show the modelled (blue) and observed (red) hydrographs for the transition period between low and high flows between October 2003 and February 2004 for the five studied catchments. Actual evaporation simulated by the models is shown in green. Precipitation and temperature are shown in the first row. Note: the four graphs with precipitation and temperature on top are the same. The ratio between the first and highest peak and the total modelled discharge were used as signature, these were evaluated by computing the relative error for each model realisation for each model and catchment. The smallest relative error for each model and catchment is presented with the graphs.

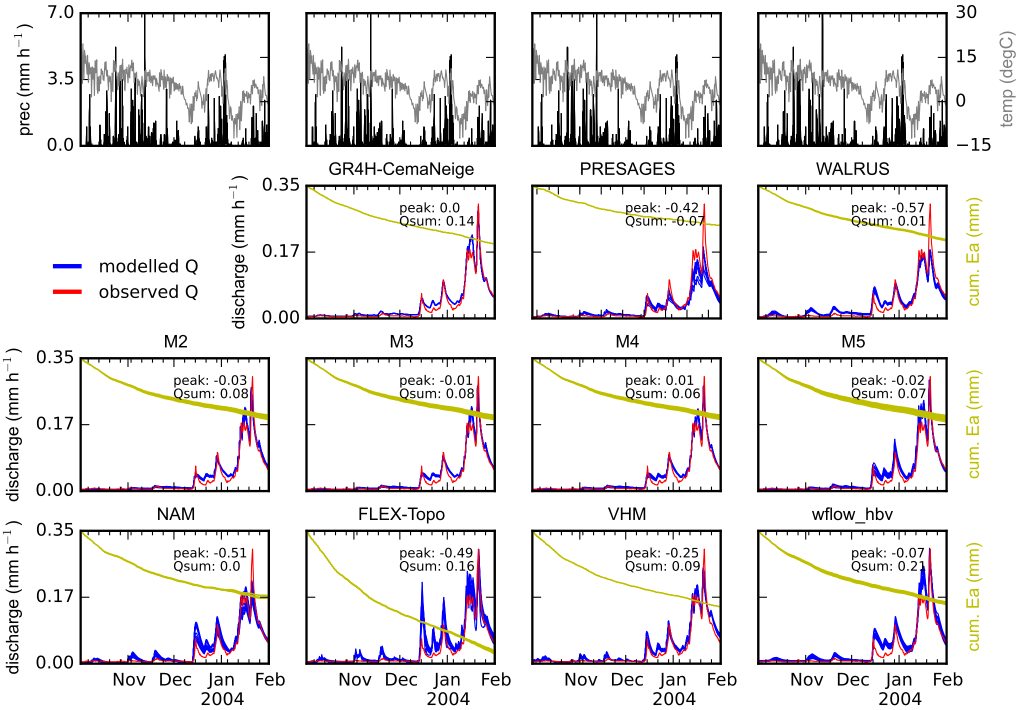

Figure 26: Ourthe at Tabreux

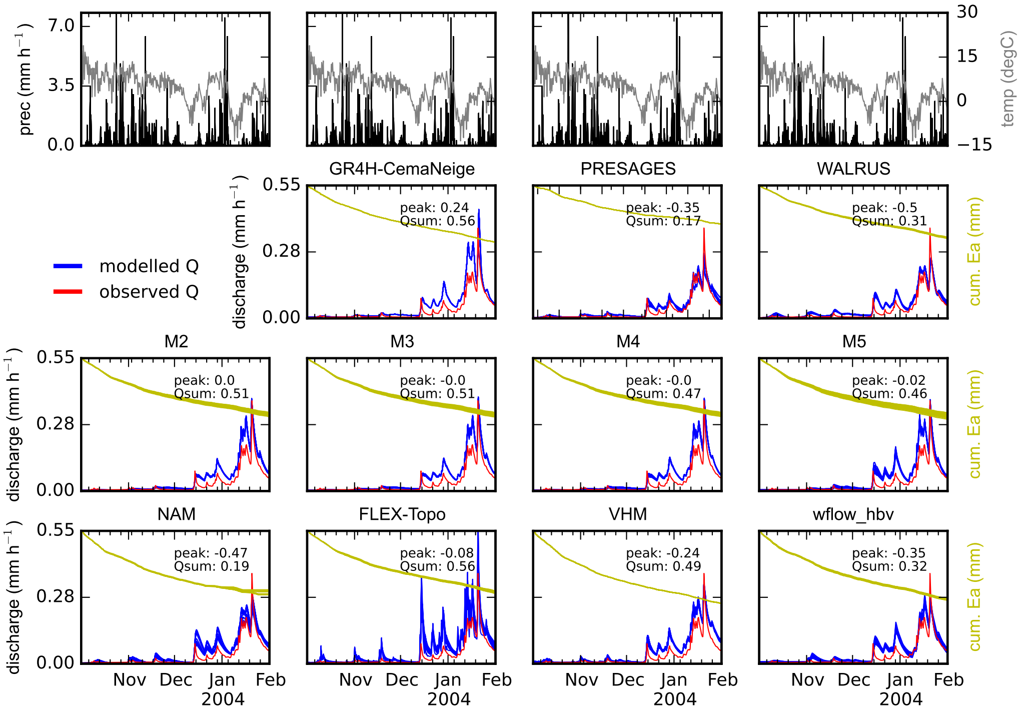

Figure 27: Ourthe Orientale at Mabompré

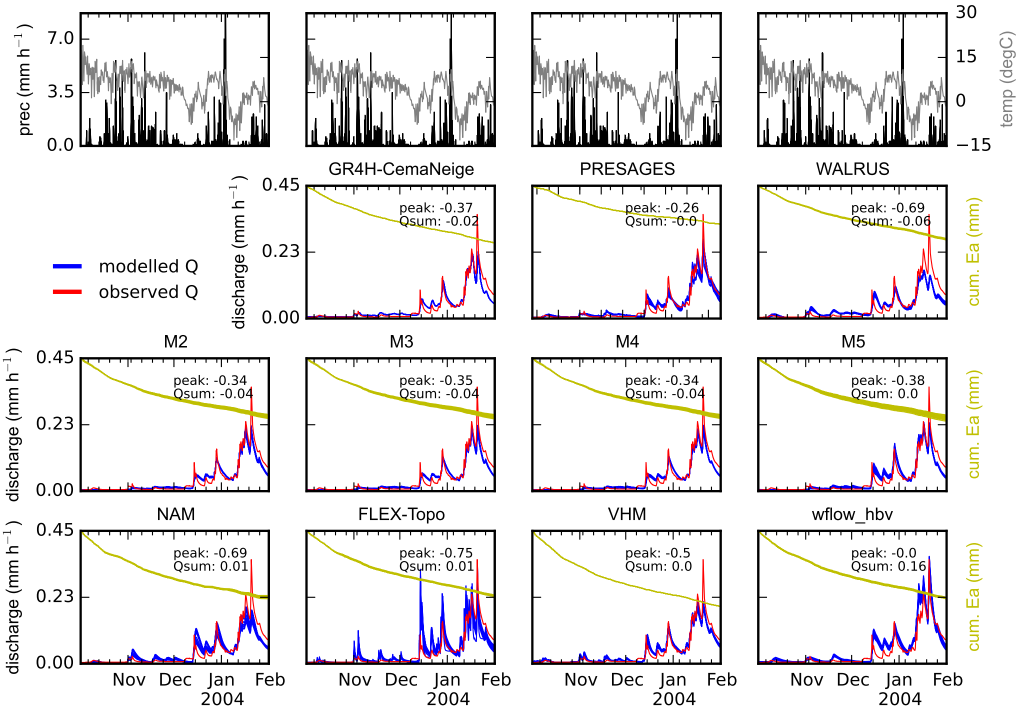

