Hydrological measurements and modelling in FVG - part 2

6th Workshop on Water Resources in Developing Countries

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summary

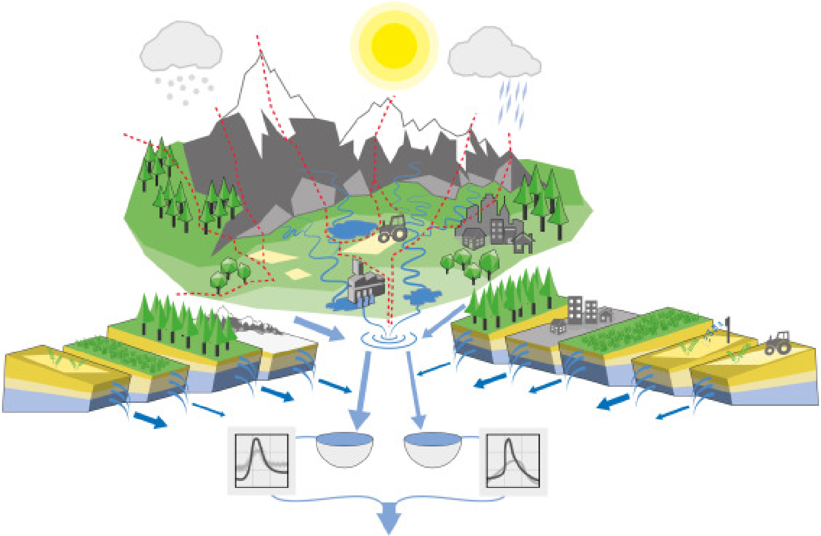
model HYPE

HYPE: verification

FUSE: calibration

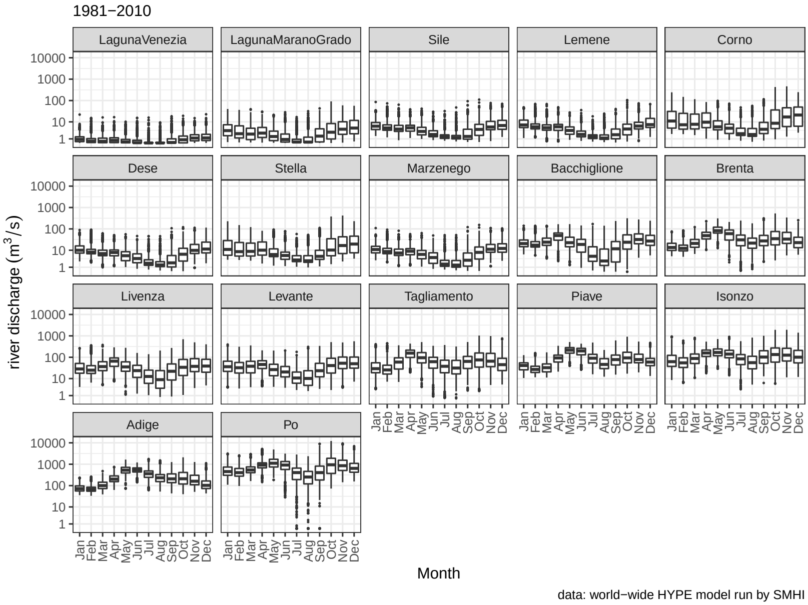
FUSE: verification

model HYPE



[Hundecha et al., 2016]

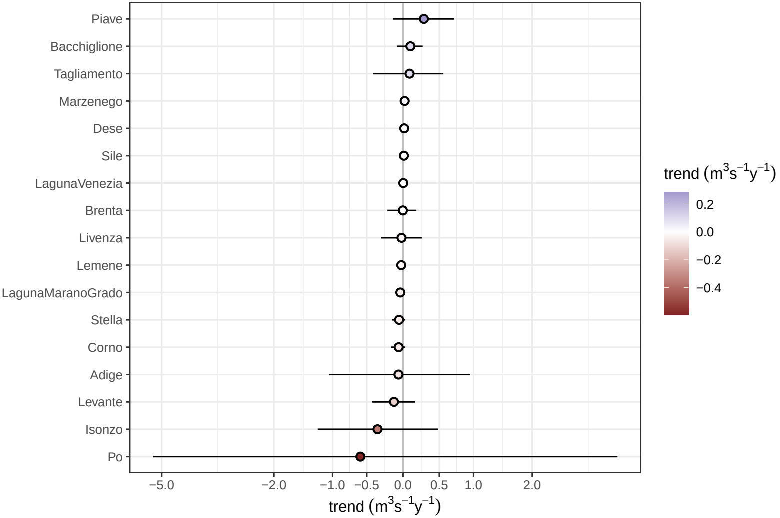
https://hypeweb.smhi.se/explore-water/forecasts/


