Nivo glaciological changes in Alpine catchments: impacts on hydrological regimes and aquatic ecosystems: Focus on potential evapotranspiration (PET)

Anthony Lemoine, Isabelle Gouttevin, Thomas Condom, Sophie Cauvy-Fraunié, Juliette Becquet, Jordi Bolibar Navarro, Antoine Rabatel

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INRAE – UR RiverLy / UGA – IGE / Météo-France – CEN

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Introduction

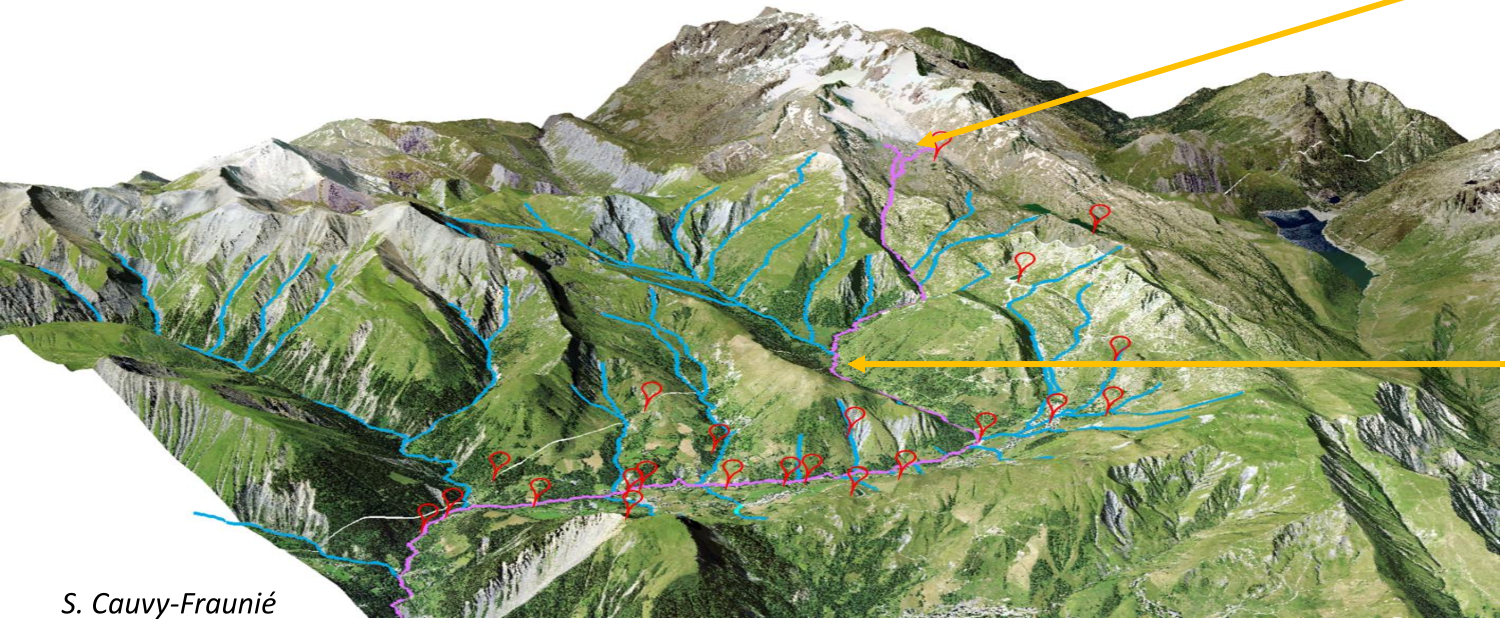
Water resource issues in the mountains

Case study : Arvan river (58 km²), Grandes-Rousses massif (Savoie)

Decrease of the water stock in solid form
→ induces irreversible changes on the hydrological regimes of alpine rivers and affects their ecological functioning.

St Sorlin glacier

Arvettaz and Arvan rivers



S. Cauvy-Fraunié

Glacier and snow contributions — Hydroecological sampling point

Snow contribution

Hydro-glaciological modeling chain

Dynamical glacier model

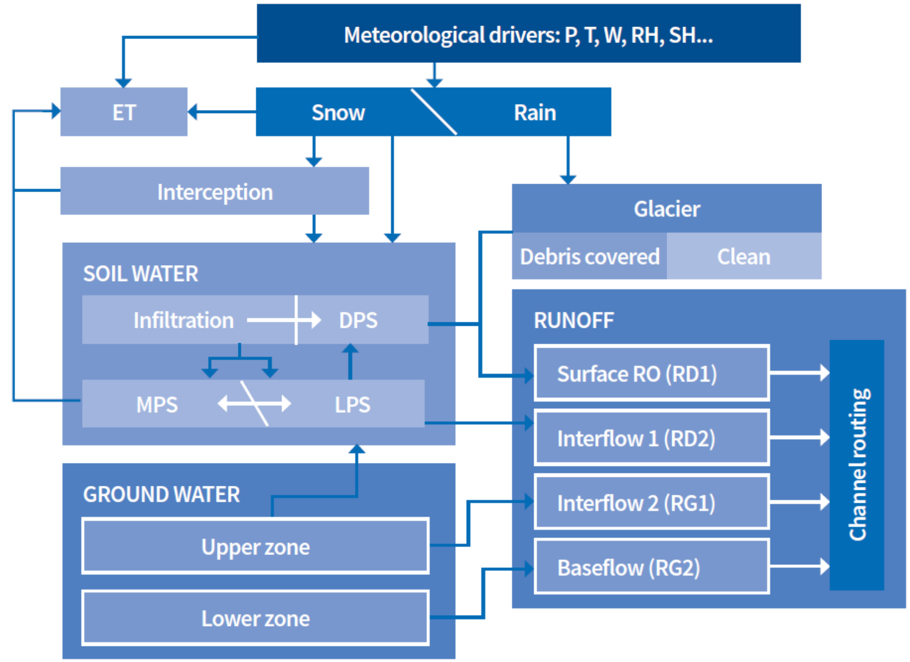
ALPGM
ALpine Parameterized Glacier Model

Bolibar et al., 2019

Annual surfaces of the 4 "glacier" HRUs

Meteorological reanalysis

PET



J2000 semi-distributed hydrological model

Krause et al., 2000 ; Nepal et al., 2016

Outputs

Impact of PET formulation for the hydrological cycle in mountainous environment?