Figure 28: Ourthe Occidentale at Ortho

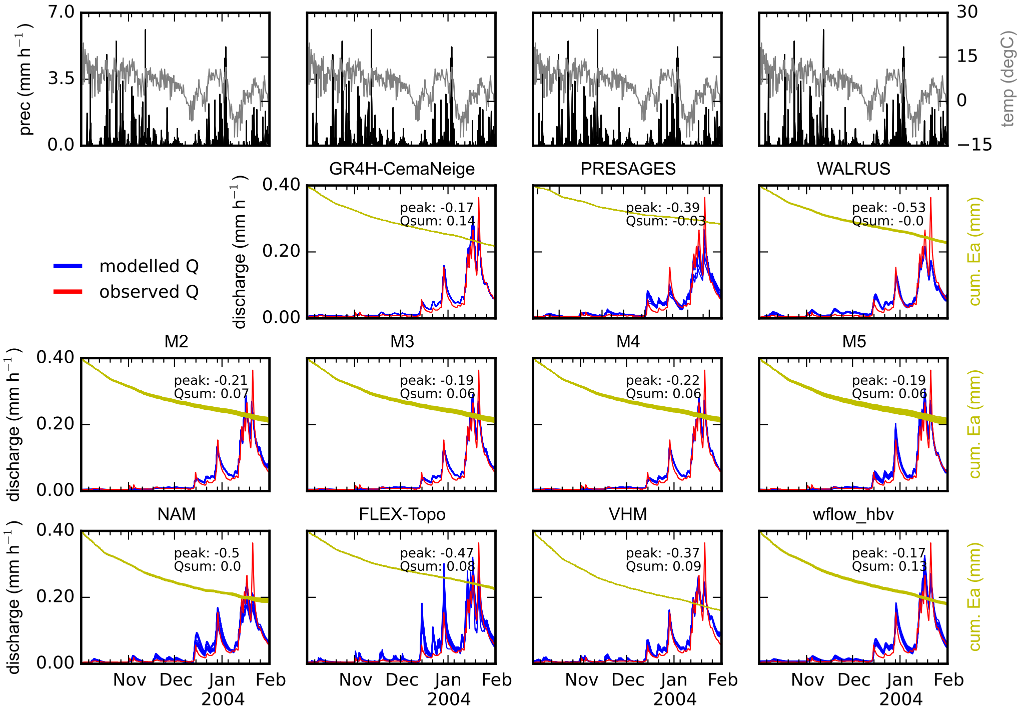

Figure 29: Lesse at Gendron

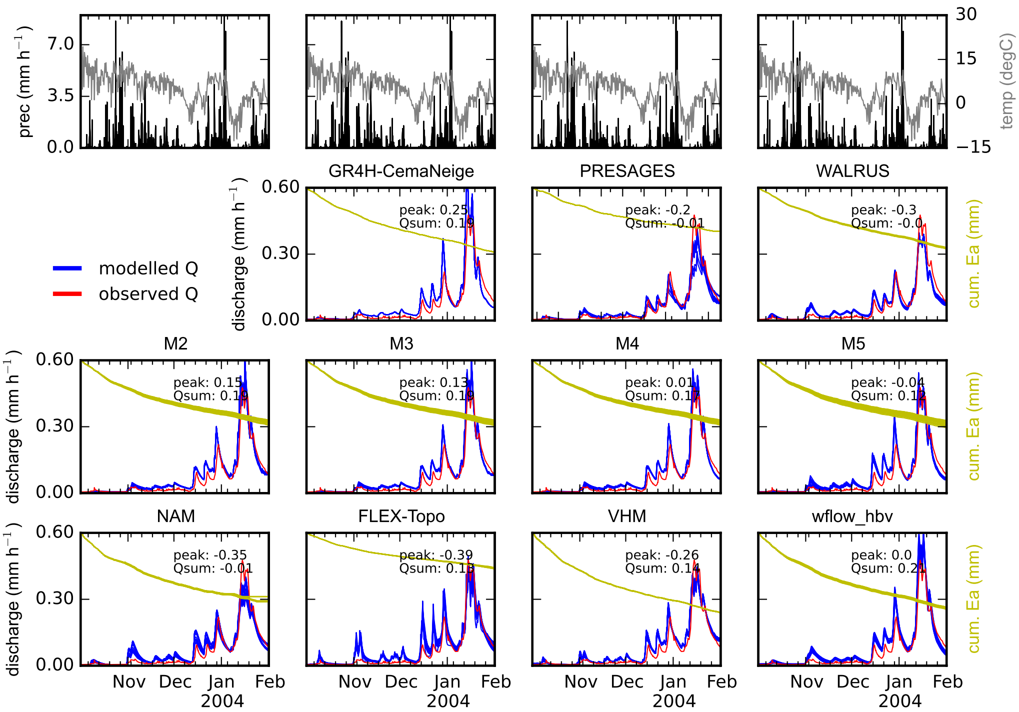

Figure 30: Semois at Membre

8 Hydrographs for a high flow period without influence of snow (Nov 2002 - Feb 2003)

The figures below show the modelled (blue) and observed (red) hydrographs for a high flow period not influenced by snow in Nov 2002 - Feb 2003 for the five studied catchments. Actual evaporation simulated by the models is shown in green. Precipitation and temperature are shown in the first row. Note: the four graphs with precipitation and temperature on top are the same. The magnitude and timing of the highest peak were used as signature, these were evaluated by computing the relative error for each model realisation for each model and catchment. The smallest relative error for each model and catchment is presented with the graphs.