1981−2010
LagunaVenezia
LagunaMaranoGrado
Sile
Lemene
Corno
Dese
Stella
Marzenego
Bacchiglione
Brenta
Livenza
Levante
Tagliamento
Piave
Isonzo
Adige
Po
10000
1000
100
10
1
river discharge (m^3/s)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month
data: world−wide HYPE model run by SMHI

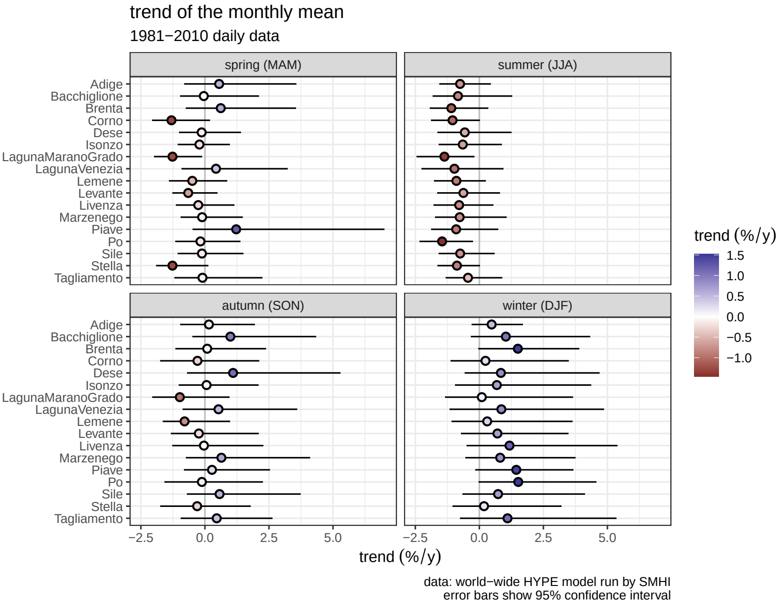
Adige
Bacchiglione
Brenta
Corno
Dese
Isonzo
LagunaMaranoGrado
LagunaVenezia
Lemene
Levante
Livenza
Marzenego
Piave
Po
Sile
Stella
Tagliamento
200%
100%
0%
−100%
1980
1990
2000
2010
anomaly relative to the seasonal average
Year
Season
spring
summer
autumn
winter
data: world−wide HYPE model run by SMHI

trend of the monthly mean

1981−2010



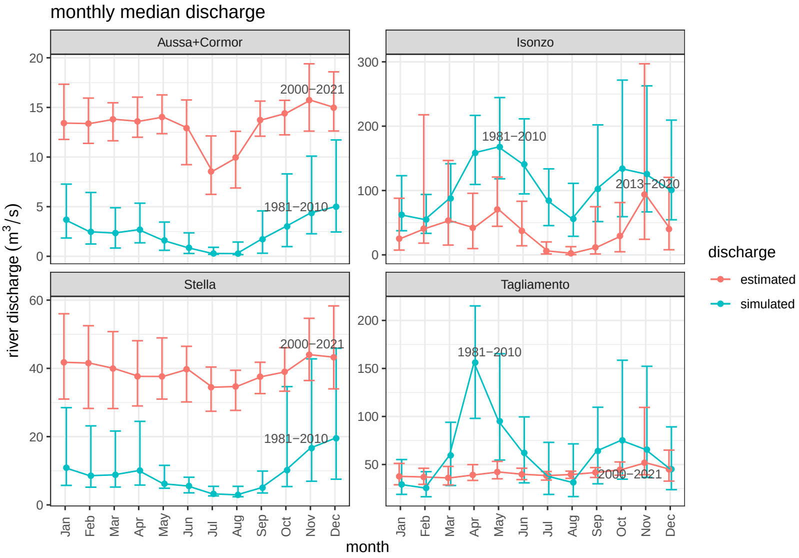
data: world−wide HYPE model run by SMHI
error bars show 95% confidence interval


trend of the monthly mean
1981−2010 daily data
spring (MAM)
summer (JJA)
autumn (SON)
winter (DJF)
Adige
Bacchiglione
Brenta
Corno
Dese
Isonzo
LagunaMaranoGrado
LagunaVenezia
Lemene
Levante
Livenza
Marzenego
Piave
Po
Sile
Stella
Tagliamento
−2.5
0.0
2.5
5.0
trend (%/y)
1.5
1.0
0.5
0.0
−0.5
−1.0
data: world−wide HYPE model run by SMHI
error bars show 95% confidence interval