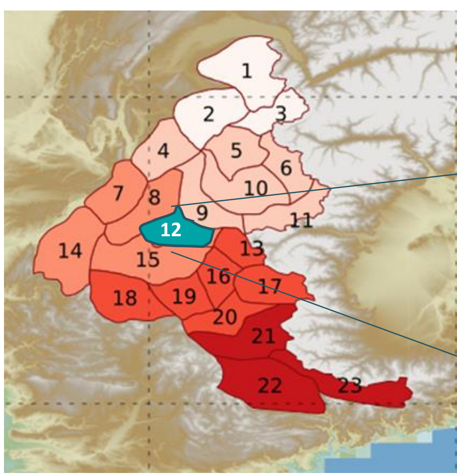
Data and methods

S2M meteorological reanalysis

Durand et al., 2009 ; Vernay et al., 2022

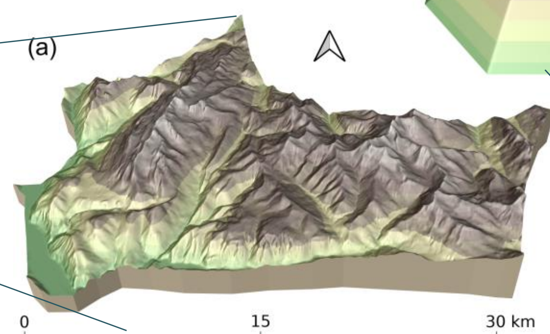
SAFRAN–SURFEX/ISBA–Crocus–MEPRA

- Meteorological reanalysis since 1948 for Corsica, the Pyrenees and the Alps.
- Each mountain range is divided into massifs.
- Massifs are represented by altitudes bands of 300 m.

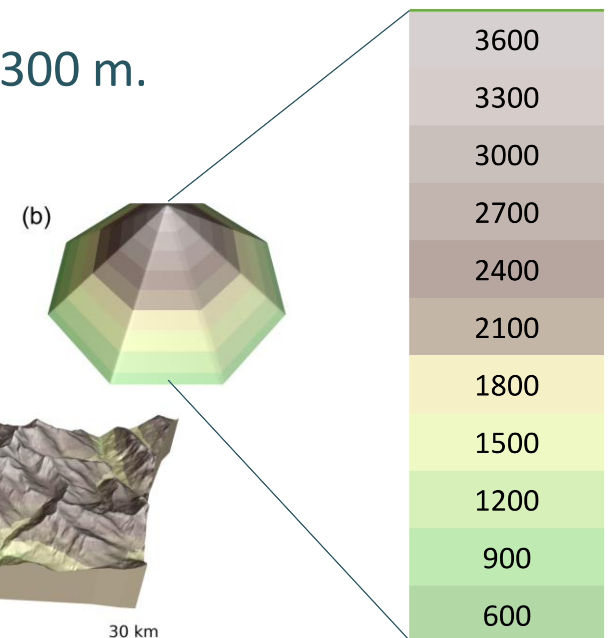


Vernay *et al.*, 2022

Grandes-Rousses massif

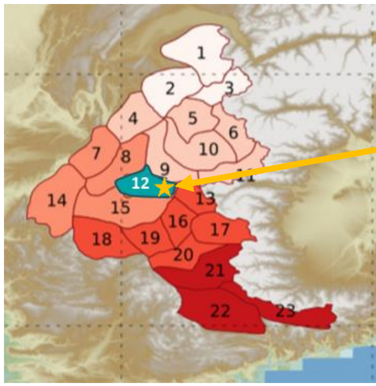


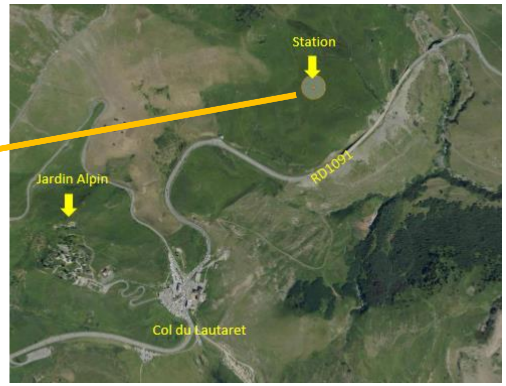
Alt. (m)



Evapotranspiration in situ data at Lautaret pass

FluxAlp station (East of Grandes-Rousses massif)





- Under the Lautaret pass (towards Briançon).
- Meteorological station.
- Turbulent fluxes by eddy covariance and actual evapotranspiration (AET).
- Half-hourly time step since 2012.
- Altitude: 2050 m.
- Alpine meadow.

Potential evapotranspiration formula

Two approaches

Energy based approach	Temperature based approach
Penmann-Monteith	Hargreaves

$f(alti, t_a)$ $f(alti, q_a)$

$f(\alpha, t_a, r_g, R_a)$

$$PET = \frac{\Delta\ (R_n - G) + \dfrac{\left(\rho\ C_p\ \delta_e\right)}{r_a}}{\lambda\left[\Delta + \gamma\left(1 + \dfrac{r_s}{r_a}\right)\right]}$$