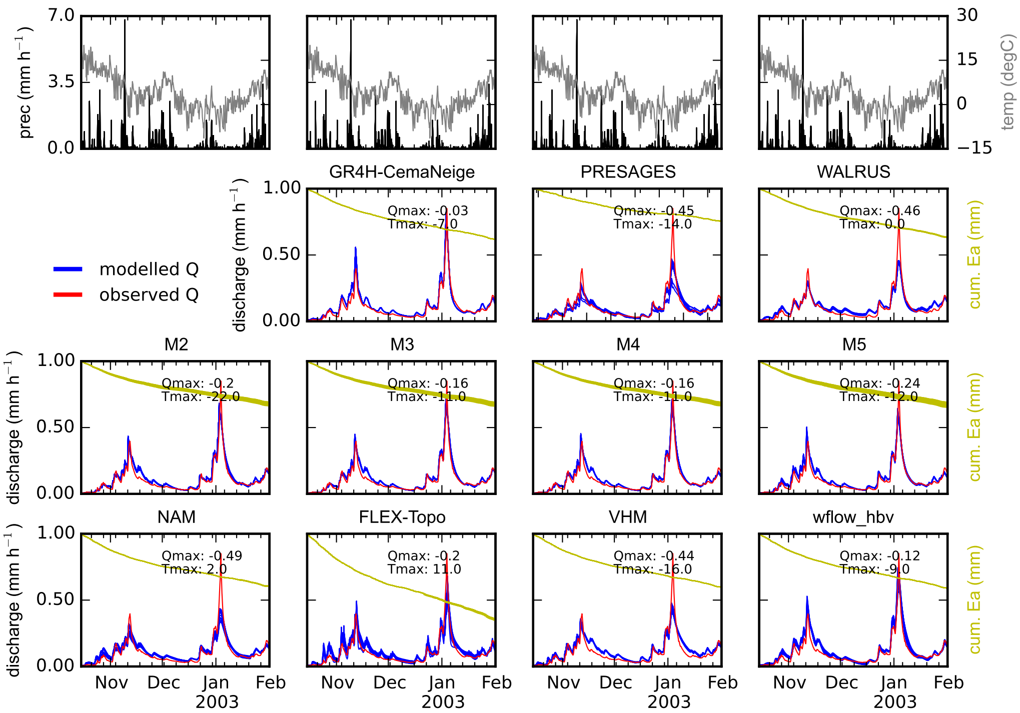

Figure 31: Ourthe at Tabreux

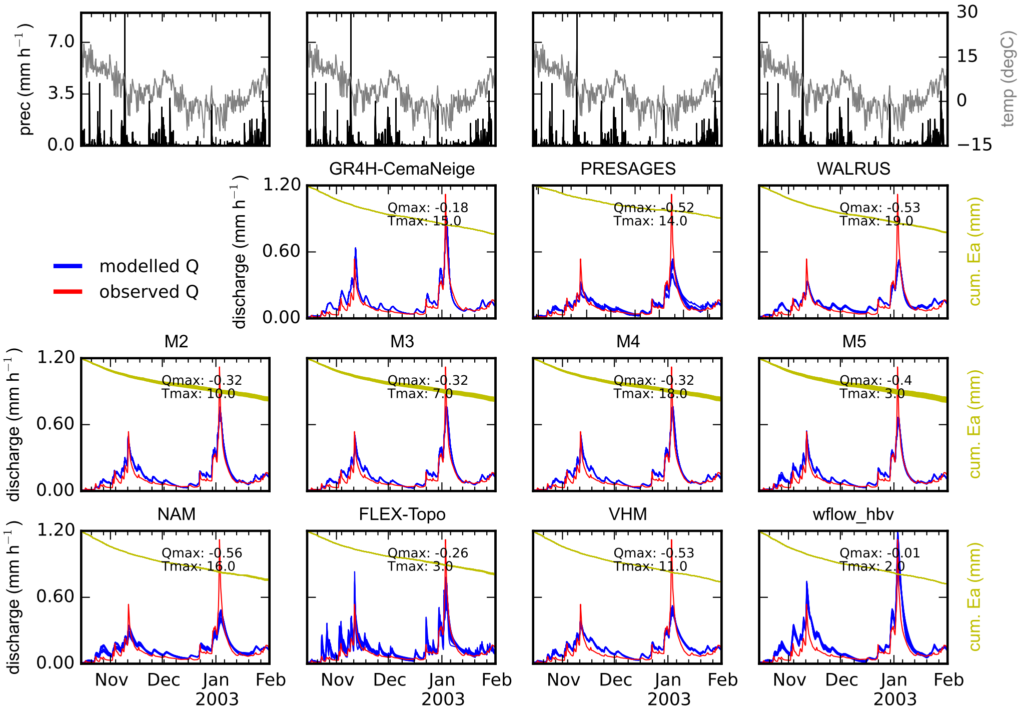

Figure 32: Ourthe Orientale at Mabompré

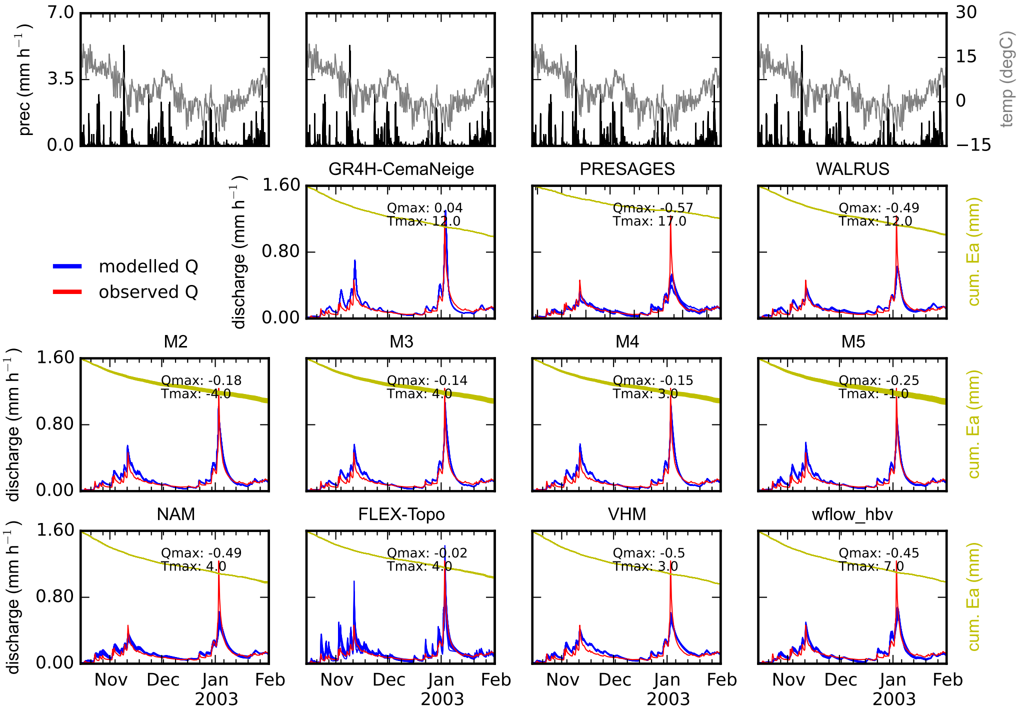

Figure 33: Ourthe Occidentale at Ortho

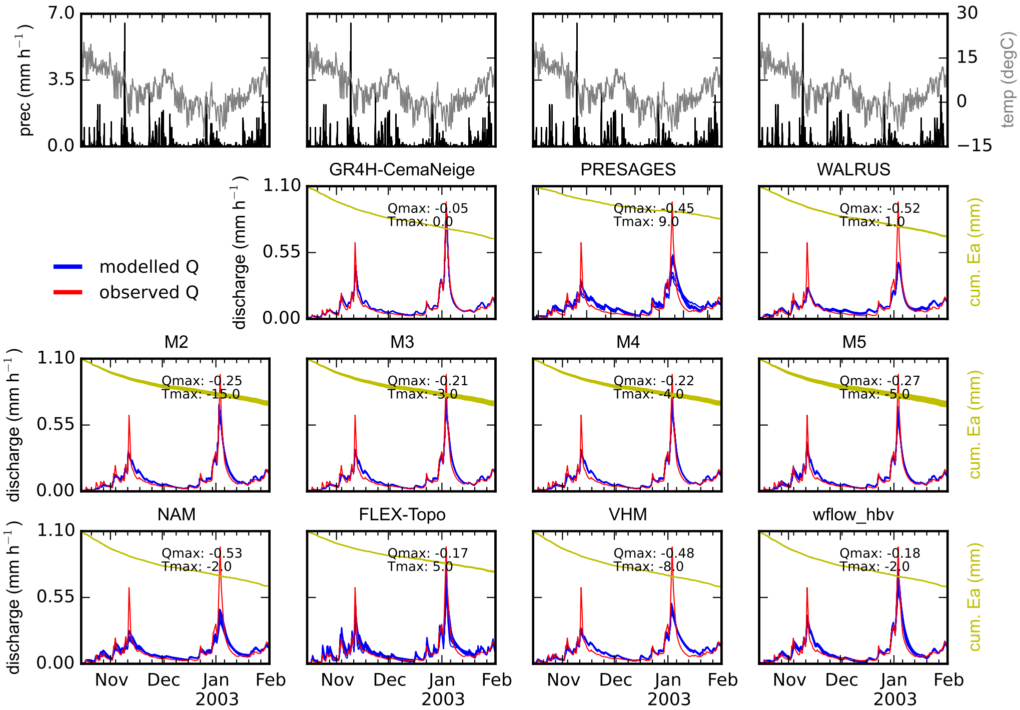

Figure 34: Lesse at Gendron

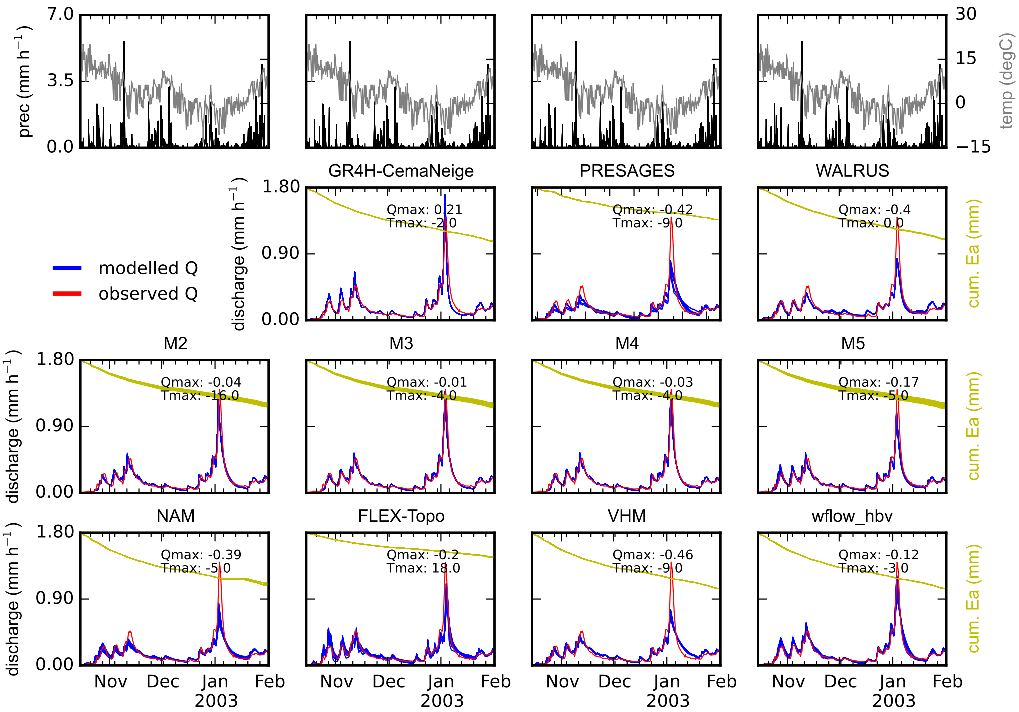

Figure 35: Semois at Membre

9 Hydrographs for a high flow period with influence of snow (Nov 2009 - Mar 2010)

The figures below show the modelled (blue) and observed (red) hydrographs for a high flow period influenced by snow in Nov 2009 - Mar 2010 for the five studied catchments. Actual evaporation simulated by the models is shown in green. Precipitation and temperature are shown in the first row. Note: the four graphs with precipitation and temperature on top are the same. The volume and timing of the snow melt peak in the beginning of March were used as signature, these were evaluated by computing the relative error for each model realisation for each model and catchment. The smallest relative error for each model and catchment is presented with the graphs.