HYPE: Statistics

- SMHI provided daily output for the 1981-2010 thirty-year period for all major watercourses **globally**.
- The global operational configuration is straightforward, but there is potential to execute the model with greater detail and fine-tune it at a local scale.
- North Adriatic: flow rates **decrease in summer** and **increase in winter**.
- Summer decrease is statistically significant only for the **Po River** and the **Marano and Grado Lagoon**.

HYPE: verification



simulated discharge: world−wide HYPE model run by SMHI
estimated discharge: from hydrometric levels
(bars represent interquartile range)

symbol	description	formula
NMB	normalized mean bias	$\frac{1}{\bar{O}}\sum_{i=1}^{n}(M_i - O_i)$
NMGE	normalised mean gross error	$\frac{1}{\bar{O}}\sum_{i=1}^{n}\lvert M_i - O_i\rvert$
r	Pearson correlation coefficient	$\frac{1}{n-1}\sum_{i=1}^{n}\frac{(M_i-\bar{M})}{\sigma_M}\cdot\frac{(O_i-\bar{O})}{\sigma_O}$
IOA	Index of Agreement	$\begin{cases} 1 - \frac{\sum_{i=1}^{n}\lvert M_i - O_i\rvert}{2\cdot\sum_{i=1}^{n}\lvert O_i-\bar{O}\rvert} & \Leftarrow \frac{\sum_{i=1}^{n}\lvert M_i - O_i\rvert}{2\cdot\sum_{i=1}^{n}\lvert O_i-\bar{O}\rvert} \leq 1 \\ \frac{2\cdot\sum_{i=1}^{n}\lvert O_i-\bar{O}\rvert}{\sum_{i=1}^{n}\lvert M_i - O_i\rvert} - 1 & \Leftarrow \frac{\sum_{i=1}^{n}\lvert M_i - O_i\rvert}{2\cdot\sum_{i=1}^{n}\lvert O_i-\bar{O}\rvert} > 1 \end{cases}$

HYPE: skill scores 2000–2010

index	river	annual skill scores		
		min	ave	max
IOA	Aussa+Cormor	-0.65	-0.35	0.04
	Stella	-0.67	-0.28	0.25
	Tagliamento	-0.75	-0.07	0.57
NMB	Aussa+Cormor	-0.82	-0.71	-0.55
	Stella	-0.72	-0.55	-0.23
	Tagliamento	0.20	0.62	0.85
NMGE	Aussa+Cormor	0.59	0.73	0.82
	Stella	0.59	0.68	0.86
	Tagliamento	0.68	1.00	1.40
r	Aussa+Cormor	0.40	0.62	0.76
	Stella	0.23	0.58	0.84
	Tagliamento	0.27	0.52	0.72