$f(t_a)$ $f(u_a)$

$f(alti)$

$$PET = 0.0022\ R_A\ \delta_t{}^{0.5}\ (T + 17.8)$$

$f(lat)$ $f(t_a)$

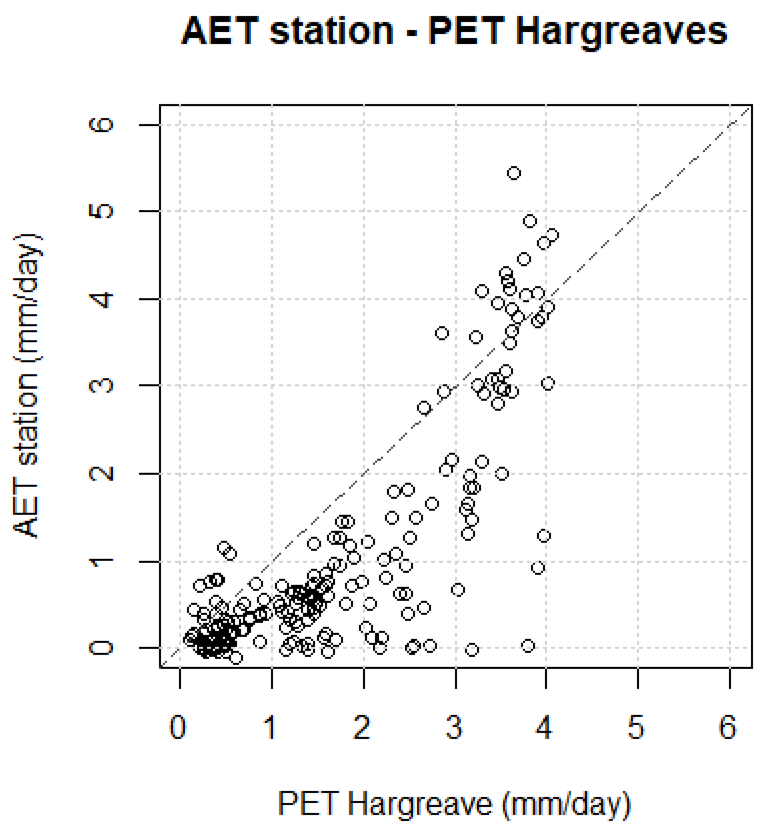
$f(t_a min, t_a max)$

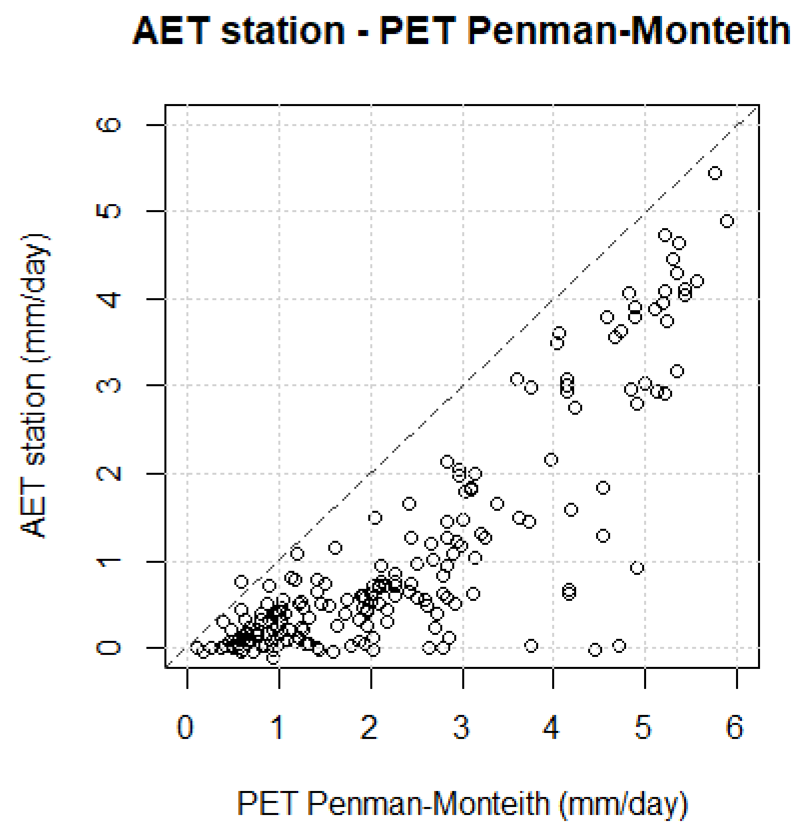
meteorological variables : air temperature (t_a), min. air temperature ($t_a min$), max. air temperature ($t_a max$), specific humidity (q_a), wind speed (u_a), longwave radiation (r_g), shortwave radiation (R_a), albedo (α), altitude ($alti$), latitude (lat)