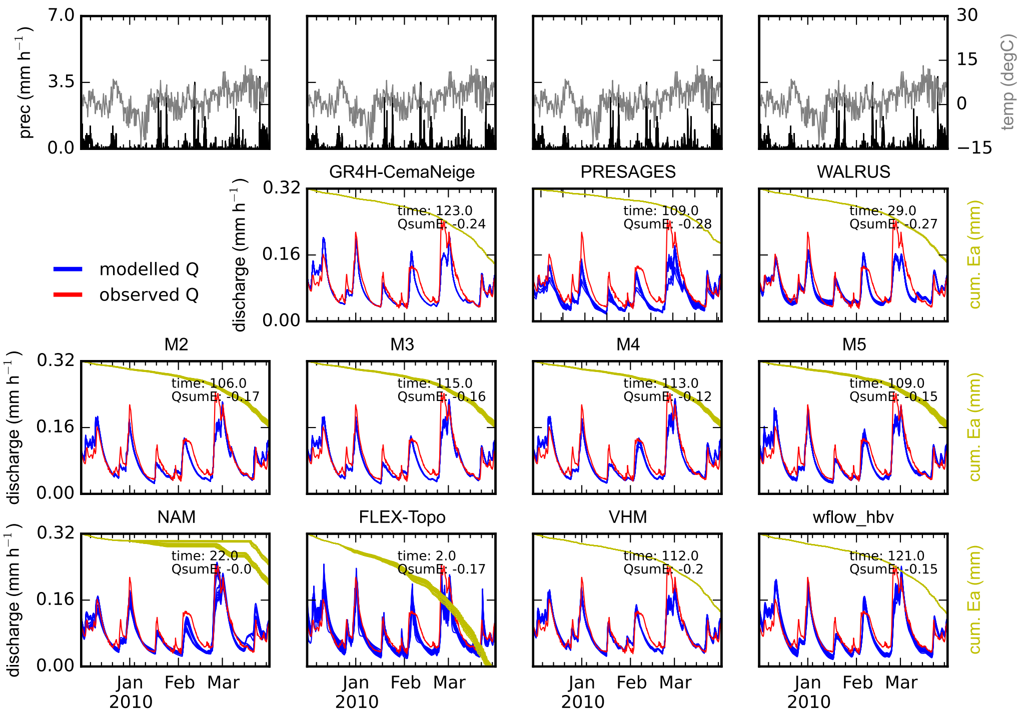

Figure 36: Ourthe at Tabreux

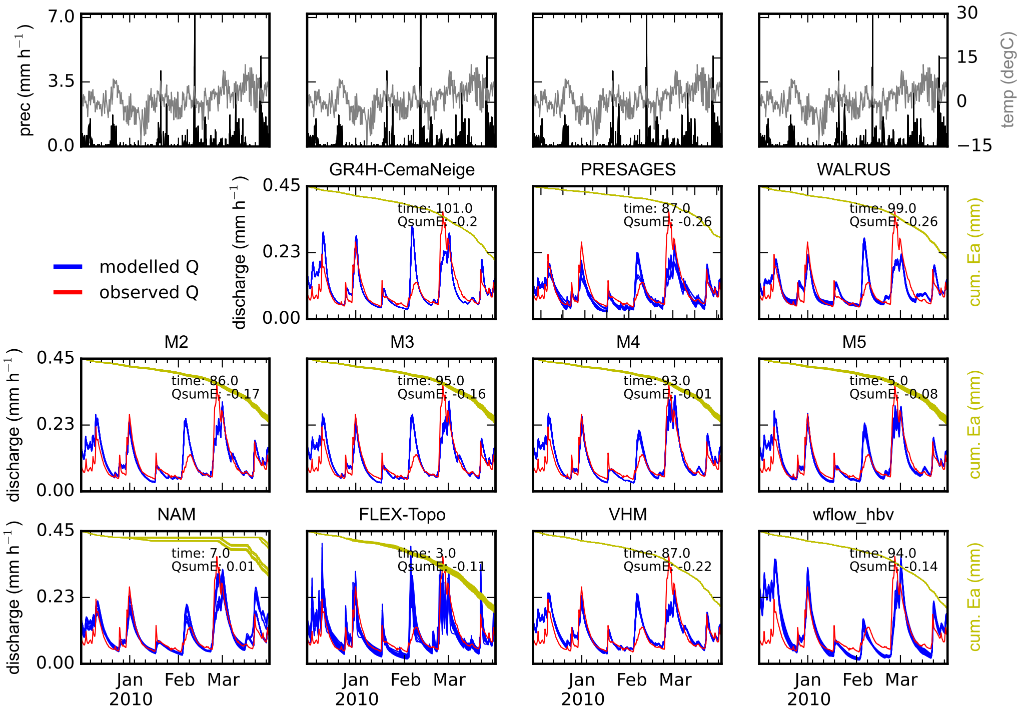

Figure 37: Ourthe Orientale at Mabompré

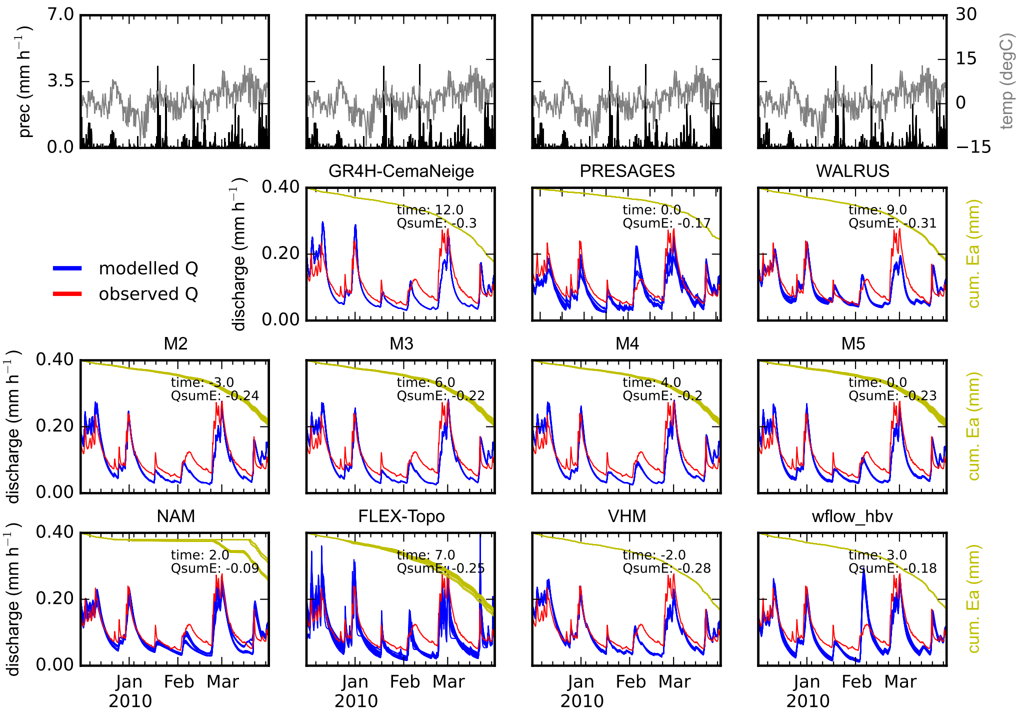

Figure 38: Ourthe Occidentale at Ortho

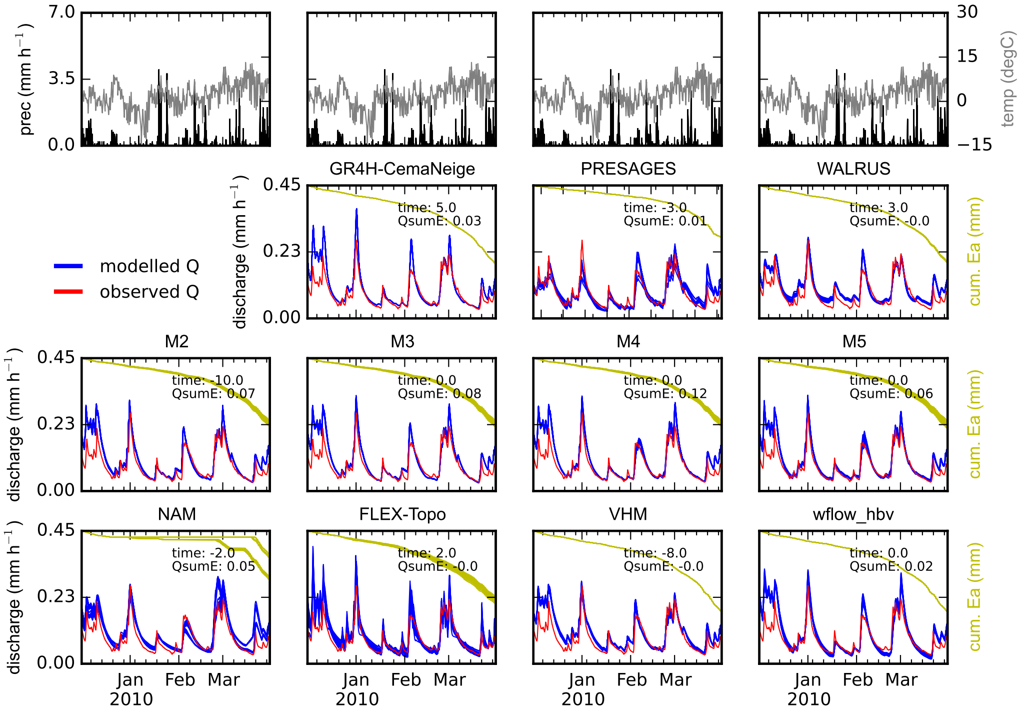

Figure 39: Lesse at Gendron

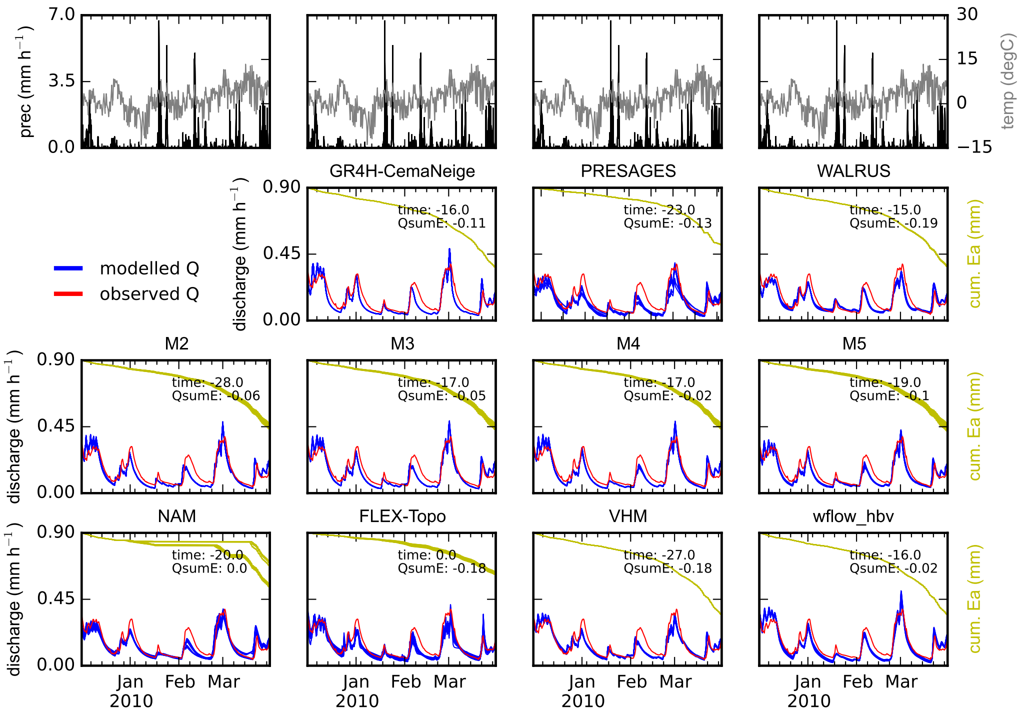

Figure 40: Semois at Membre

10 Influence of the operation of Nisramont dam and reservoir on hydrological modelling of the Ourthe catchment

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10.1 Introduction

The analysis presented here aims at clarifying the potential influence of Nisramont dam and reservoir on the hydrological modelling of the Ourthe catchment. The focus is set on the daily time scale. The analysis is based on two datasets provided by the Service Public de Wallonie (SPW): discharge measurements and reservoir level measurements. In the following, we provide a short description of the dam and reservoir system (Section 10.2) and we detail the characteristics of available data (Section 10.3). The two types of data are successively interpreted (Section 10.4 and Section 10.5) and conclusions are drawn (Section 10.6).

10.2 Dam and reservoir system

Nisramont dam is a concrete 116 m long gravity dam, which was completed in 1958. It was initially designed as a temporary structure for the construction works of another larger dam, which was eventually not constructed. The main purpose of Nisramont reservoir is drinking water supply. The normal discharge abstracted for water supply is 0.28 m^3 s^{-1}. The dam is also used for hydropower production (max. ~ 12 m^3 s^{-1}).
