

Assessment of the WRF-Hydro uncoupled hydro-meteorological model on flashy watersheds of the tropical island of New Caledonia (South-West Pacific)

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1. Introduction

- Small tropical mountainous islands present pitfalls for hydrological modeling owing to their great spatial heterogeneities and are prone to **flash floods** due to extreme weather events.
- Some modeling success was obtained by adjustment of lumped statistical models [3].
- Growing use of physics-based distributed hydrological models like the **WRF-Hydro modeling system** with flourishing of fine spatial resolution / high frequency satellite data
- Need to work with fine-scaled (<1x1 km²) or observed spatially interpolated rainfall.
- Little studies on small watersheds and with observed rainfall using WRF-Hydro [2].
- The goal of this work is to use WRF-Hydro to derive **physical parameters** and **enhance hydrological knowledge and modeling of New Caledonia watersheds** in the context of transient climate and land use:
 - Great variability in space and time of land cover that likely leads to complex hydro-meteorological mechanisms
 - Climate change projections: reduction in the frequency and intensity of extreme precipitation events by ~ 20% by 2080 [4]

2. Study zone

- Grande Terre (400 km long and 50 km wide) is the main island of **New Caledonia**, a special collectivity of France in the SW Pacific (Fig. 1) **with tropical climate and high annual precipitation** (~ 1850 mm).
- Study of 6 small (a few 100 km²) and steep watersheds prone to flash-floods resulting from intense tropical events (Table 1):
 - (i) Coulée (ii) Dumbéa (iii) Couvelée
 - (iv) Pouembout (v) Thio (vi) Tontouta
- Evergreen forests and shrub on peridotite basement or woody savanna on micaschists upstream of gauging stations.