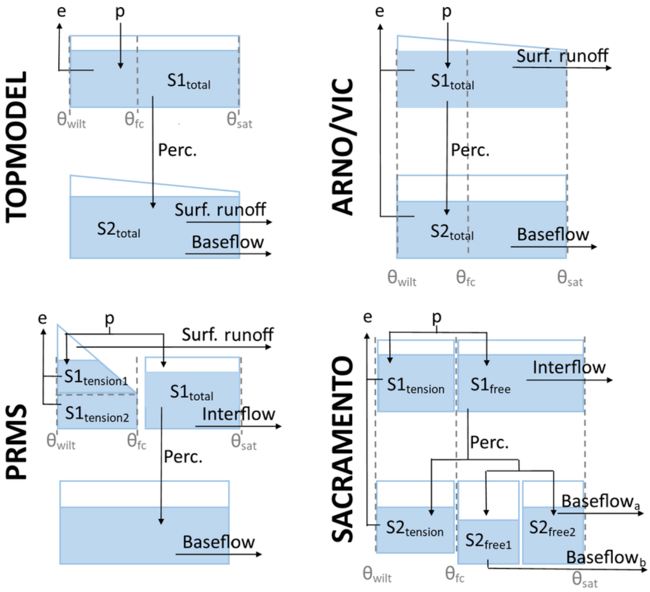
HYPE: Statistics

- Inputs to the **Lagoon** are significantly **underestimated**.
- **Isonzo**: Seasonal trend well reproduced, but constant **overestimation**.
- **Tagliamento**: Significant **overestimation** in the rainiest months, when some of the waters likely **recharge** the **artesian aquifer** or are **transferred** to neighboring basins.
- Decent **correlation**, but unsatisfactory **Index Of Agreement**.

FUSE: calibration

FUSE

- FUSE [Clark et al., 2008]
- R package `fuse` [Vitolo et al., 2016]
- FUSE proposes **1248 possible architectures** of simple hydrological models, derived from 4 archetypes.
- Each architecture has a given number of **parameters**, whose values are modifiable, each within a suggested range.
- For each basin, the **most performing models** are iteratively selected (highest IOA during the period 2014–2017, excluding a 100-day spin-up), testing all possible architectures with different combinations of parameters, totaling about one hundred thousand simulations, i.e., over one hundred million simulated days.



[Lane et al., 2019] adapted from [Clark et al., 2008]

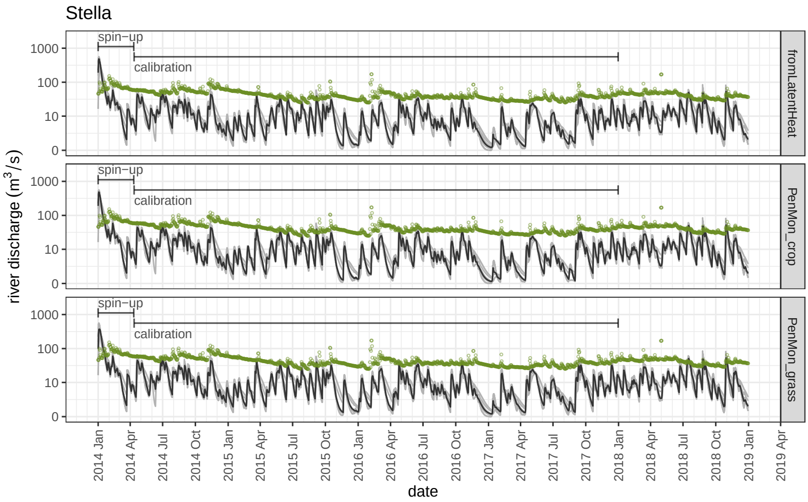
elements	options	rivers			
		Corm	Stel	Ison	Tagl
rainfall error	additive	x	x	-	x
	multiplicative	-	-	x	-
upper soil layer	defined by a single state variable	x	x	x	x
lower soil layer	baseflow reservoir of fixed size	x	-	-	x
	baseflow reservoir of unlimited size, frac rate	-	x	-	-
	tension reservoir plus two parallel tanks	-	-	x	-
surface runoff	TOPMODEL parameterization	x	x	x	x
vertical drainage	defined by moisture content in lower layer	x	x	x	x
evapotranspiration	root weighting	x	-	-	x
	sequential evaporation model	-	x	x	-
interflow	interflow allowed	x	x	x	-
	no interflow	-	-	-	x
routing	use a Gamma distribution	x	x	x	x

parameters	rivers			
	Corm	Stel	Ison	Tagl
additive rainfall error (mm)	3.1	9	-	-1.8
multiplicative rainfall error (-)	-	-	1	-
depth of the upper soil layer (mm)	46	280	240	51
depth of the lower soil layer (mm)	3200	2500	2400	4900
fraction total storage in tension storage (-)	0.65	0.41	0.51	0.29
fraction of roots in the upper layer (-)	0.41	-	-	0.11
model percolation multiplier for dry soil layer (-)	29	180	160	36
model percolation expon. coeff. for dry soil layer (-)	3.7	4.4	4	2.6
interflow rate (mm day^{-1})	360	350	750	-
baseflow rate (mm day^{-1})	860	-	-	33
baseflow exponent (-)	6.1	4.6	9.4	2.8
mean value of the topographic index (m)	6.5	8.4	5.2	5.7
shape param. for the topogr. index Gamma distrib. (-)	4.7	3.7	3.9	5
time delay in runoff (days)	1.4	1.8	1.9	0.87
baseflow depletion rate (day^{-1})	-	1/59	-	-
fraction storage in 1st baseflow reservoir (-)	-	-	0.60	-
fraction of percolation to tension storage (-)	-	-	0.33	-
baseflow depletion rate 1st reservoir (day^{-1})	-	-	1/5.6	-
baseflow depletion rate 2nd reservoir (day^{-1})	-	-	1/42	-