The maximum reservoir depth is about 15 m and the initial storage capacity was approximately 2.5 million m^3. Based on bathymetric data obtained by sonar measurements (source: SPW), a study conducted in 2010 by ULg-HECE concluded that the remaining storage capacity of the reservoir is close to 2 million m^3. This difference is in agreement with previous estimates of the sedimentation rate in the reservoir. The dam is operated to generally maintain the reservoir level close to 275.05 m Deuxième Nivellement Général (DNG).

10.3 Available data

Two datasets were used in this analysis: discharges measured at three gauging stations (Table 11) and time series of measured reservoir levels (Table 12).
As shown in Figure 41, two of the three considered gauging stations are situated on two branches of the Ourthe river upstream of the reservoir, while the third one is located approximately 650 m downstream of the dam. The record length at the gauging stations varies between 33 and 37 years (Table 11). The analysis conducted here is based only on data from the period common to all three gauging stations: 1982 - 2014. The inflow and outflow discharges at Nisramont reservoir were estimated by combining the time series recorded at the three gauging stations and correcting them for changes in the catchment area between the respective locations of the stations and the dam/reservoir.
Two time series of the reservoir level were also used in the analysis (stations A and B in Table 12). They are of shorter duration than the available time series for river discharges. As depicted in Figure 41, station A is located on the upstream face of the dam, while station B is situated on the left bank of the reservoir about 400 m upstream of the dam. At the former, the available length of records is 10 years, whereas the latter has less than 3 years of records.