Results

Correlation between AET and PET at Lautaret pass

AET (station measurement), PET (formula with station data) in 2017





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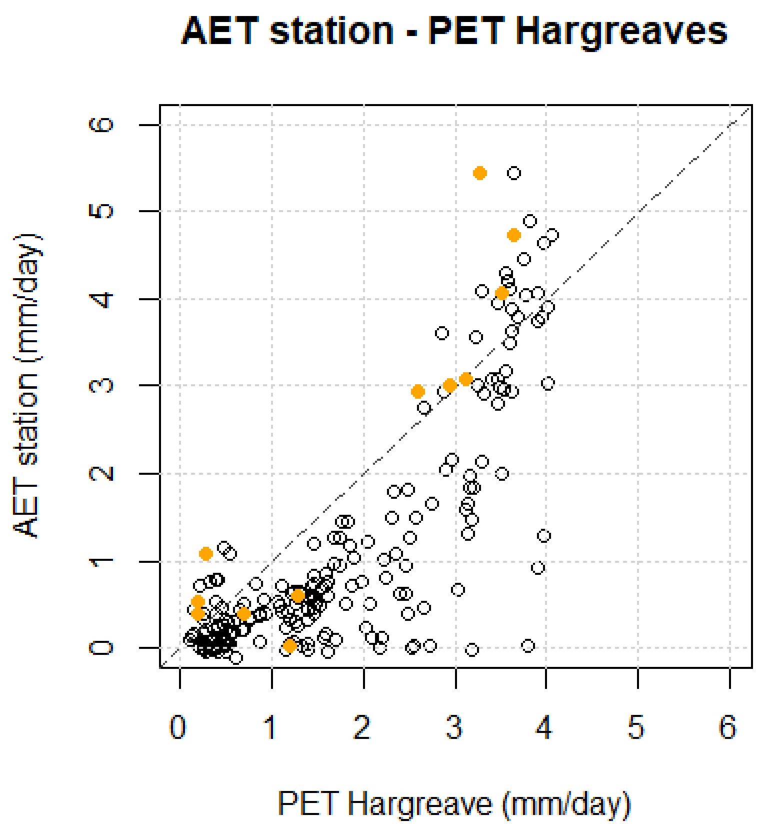
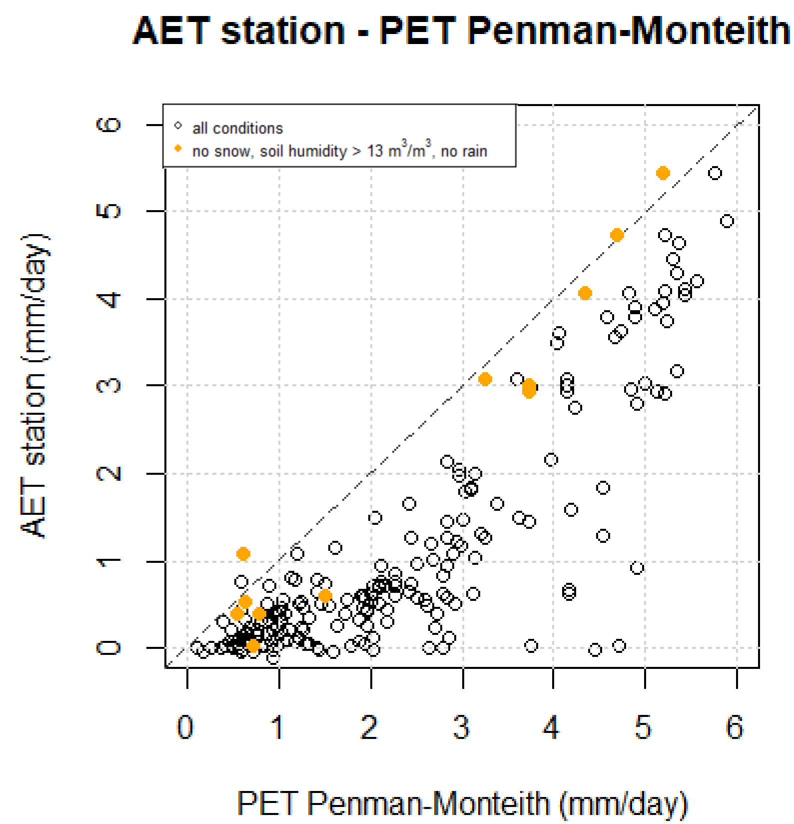


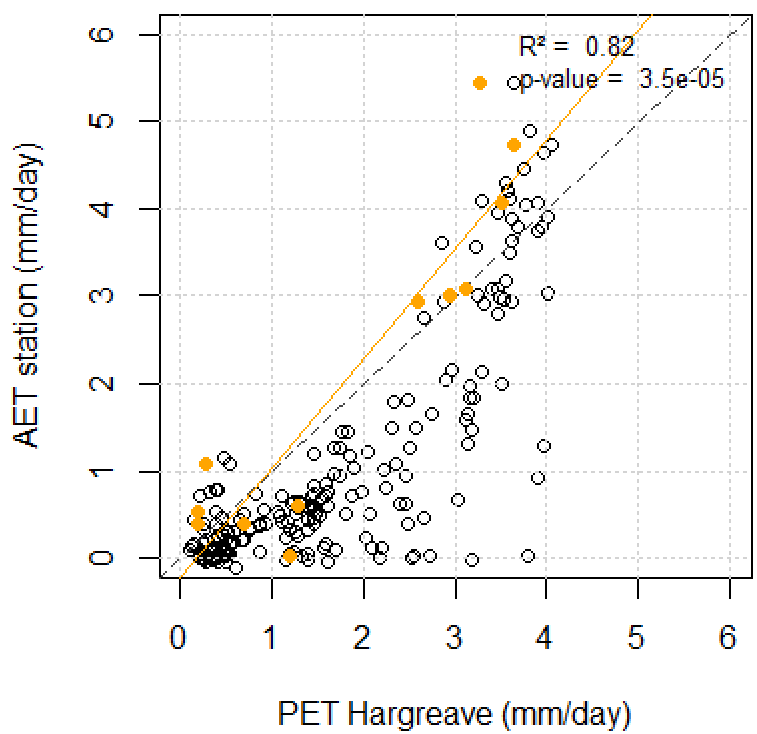


- PET equivalent to AET with : no snow on the ground, water saturated soil and no rain.

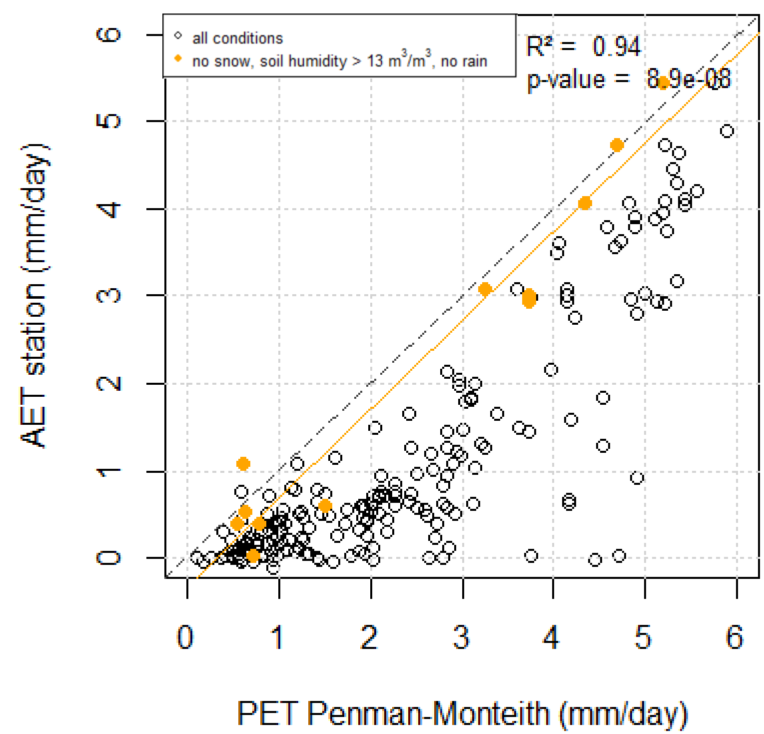
Correlation between AET and PET at Lautaret pass