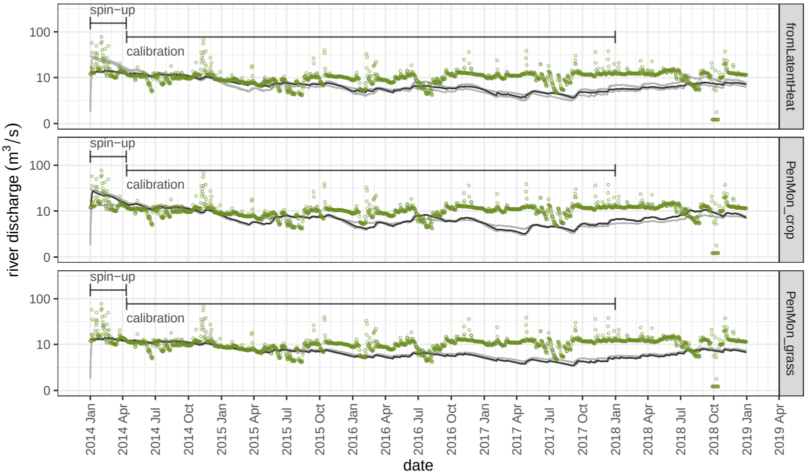
FUSE: Calibration

- The upper soil layer, surface runoff, and percolation are represented with the same algorithm across all basins.
- By imposing an additive error in precipitation, we can account for the fact that watershed budgets do not close.