Table 11: Location and characteristics of the gauging stations.

Nr	Station	River	x-coordinate (m)	y-coordinate (m)	Period
1	Nisramont	Ourthe	243,246	92,890	01/01/1978 - 31/12/2014
2	Ortho	Ourthe Occidentale	241,396	89,185	01/01/1982 - 31/12/2014
3	Mabompré	Ourthe Orientale	246,721	92,538	01/01/1978 - 31/12/2014

Table 12: Location and characteristics of the reservoir level measurements.

Nr	Station	River	x-coordinate (m)	y-coordinate (m)	Period
A	Nisramont reservoir	Ourthe	242,973	93,423	01/01/2006 - 31/12/2015
B	Nisramont reservoir (upstream)	Ourthe	242,584	93,290	20/02/2013 - 31/12/2015

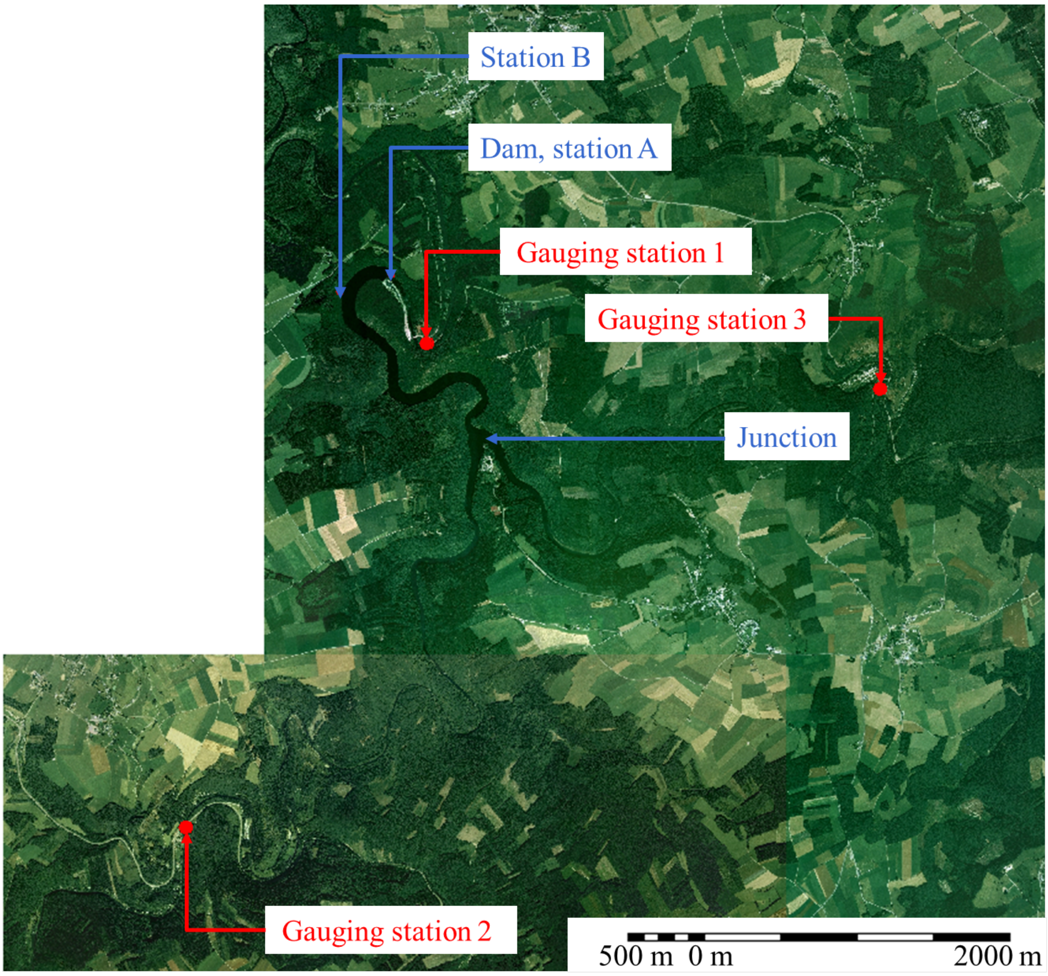

Figure 41: Location of the dam and the gauging stations.

10.4 Interpretation of discharge data

We first compare the normal discharge abstracted for water supply (0.28 m^3 s^{-1}) to the river discharge values. As shown by the flow duration curves in Figure 42, the river discharge virtually never drops to a value as low as the abstracted discharge. From this perspective, the effect of water abstraction could be neglected. However, caution should be taken when focusing on low flow periods, since about 22 % of time, the abstracted discharge represents 10 % or more of the river discharge (Figure 42). Figure 43 displays the estimated outflow discharge as a function of the estimated inflow discharge at the Nisramont reservoir, based on data at the gauging stations. Three main observations can be made from this graph:

- for relatively high inflow discharges (above $\sim$ 8 m^3 s^{-1}), most data points fall within the $\pm$ 10 % range, suggesting that the variation in the river discharge resulting from the dam and reservoir system rarely exceeds 10 % in magnitude;
- for smaller inflow discharges (in-between $\sim$ 4 m^3 s^{-1} and $\sim$ 8 m^3 s^{-1}), most data points fall within the $\pm$ 1 m^3 s^{-1} range, suggesting that, in general, the dam and reservoir system does not lead to changes by more than $\pm$ 1 m^3 s^{-1} in the river discharge;
- for relatively low inflow discharges (below $\sim$ 4 m^3 s^{-1}), the change in the river discharge between upstream and downstream of the Nisramont reservoir is also limited to 1 m^3 s^{-1}; but in this case, the outflow discharge data show a bias towards lower values compared to the inflow discharge.

The third observation is a hint that, in case of low flow in the river (below $\sim$ 4 m^3 s^{-1}), the outflow discharge released at the dam is generally lower than the inflow. This is consistent with the operation rules of the dam.
The estimated variations in discharge between upstream and downstream of the dam ($\pm$ 10 %, $\pm$ 1 m^3 s^{-1}) are however of the same order of magnitude as the uncertainties which can be expected in the discharge measurements. Therefore, it may be questioned whether the discharge variations shown in Figure 43 are truly representative of the actual effect of the reservoir. In an attempt to better capture the effect of the reservoir, we also analyzed the available time series of reservoir level measurements, as detailed hereafter.

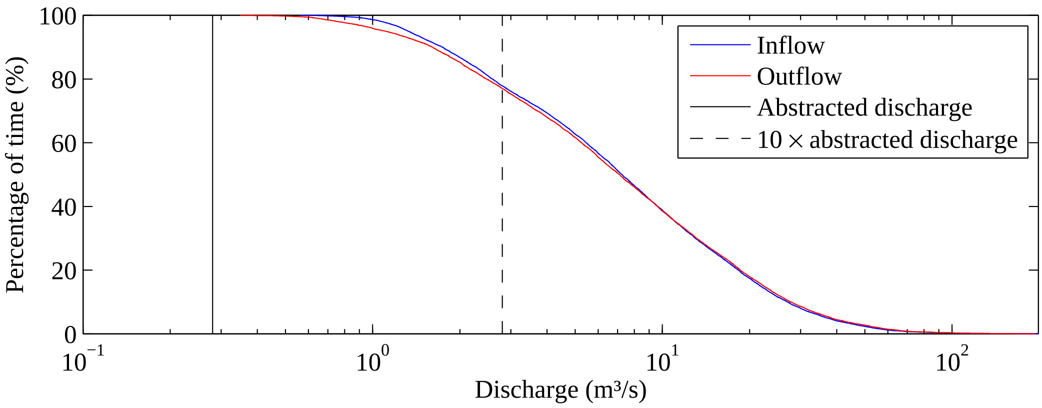

Figure 42: Flow duration curves of inflow and outflow discharge at the dam.

10.5 Interpretation of reservoir level data

The time series of reservoir level have the potential to indicate to which extent the reservoir operation involves temporary water storage. As shown by data discussed below, this effect is very limited at Nisramont reservoir.