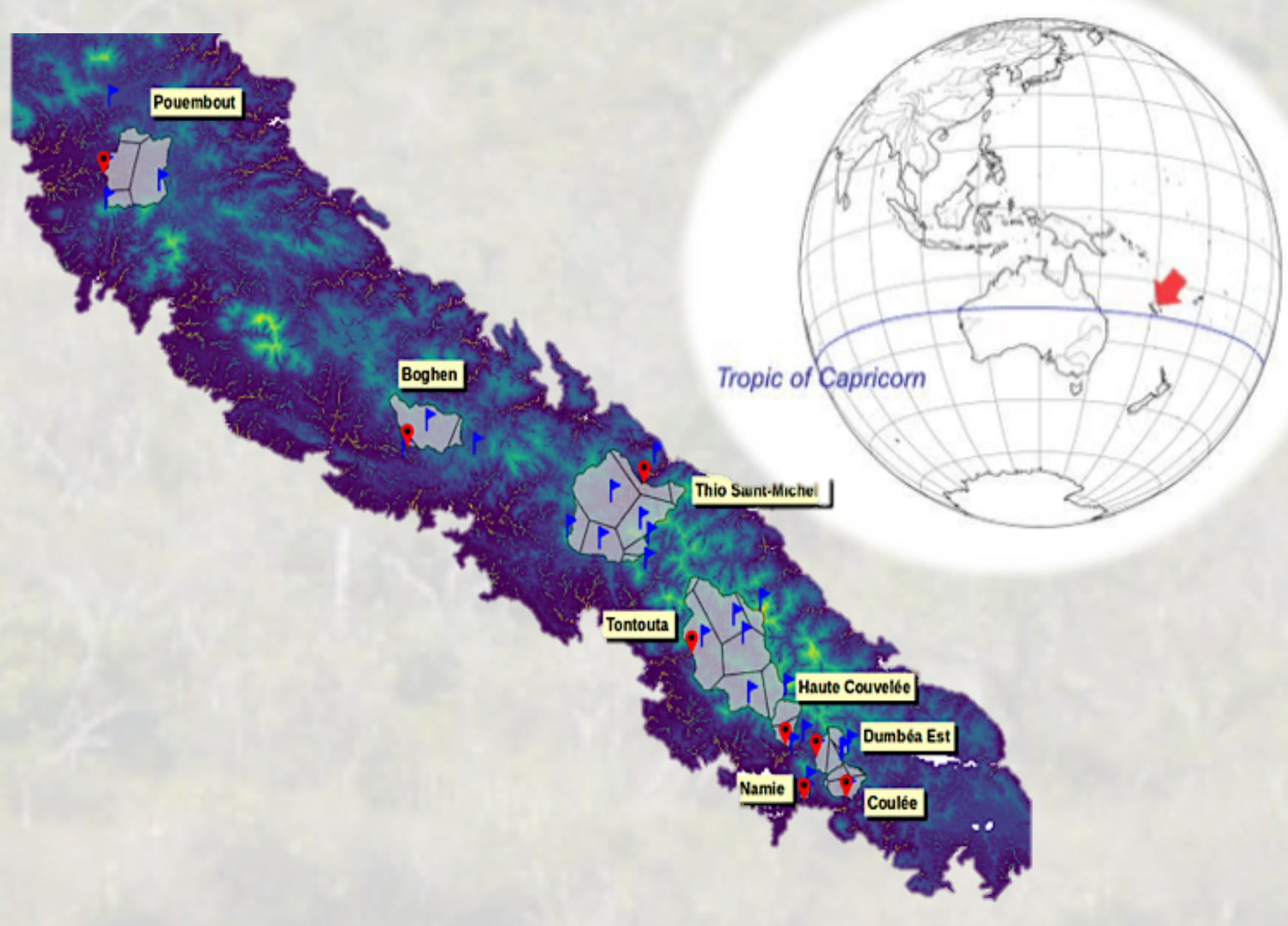


Fig. 1: Studied watersheds in the south of Grande Terre, New Caledonia

3. Materials and methods

- Hydro-meteorological distributed modelling :

The WRF-Hydro / Noah-MP Land Surface Model framework (Fig. 2)

- Noah-MP: partition of rainfall in surface runoff and infiltration = vertical routing
- WRF-Hydro : lateral flow algorithms with the diffusive wave equations

- 2-yr long one-way meteorological forcing: Surface atmospheric state variables from downscaled **WRF hourly simulations** at 4x4 km² spatial resolution

- WRF rainfall is replaced by hourly observations from **24 tipping bucket rain gauges** with two spatial interpolation methods on hydrological grid:
 - Thiessen polygon or IDEW algorithm (Fig. 3)

- Discharge hourly data from **six stream gauges**
- Validation metrics : NSE, KGE, NSE_{log10}

- WRF-Hydro automatic calibration on **seven parameters** with 9-months spin-up runs using the **DDS algorithm** [5]
- Independent calibrations upon **three characteristic rainy events** for each watershed:

1. Strong storm from June 30 to July 5, 2013

2. Weak rainfall from Nov. 30 to Dec. 5, 2013

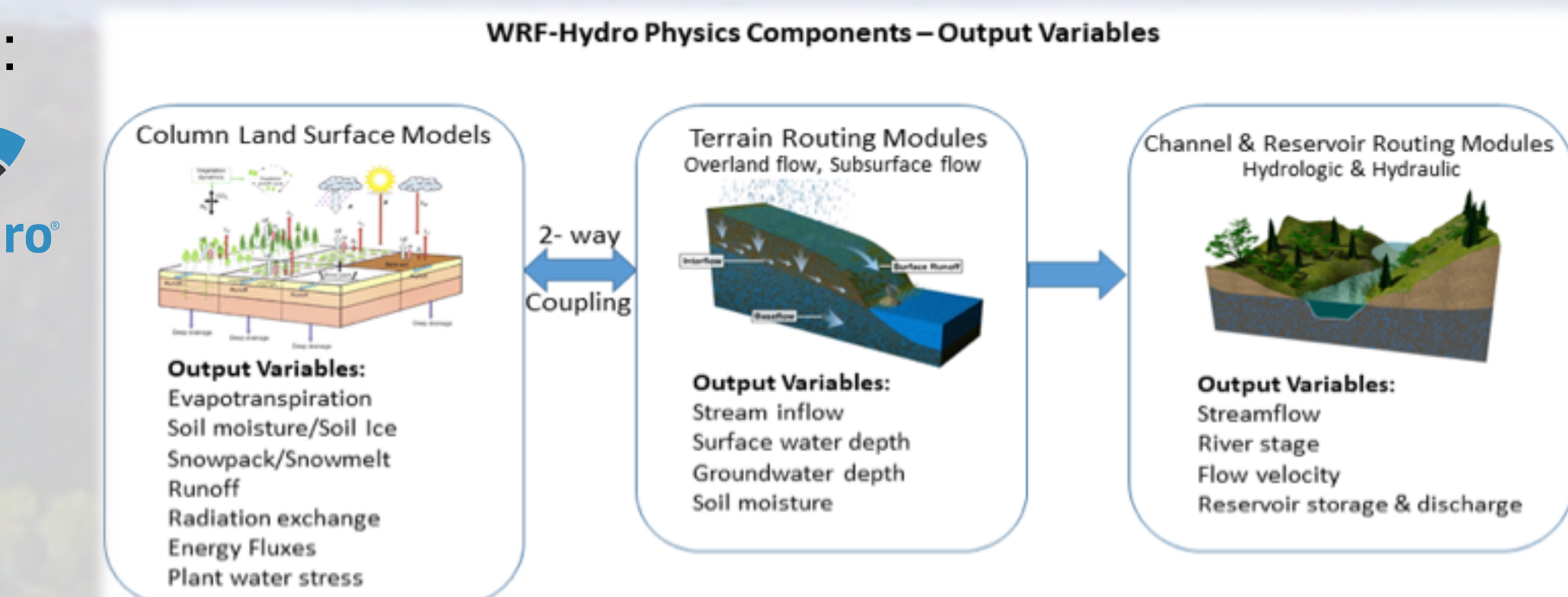


Fig. 2: Conceptual scheme of WRF-Hydro / Noah-MP (Source: NCAR)

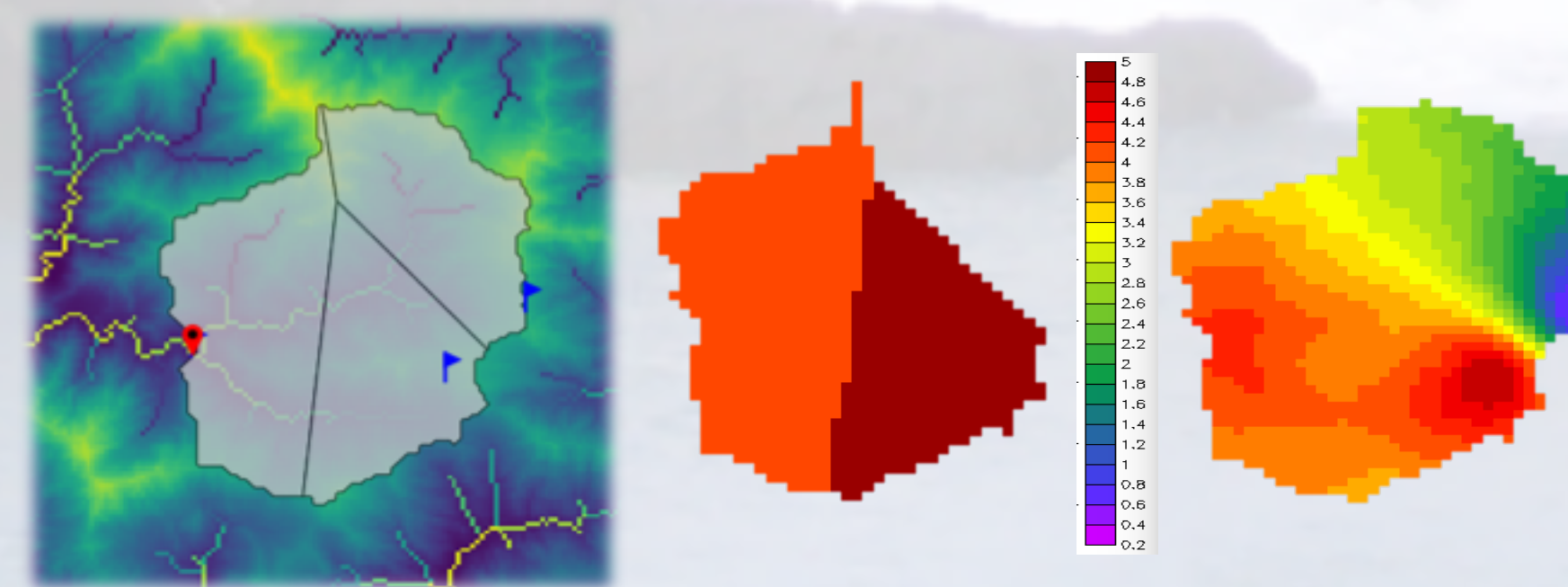


Fig. 3: Rainfall spatial interpolation on Dumbéa watershed. Left: Location of rain (blue flags) and stream (red marks) gauges on topography & stream network. Middle: Thiessen polygon method. Right : IDEW algorithm. Rainfall is in mm.h⁻¹ at a given time step.