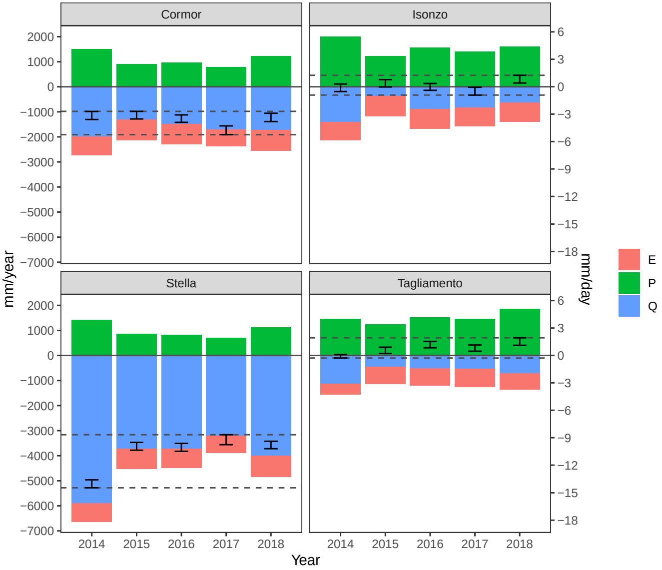
FUSE: verification

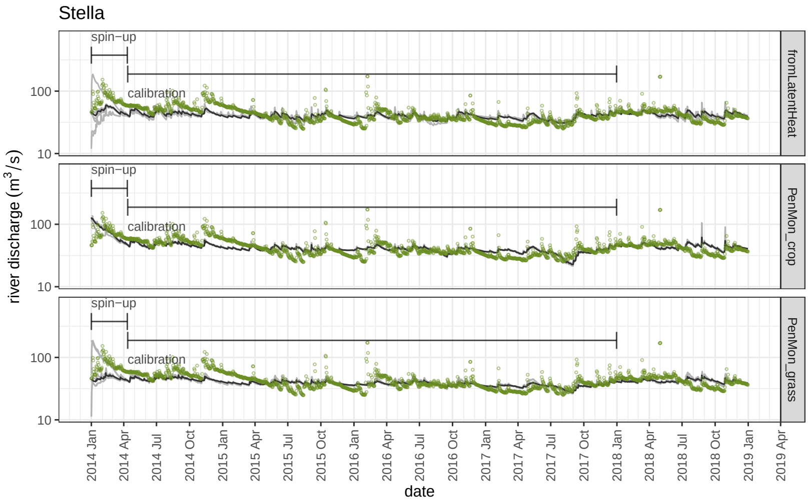

Stella
spin−up
calibration
fromLatentHeat
PenMon_crop
PenMon_grass
river discharge (m3/s)
1000
100
10
0
2014 Jan
2014 Apr
2014 Jul
2014 Oct
2015 Jan
2015 Apr
2015 Jul
2015 Oct
2016 Jan
2016 Apr
2016 Jul
2016 Oct
2017 Jan
2017 Apr
2017 Jul
2017 Oct
2018 Jan
2018 Apr
2018 Jul
2018 Oct
2019 Jan
2019 Apr
date

Cormor

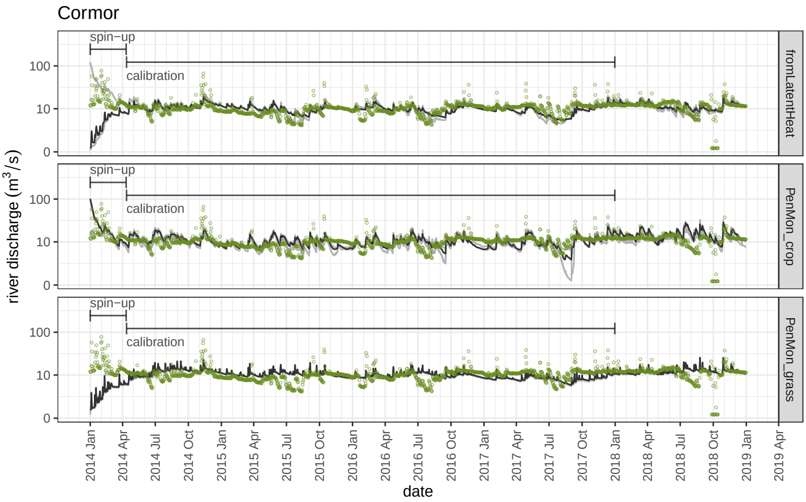


spin−up
calibration
fromLatentHeat
PenMon_crop
PenMon_grass
river discharge (m³/s)
100
10
0
2014 Jan
2014 Apr
2014 Jul
2014 Oct
2015 Jan
2015 Apr
2015 Jul
2015 Oct
2016 Jan
2016 Apr
2016 Jul
2016 Oct
2017 Jan
2017 Apr
2017 Jul
2017 Oct
2018 Jan
2018 Apr
2018 Jul
2018 Oct
2019 Jan
2019 Apr
date

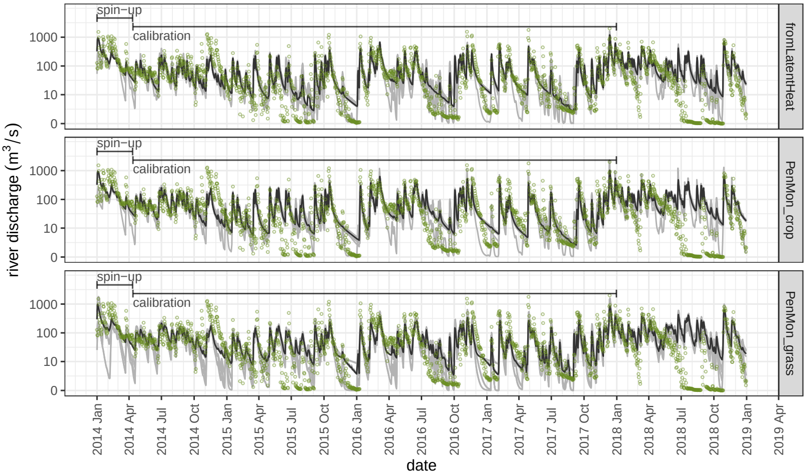

Cormor
Isonzo
Stella
Tagliamento
mm/year
mm/day
Year
E
P
Q
2000
1000
0
−1000
−2000
−3000
−4000
−5000
−6000
−7000
6
3
0
−3
−6
−9
−12
−15
−18
2014
2015
2016
2017
2018