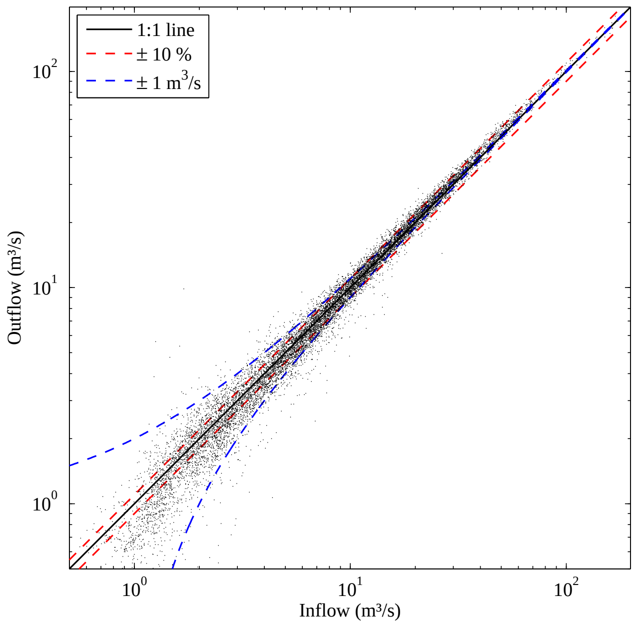

Figure 43: Daily outflow discharge vs inflow discharge at Nisramont reservoir.

Over the last decade, the reservoir level remained mostly in-between 274.85 m and 275.2 m, as shown by the time series in Figure 44 and by Figure 45. Only during about 48 hours in November 2015 (23-25/11/2015), the reservoir level deviated from normal operation conditions and dropped below 274.5 m (down to 272.7 m). This is due to a maintenance operation and was however considered here as unrepresentative of the standard operation of the system.

The differences between the measurements of reservoir levels at the dam (station A) and 400 m upstream (station B) are generally below 1 cm and their mean value is 4 mm (Figure 46). This is an indicator of the uncertainty on the reservoir level measurements. The significant differences in Figure 45 between the curves related to stations A and B suggest that the length of record at station B is too short to be representative of the whole period. Therefore, data from station B are not considered in the following.

The stage-storage relationship of the reservoir is known from bathymetric data obtained by SPW using sonar measurements. Based on this stage-storage relationship, the time series of measured reservoir levels were translated into time series of reservoir storage (Figure 47). Consistently with the limited fluctuations in the reservoir level, Figure 47 indicates that the active storage in Nisramont reservoir is of the order of 0.15 - 0.20 million m^3. Such a variation in storage over one day corresponds to a mean variation in daily discharge of $\sim$ 2 m^3 s^{-1}. This is an upper bound of the potential effect of the reservoir on the flow since the time series show much smaller variations in the storage over periods of the order of one day. Indeed, as shown in Figure 48, the storage variations over periods of one day generally do not exceed 0.5 - 2 x 10^4 m^3, corresponding thus to differences between daily inflow and outflow discharges of the order of 0.05 - 0.2 m^3 s^{-1} (Figure 48).

To appreciate the error affecting this estimation of the difference between inflow and outflow discharge, let us assume an error on the reservoir level of the order of 1 cm, which corresponds roughly to the mismatch between the measurements performed at the two stations A and B (Figure 46). From the stage-storage characteristics of the reservoir, a 1 cm difference in water level may be related to a variation

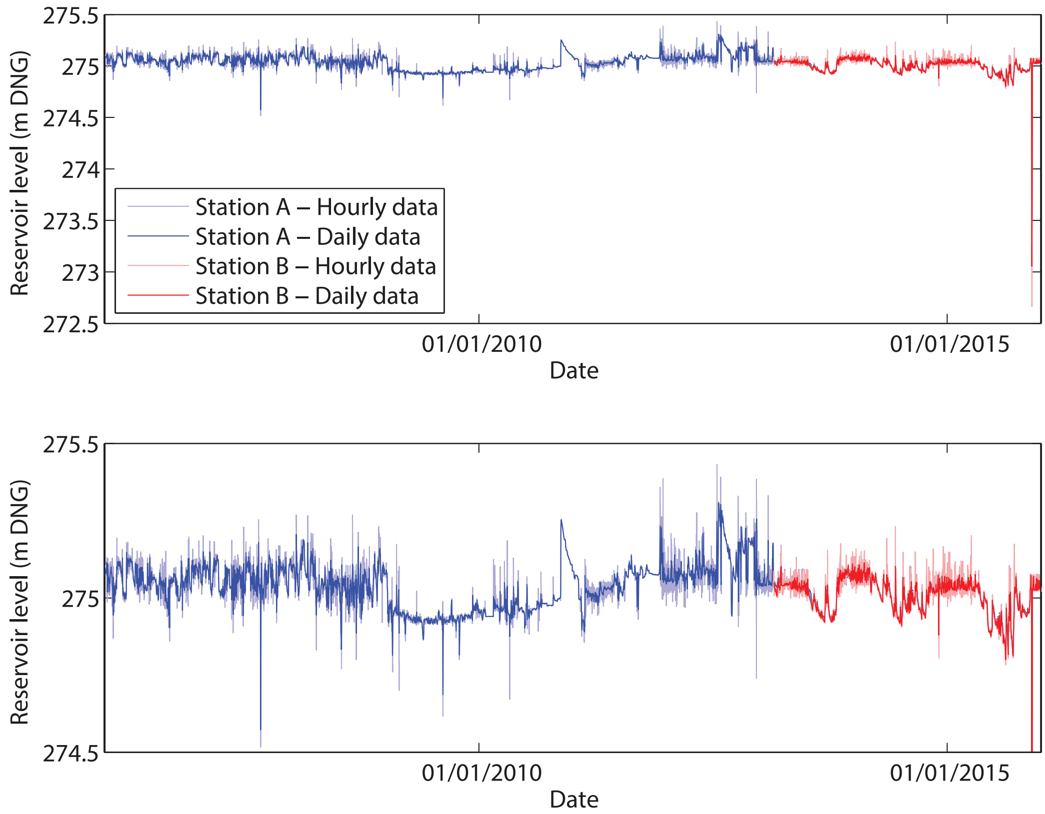

Figure 44: Hourly evolution of the level in Nisramont reservoir.

in storage of $\sim$ 4700 m^3, hence a corresponding difference in daily discharge of 0.05 m^3 s^{-1}. This error remains of the order of magnitude of the lower bound of the estimated influence of the reservoir on the flow (0.05 - 0.2 m^3 s^{-1}), as deduced from the reservoir level measurements. This is hence considered as giving a more reasonable picture of the influence of the reservoir on the flow than the estimations deduced from the measurements at the upstream and downstream gauging stations (Section 10.4).

10.6 Conclusion

The present data analysis aims at estimating the influence of Nisramont reservoir on the flow in river Ourthe. It was conducted in two steps. First, a 33-year long series of discharge measurements at three gauging stations has been used. These data have revealed a limited influence of the reservoir on the discharge in the river, since the variations in the river discharge between upstream and downstream of the reservoir were found in the range $\pm$ 10 % of the inflow discharge or $\pm$ 1 m^3 s^{-1}. Only during low flow periods, a systematic decrease in the river discharge seems to be caused by the dam and reservoir system. This decrease does not exceed 1 m^3 s^{-1} for most observation data. Although the discharge abstracted for drinking water supply (0.28 m^3 s^{-1}) could not be captured explicitly from the discharge data processed here, its value remains in agreement with the findings of the analysis.
Second, a 10-year long record of the reservoir level has been considered. Combined with the stage-storage characteristics of the reservoir, it indicates that the variation in the flow discharge induced specifically by temporary storage in the reservoir is generally of the order of 0.2 to 0.5 m^3 s^{-1}. Although this result is smaller than the values deduced from the observed discharges, there is no contradiction between the two estimations. The influence of errors in the reservoir level measurements was appreciated and it suggests a good level of confidence in the conclusions drawn from these records.