	BEXP	SMC _{MAX} (m ³ .m ⁻³)	SLOPE	OVROUGH TFAC	MANN	REFKDT (day ⁻¹)	DKSAT (m.s ⁻¹)
Description	(i) Pore size distribution index	(ii) Maximum soil moisture content	(iii) Percolation coefficient	(iv) 2D overland roughness	(v) Manning's coefficient for channel roughness	(vi) Surface infiltration coefficient	(vii) Saturated soil hydraulic conductivity
Reference range	Dependent on soil texture 0.1 - 5	0 - 1	0.1 - 1	0 - 1	0.01 - 0.1	0.1 - 10	Dependent on soil texture 10 ⁻⁶ - 10 ⁻⁵

3. Edna tropical depression from February 2 to 7, 2014

4. Results and discussion

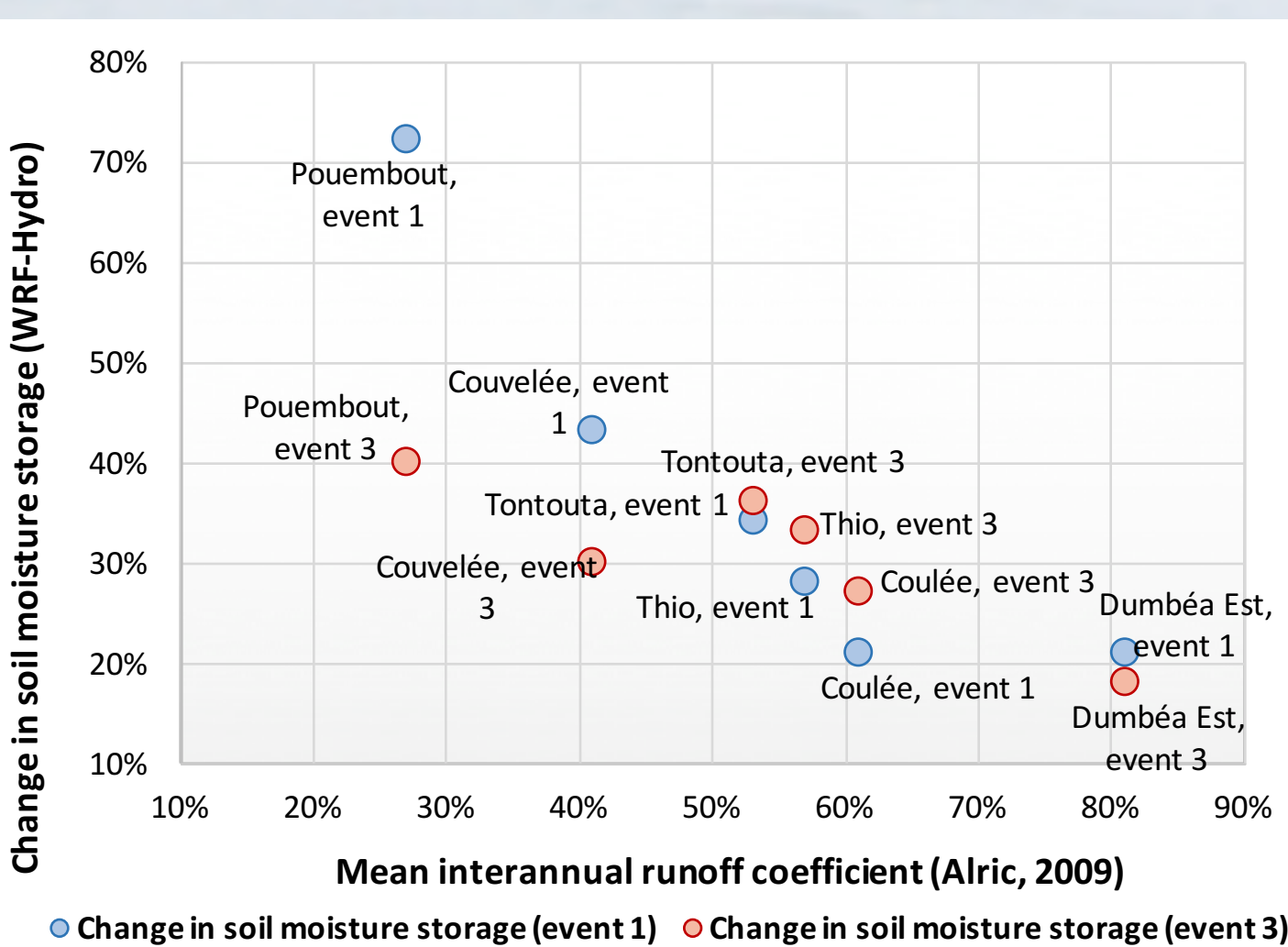


Fig. 4: Simulated change in soil moisture storage by WRF-Hydro as a function of mean interannual runoff coefficient (Alic, 2009) [1] during two flash-flood events.

- Fairly good results except for the Pouembout watershed.
- Simulation performance is **increasing with runoff coefficient** → difficulty in modelling vertical and horizontal flow routing for subsurface and groundwater.