AET (station measurement), PET (formula with station data) in 2017

AET station - PET Hargreaves



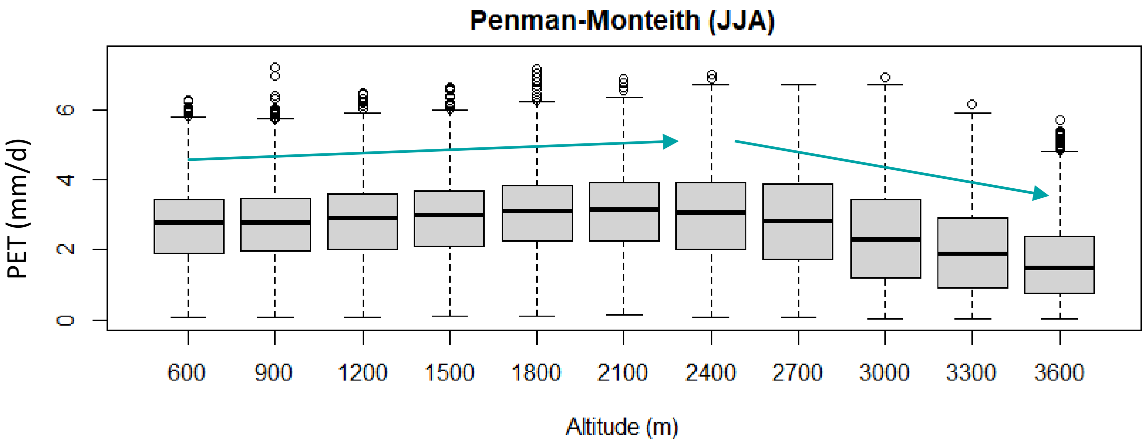
AET station - PET Penman-Monteith

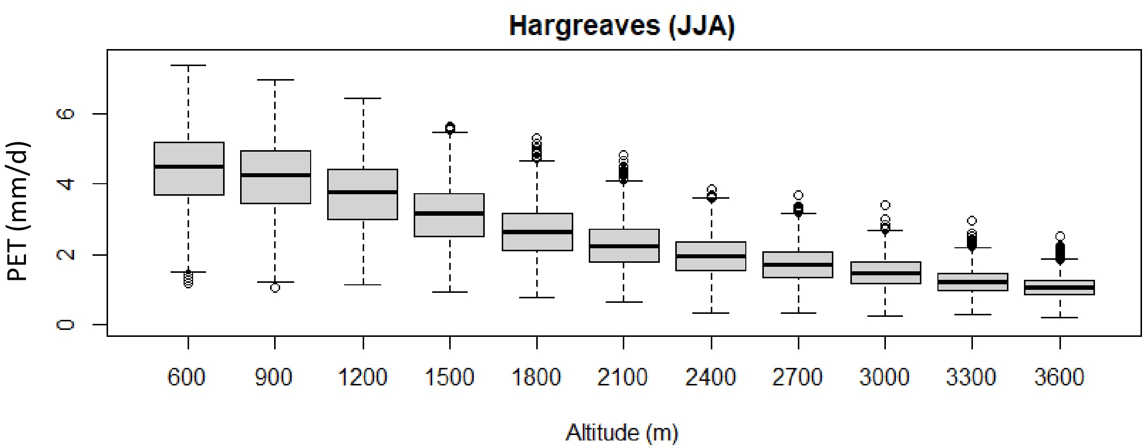


→ PET calculated with P-M gives a stronger correlation than with Hargreaves formula.

PET of Penman-Monteith and Hargreaves

Evolution by altitude bands over 1958-2018 (summer)





- P-M: mean PET increase from 600 m.a.s.l to 2100 m.a.s.l and then decrease.
- Hargreaves : decrease of PET with altitude.
- At 600 m.a.s.l, 3 mm/d (P-M) and 4.5 mm/d (Hargreaves) for PET average.
- At 2100 m.a.s.l, 3.5 mm/d (P-M) and 2.5 mm/d (Hargreaves) for PET average.
- For PET Hargreave, dispersion decreases with altitude.

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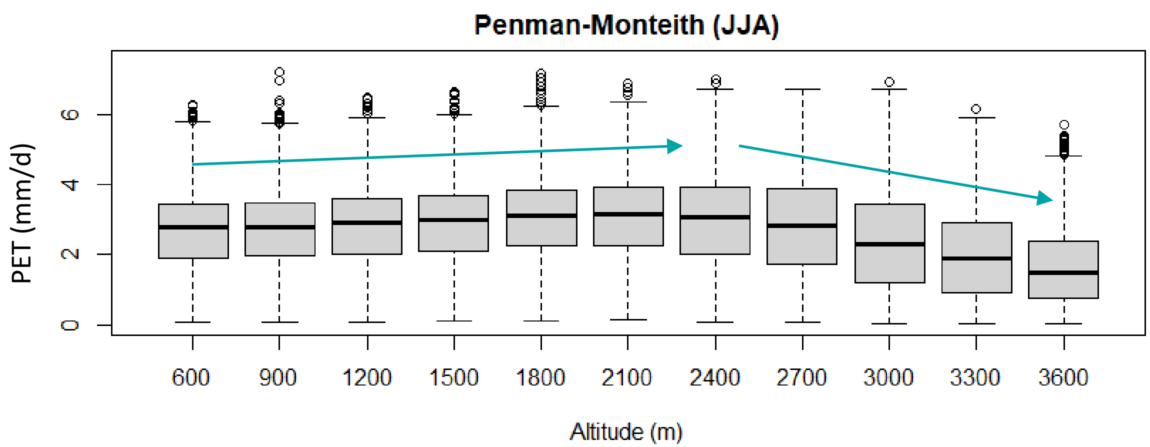