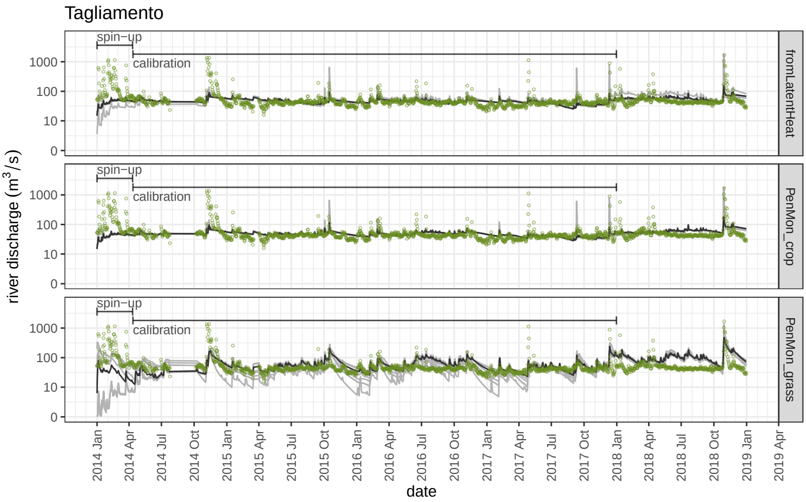
Stella
spin−up
calibration
fromLatentHeat
PenMon_crop
PenMon_grass
river discharge (m3/s)
100
10
2014 Jan
2014 Apr
2014 Jul
2014 Oct
2015 Jan
2015 Apr
2015 Jul
2015 Oct
2016 Jan
2016 Apr
2016 Jul
2016 Oct
2017 Jan
2017 Apr
2017 Jul
2017 Oct
2018 Jan
2018 Apr
2018 Jul
2018 Oct
2019 Jan
2019 Apr
date

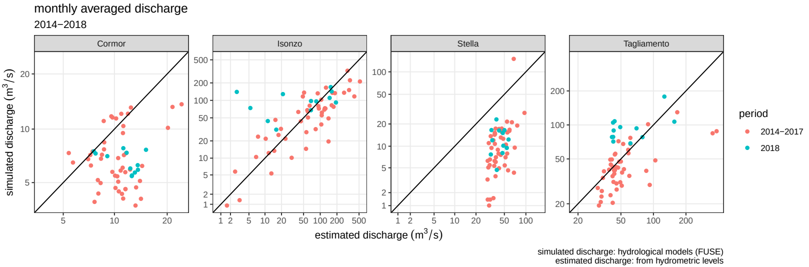

Cormor
spin−up
calibration
fromLatentHeat
PenMon_crop
PenMon_grass
100
10
0
river discharge (m³/s)
2014 Jan
2014 Apr
2014 Jul
2014 Oct
2015 Jan
2015 Apr
2015 Jul
2015 Oct
2016 Jan
2016 Apr
2016 Jul
2016 Oct
2017 Jan
2017 Apr
2017 Jul
2017 Oct
2018 Jan
2018 Apr
2018 Jul
2018 Oct
2019 Jan
2019 Apr
date

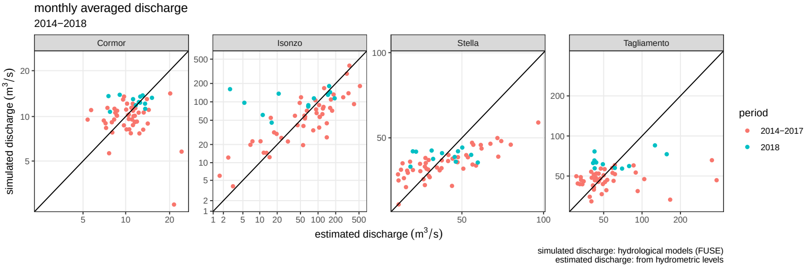
Isonzo



spin−up
calibration
1000
100
10
0
fromLatentHeat
PenMon_crop
PenMon_grass
river discharge (m3/s)
2014 Jan
2014 Apr
2014 Jul
2014 Oct
2015 Jan
2015 Apr
2015 Jul
2015 Oct
2016 Jan
2016 Apr
2016 Jul
2016 Oct
2017 Jan
2017 Apr
2017 Jul
2017 Oct
2018 Jan
2018 Apr
2018 Jul
2018 Oct
2019 Jan
2019 Apr
date