- Water budget components** for the two studied flash-floods are **consistent with known characteristics** (Fig. 4).
- WRF-Hydro is able to suggest **agreeing physical parameters with watershed properties** [1] (Fig. 5) through automatic calibration.

June 2012 - March 2014	NSE	Multi (NSE+KGE+NSE _{log10}) / 3
Coulée	0.61	0.64
Dumbéa	0.89	0.80
Couvelée	0.74	-0.01
Pouembout	0.58	-0.34
Thio	0.76	0.41
Tontouta	0.80	0.40

Table 2: WRF-Hydro optimal performances

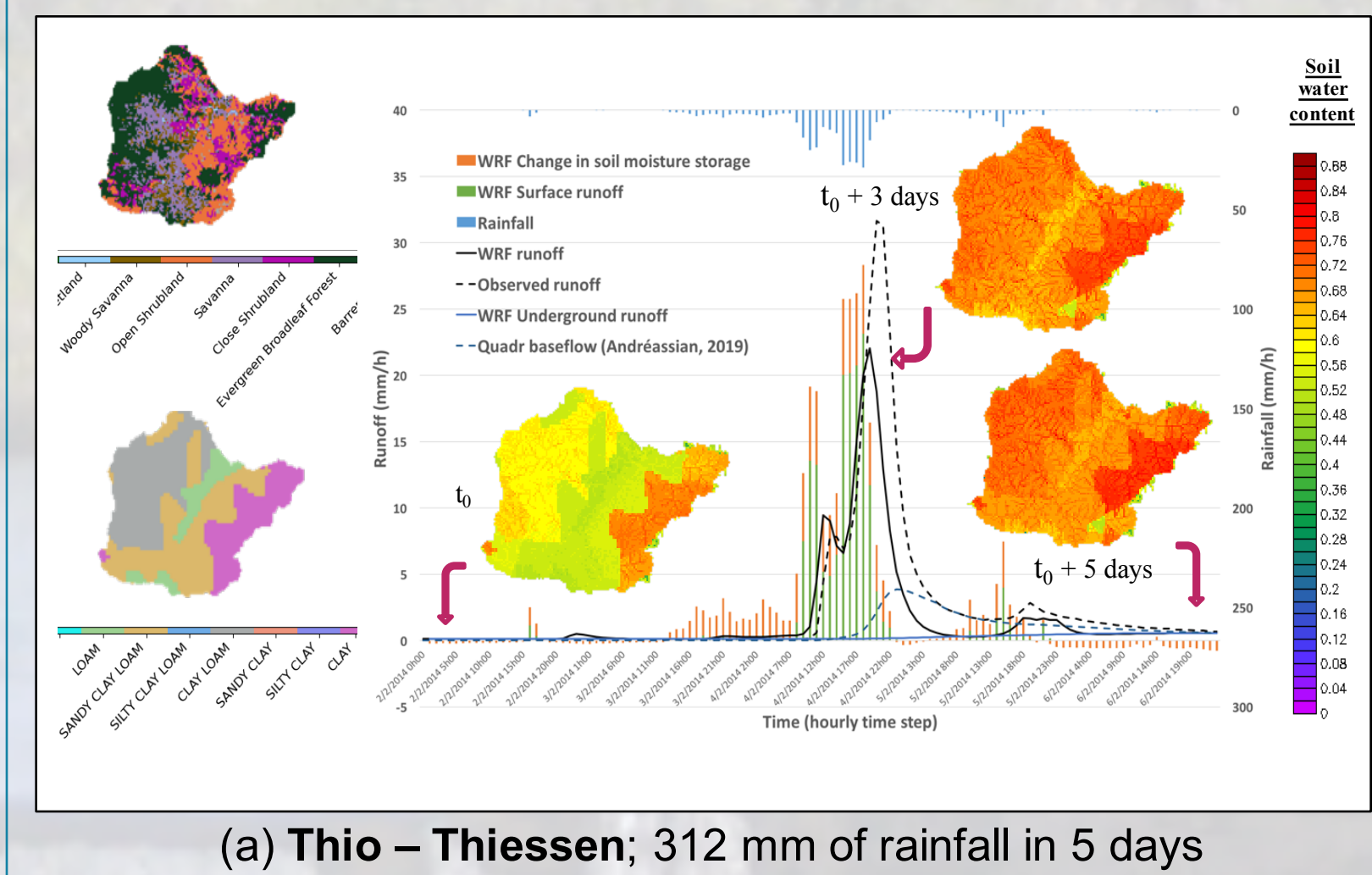
	Runoff coefficient (%)	Median flow rate (m ³ .s ⁻¹)	Recession time (days)	Median annual rainfall (mm)	Median altitude (m)	Median slope (%)	Hydraulic length (km)	Area (km ²)	Open shrubland area (%)	Dense vegetation area (%)
Coulée	61	0.915	43	2341	329	31	11	44	32	61
Dumbéa	81	1.22	63	2717	492	32	11	60	24	74
Couvelée	41	0.54	97	2027	465	46	12	40	8	90
Pouembout	27	0.67	81	1576	250	21	34	180	8	33
Thio	57	3.5	68	1571	390	30	34	345	14	59
Tontouta	53	5.7	120	1761	519	41	38	385	28	66