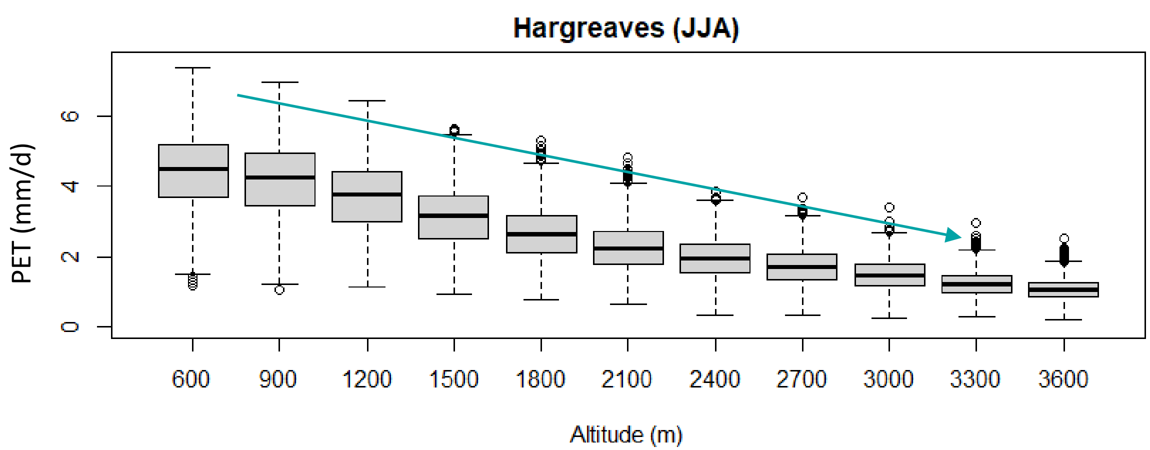

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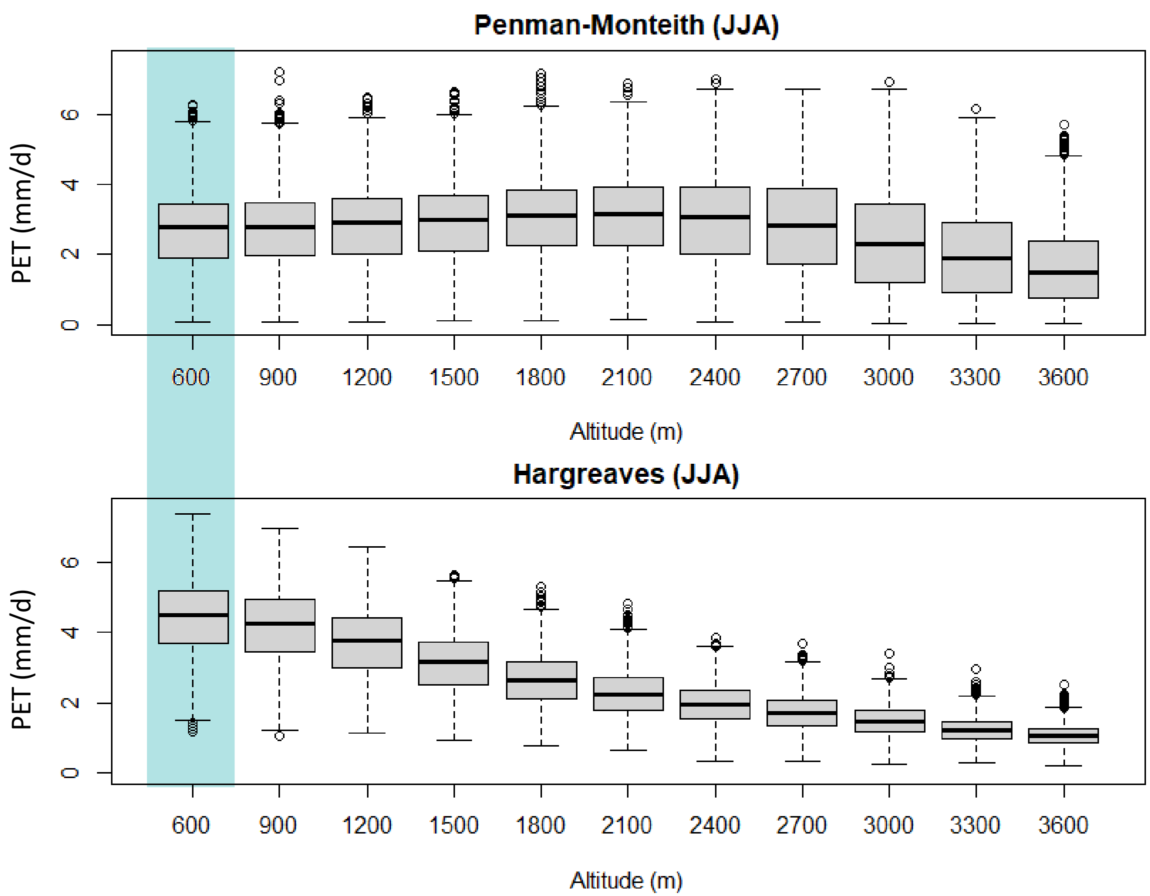