Tagliamento
spin−up
calibration
fromLatentHeat
PenMon_crop
PenMon_grass
river discharge (m3/s)
1000
100
10
0
2014 Jan
2014 Apr
2014 Jul
2014 Oct
2015 Jan
2015 Apr
2015 Jul
2015 Oct
2016 Jan
2016 Apr
2016 Jul
2016 Oct
2017 Jan
2017 Apr
2017 Jul
2017 Oct
2018 Jan
2018 Apr
2018 Jul
2018 Oct
2019 Jan
2019 Apr
date





Above: FUSE without correction for water balance gaps; Below: with correction

evapotranspiration calculation method	Index of Agreement			
	Cormor	Isonzo	Stella	Tagliamento
from latent heat flux	0.48	0.72	0.61	0.60
Penman-Monteith (crop)	0.39	0.70	0.62	0.61
Penman-Monteith (grass)	0.37	0.69	0.62	0.51

evapotranspiration	Index of Agreement			
calculation method	Cormor	Isonzo	Stella	Tagliamento
from latent heat flux	0.48	0.72	0.61	0.60
Penman-Monteith (crop)	0.39	0.70	0.62	0.61
Penman-Monteith (grass)	0.37	0.69	0.62	0.51

In some cases only, the different methods used in estimating ET lead to significantly different performance in flow prediction.

FUSE: skill scores 2014–2018

period	river	skill scores			
		NMB	NMGE	r	IOA
train (2014–2017)	Cormor	-0.03	0.24	0.39	0.48
	Isonzo	-0.28	0.61	0.67	0.72
	Stella	-0.09	0.18	0.60	0.62
	Tagliamento	-0.14	0.36	0.32	0.61
test (2018)	Cormor	-0.01	0.20	0.49	0.50
	Isonzo	0.44	0.98	0.65	0.56
	Stella	-0.03	0.18	-0.01	0.47
	Tagliamento	-0.05	0.50	0.49	0.55

HYPE vs FUSE

	HYPE	FUSE
Who runs it	SMHI	ARPA-FVG
Open source	Yes	Yes
Domain	Global	FVG
Sub-basins	Yes	No
Snow	Yes	No
Pollutants	Nitrates, phosphorus	No
Lakes	Yes	No
Aquifers	Not active	No
Land cover	Yes	No
Calibration	Large areas or global	Individual basin

HYPE vs FUSE

river	index	HYPE			FUSE	
		min	ave	max	train	test
Stella	IOA	-0.67	-0.28	0.25	0.62	0.47
	NMB	-0.72	-0.55	-0.23	-0.09	-0.03
	NMGE	0.59	0.68	0.86	0.18	0.18
	r	0.23	0.58	0.84	0.60	-0.01
Tagliamento	IOA	-0.75	-0.07	0.57	0.61	0.55
	NMB	0.20	0.62	0.85	-0.14	-0.05
	NMGE	0.68	1.00	1.40	0.36	0.50
	r	0.27	0.52	0.72	0.32	0.49

arpa FVG

HYPE vs FUSE

ICTP

river	index	HYPE			FUSE	
		min	ave	max	train	test
Stella	IOA	-0.67	-0.28	0.25	0.62	0.47
	NMB	-0.72	-0.55	-0.23	-0.09	-0.03
	NMGE	0.59	0.68	0.86	0.18	0.18
	r	0.23	0.58	0.84	0.60	-0.01
Tagliamento	IOA	-0.75	-0.07	0.57	0.61	0.55
	NMB	0.20	0.62	0.85	-0.14	-0.05
	NMGE	0.68	1.00	1.40	0.36	0.50
	r	0.27	0.52	0.72	0.32	0.49

FUSE: Verification

- Introducing an **additive error in precipitation** parameters that reflects the observed gaps in watershed budgets significantly improves prediction performance for rivers Stella and Cormor.
- Only in some cases do the different methods used in estimating ET result in significantly different flow prediction performance.
- Generally, ET calculated from LHF leads to the best predictions.
- Locally calibrated FUSE predictions generally **outperform** global HYPE predictions.

Thank you

for your attention

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Lane, R. A., Coxon, G., Freer, J. E., Wagener, T., Johnes, P. J., Bloomfield, J. P., Greene, S., Macleod, C. J., and Reaney, S. M. (2019).
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