Table 1: Physical and hydrological features of studied watersheds, from Alic (2009) [1].

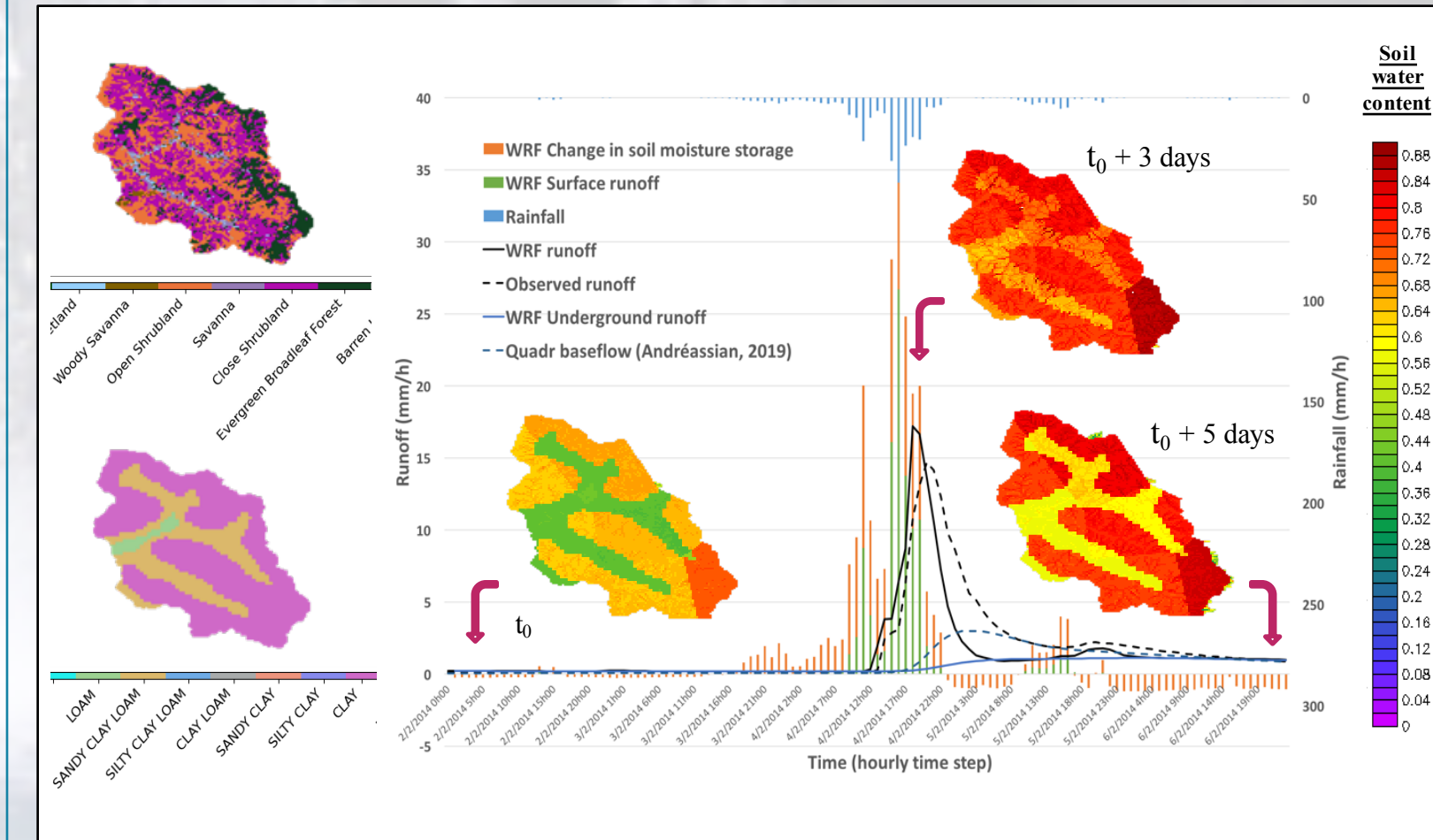
- Watersheds with **long recession periods** were attributed **low percolation rates** from the bottom soil layer to underground water buckets.
- Infiltration capacity** of New Caledonia **clay soils** had to be adjusted upward.
- Woody savanna land cover** was associated with **large soil moisture storage and high overland roughness**

		Pore size	Max soil coeff	Slope	2D roughness	River Manning	Infil coeff	NSE	Multi
WRF calibrated parameters		1.00	0.57	1.00	0.08	1.00	0.08	1.00	1.00
WRF performance indicators		0.84**	0.84**	0.84**	0.84**	0.84**	0.84**	0.84**	0.84**
WRF soil type		0.84**	0.84**	0.84**	0.84**	0.84**	0.84**	0.84**	0.84**
WRF land cover		0.84**	0.84**	0.84**	0.84**	0.84**	0.84**	0.84**	0.84**
Watersheds characteristics from Alic 2009		0.84**	0.84**	0.84**	0.84**	0.84**	0.84**	0.84**	0.84**

Fig. 5: Pearson correlation matrix with * for coefficients > 0.73 (p-value < 0.10), ** > 0.81 (p-value < 0.05) and *** > 0.92 (p-value < 0.01).



(a) Thio – Thiessen; 312 mm of rainfall in 5 days



(b) Tontouta – Thiessen; 277 mm of rainfall in 5 days

Fig. 6: Hourly water budget from rainfall (vertical bars), simulated (solid line) and observed (dashed) hydrographs. Baseflow separation as computed by WRF-Hydro (solid light blue line) and with Pelletier and Andréassian (2019) method based on observations (dashed light blue line). Spatial distribution of soil water content simulated by WRF-Hydro on Thio and Tontouta watersheds during the Edna tropical depression (event 3)

5. Conclusion

- WRF-Hydro was efficiently calibrated on short events in New Caledonia, **faithfully reproduced and shed light on flash-flood behavior** of six watersheds.
- In the context of a **drastic projected drying of New Caledonia** [4] by 2080, WRF-Hydro is built to **handle prospective modifications of New Caledonia's land cover and climate regime**.
- Calibration would need to be performed on longer periods and on additional watersheds to confirm and generalize results.
- Correct simulation of low flow regimes in New Caledonia could require enhanced modelling of subsurface and groundwater flow.

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