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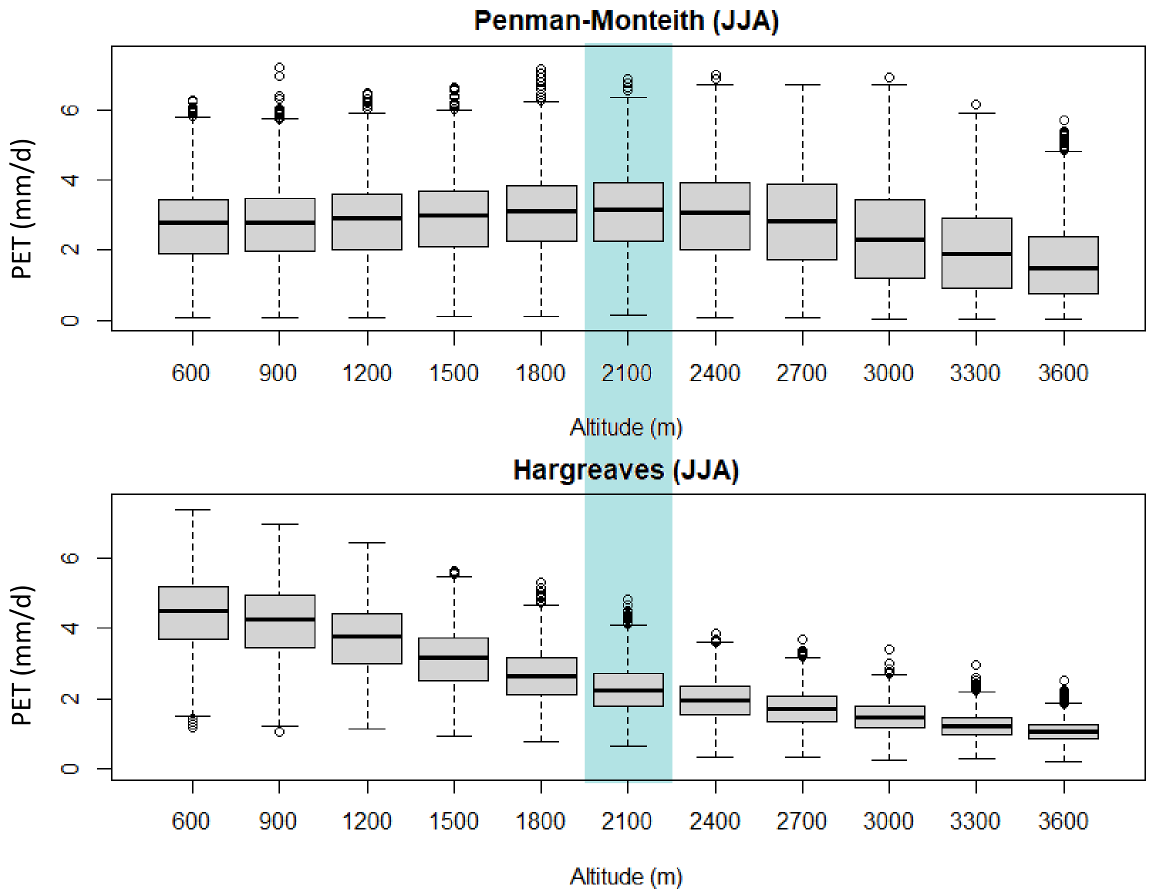

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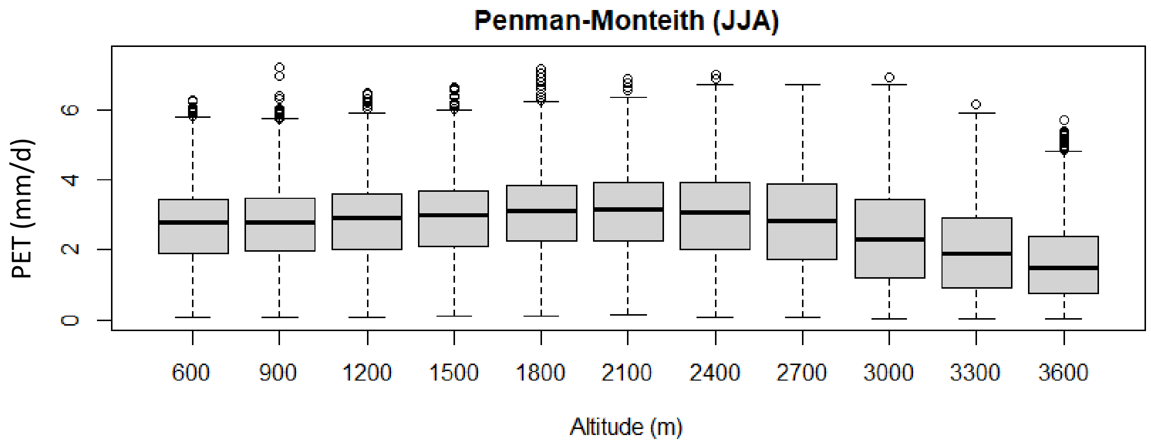