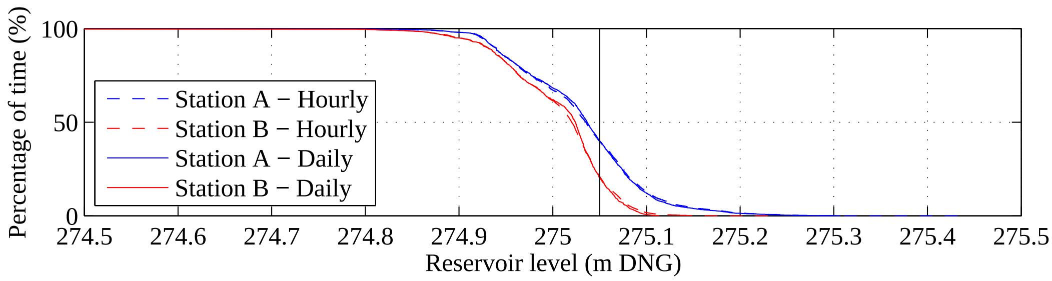

Figure 45: Percentage of time during which the reservoir level exceeds the indicated value.

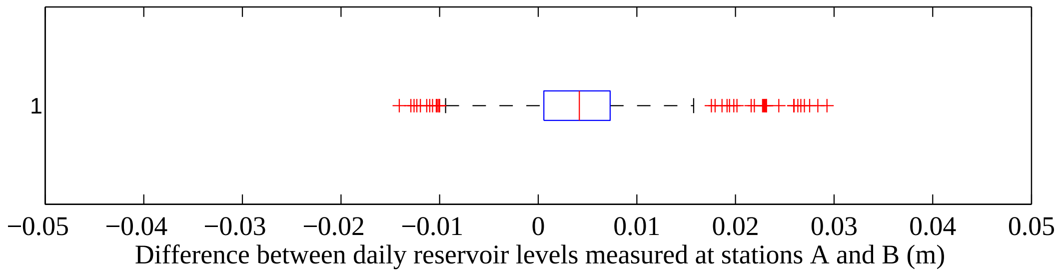

Figure 46: Boxplot of the difference between the daily measurements of the reservoir level at stations A and B.

Acknowledgement

The authors gratefully acknowledge Mr Ph. Dierickx, Ms. D. Pontegnie and Dr T. Mouzelard for fruitful discussions and for the datasets provided by "Service Public de Wallonie, Direction générale opérationnelle de la Mobilité et des Voies hydrauliques".

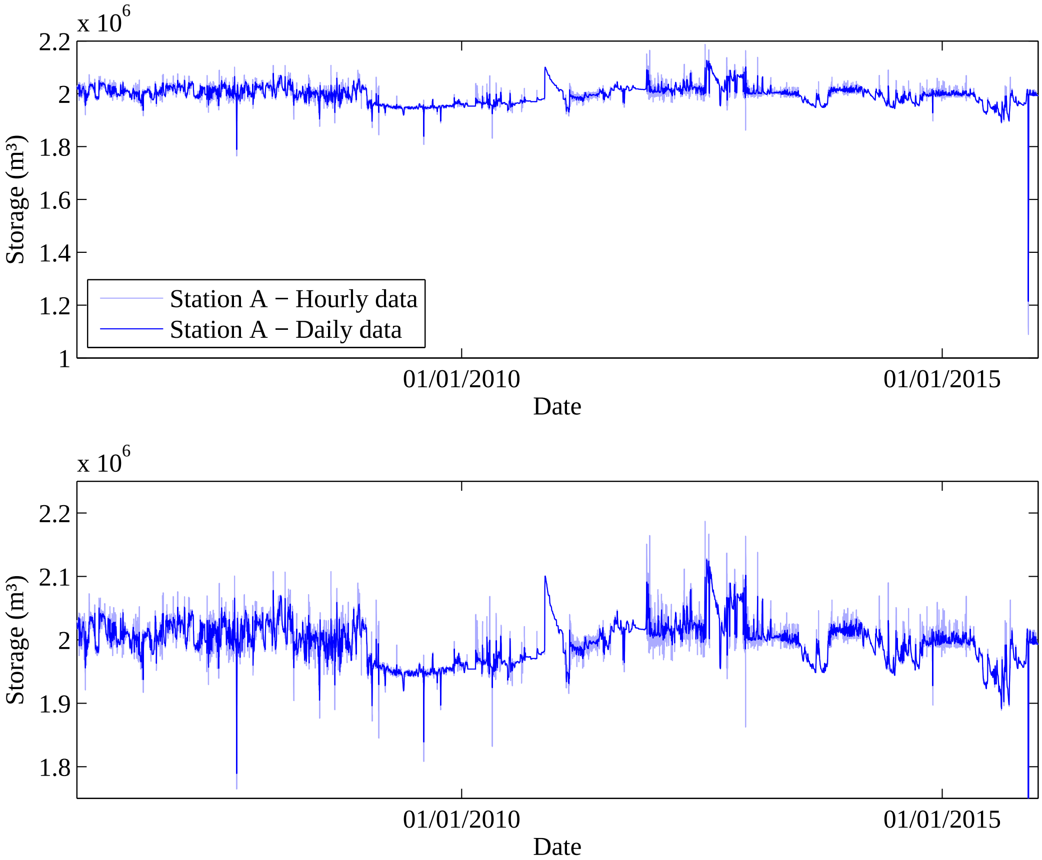

Figure 47: Hourly evolution of storage in Nisramont reservoir.

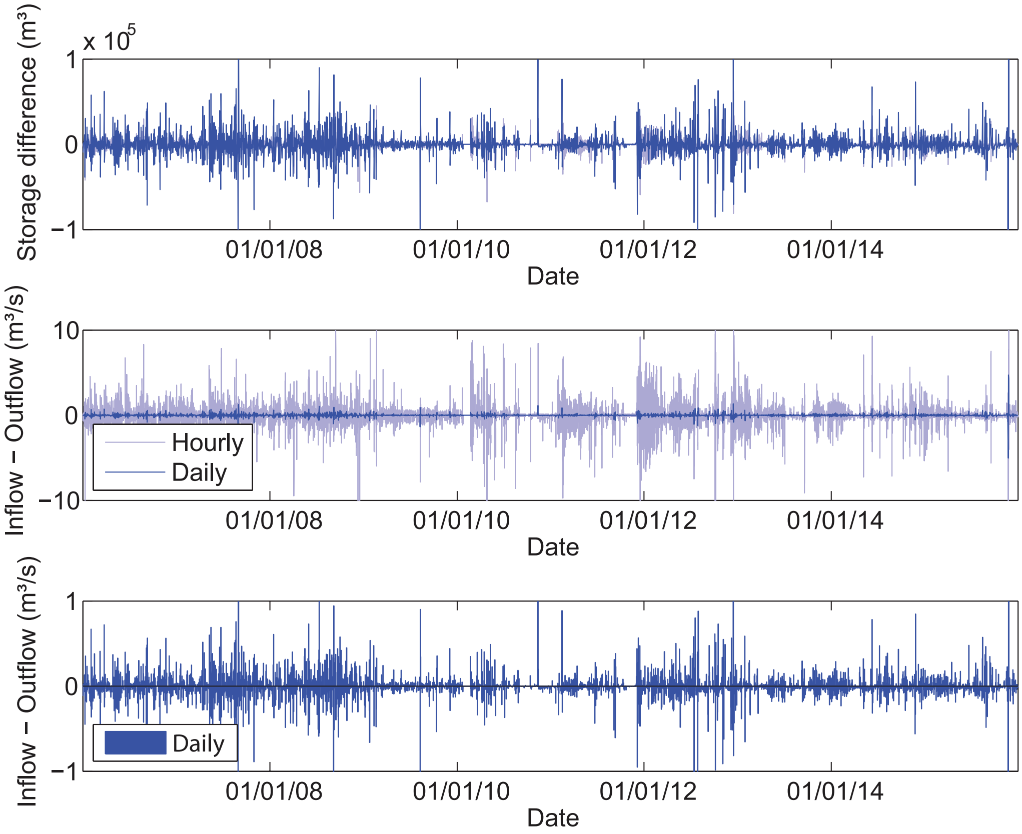

Figure 48: Hourly and daily storage variations in Nisramont reservoir (top) and corresponding differences between upstream and downstream of the reservoir (middle and bottom).