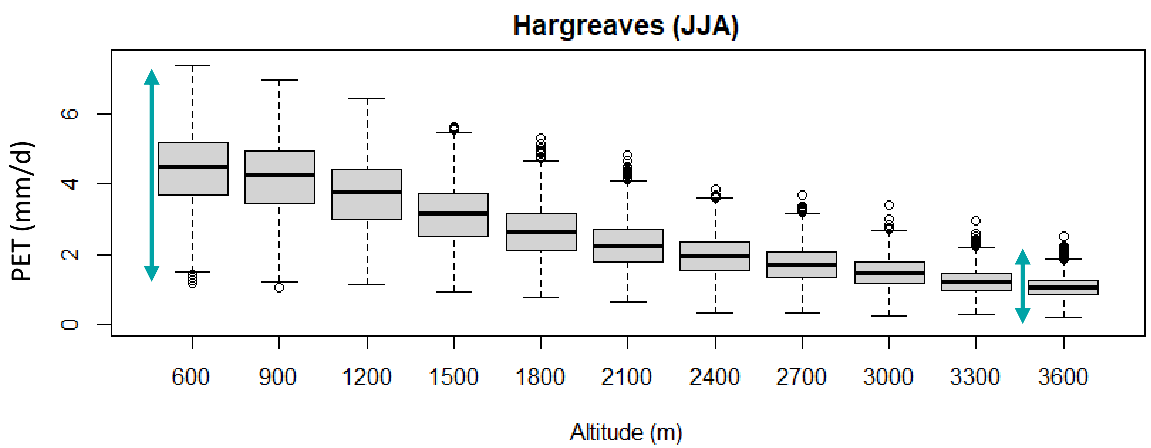

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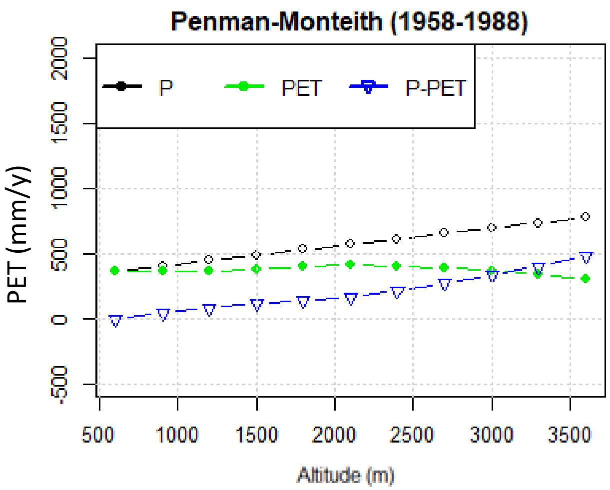
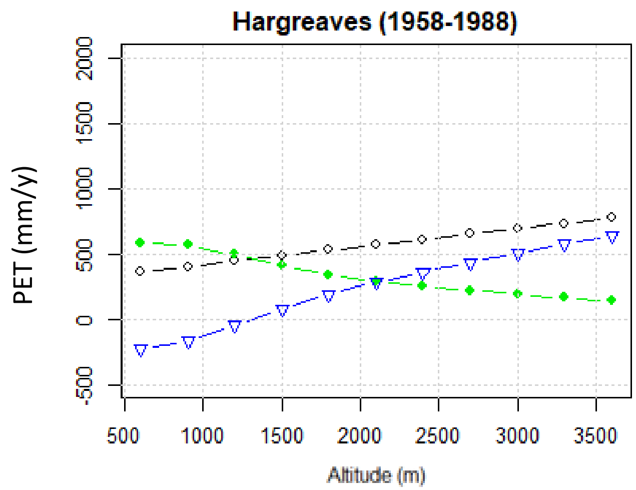
Water balance: precipitations, PET, P-PET

Mean values over 30 years





- With Hargreaves, PET stronger at low altitudes than P-M and it is the opposite for high altitudes.
- At low altitudes, there is a water deficit with the Hargreaves formulation.

- PET higher in 1989-2018 than 1958-1988 for all formulations.
- The decrease of PET with altitude on 1989-2018 is more marked than over the period 1958-1988 with Hargreave.

Water balance: precipitations, PET, P-PET

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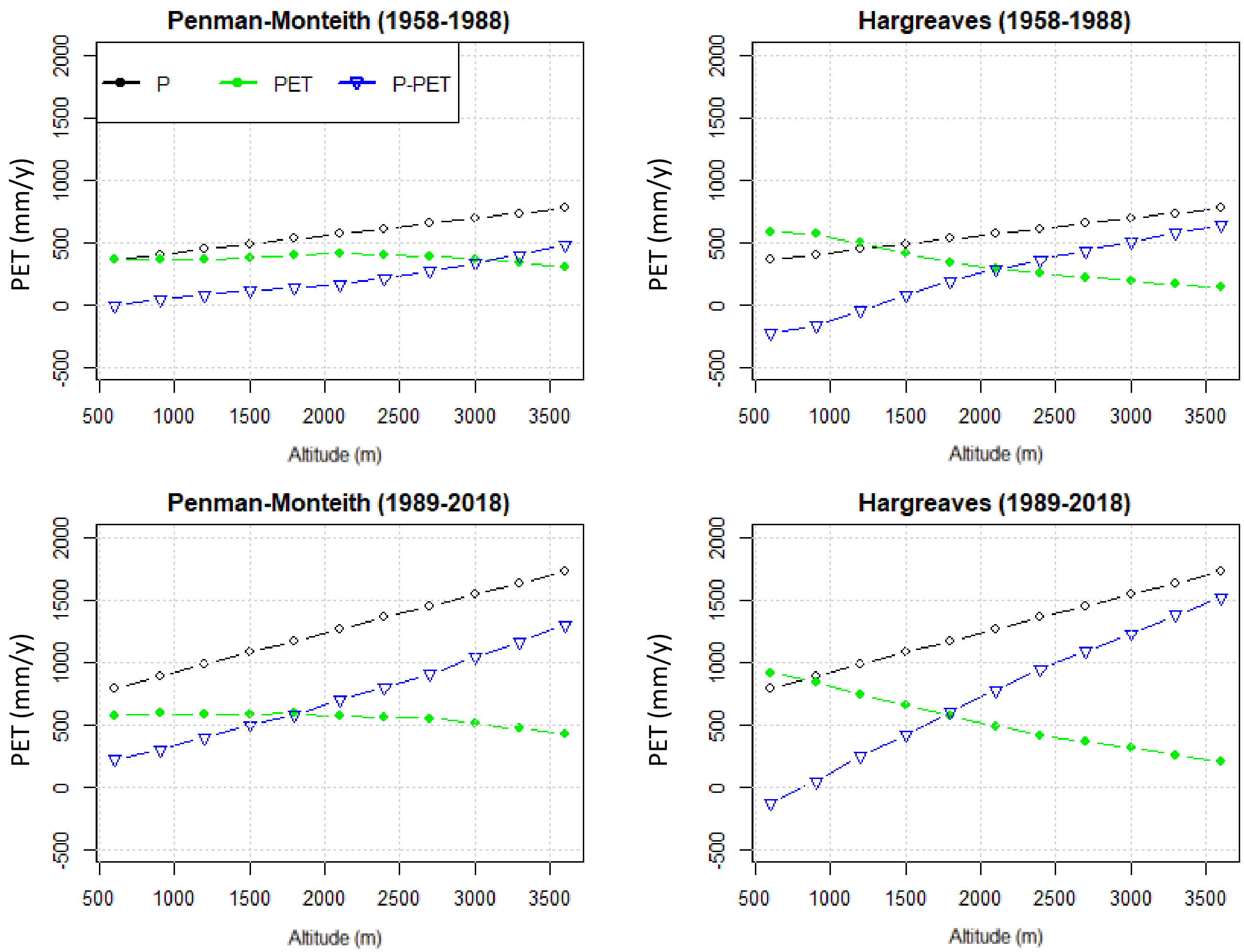

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Take home message

→ It is the unique air temperature dependence in Hargreaves that governs this altitudinal evolution, whereas the P-M dependencies are more complex.

Conclusions

Conclusions and perspectives

- Validation of the Penman-Monteith formula using data from the FluxAlp station (Lautaret pass);
- Potential evapotranspiration does not evolve linearly with altitude depending on the formulation used;
- PET increases at low altitudes in recent years, regardless of the calculation formula chosen;
- Extend the analysis of the evolution of PET on several massifs;
- Simulate the PET in future climate and analyze impact of PET formulation on the evolution of the water resource.

Thank you !

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