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

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 and Antoine Rabatel

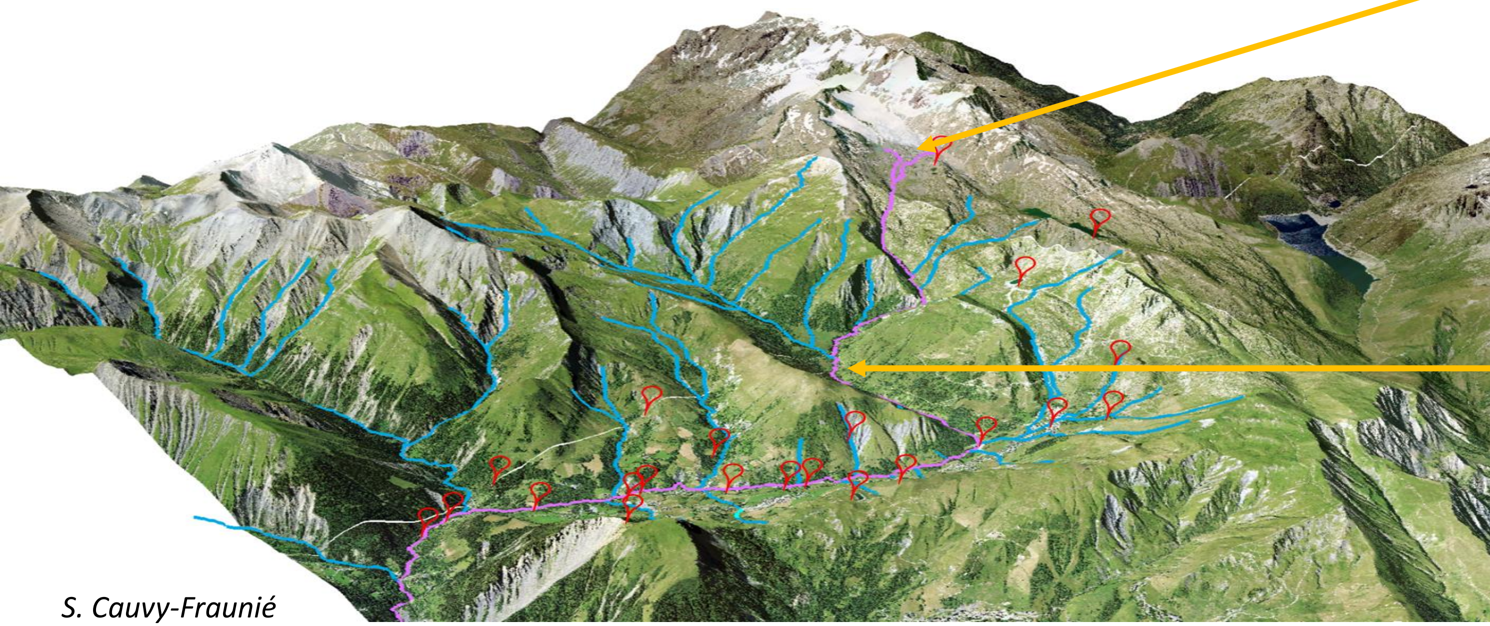
INRAE – UR RiverLy / UGA – IGE / Météo-France – CEN

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.



S. Cauvy-Fraunié

St Sorlin glacier

Arvettaz and Arvan rivers

Glacier and snow contributions

Hydroecological sampling point

Snow contribution

Hydro-glaciological modeling chain

Dynamical glacier model

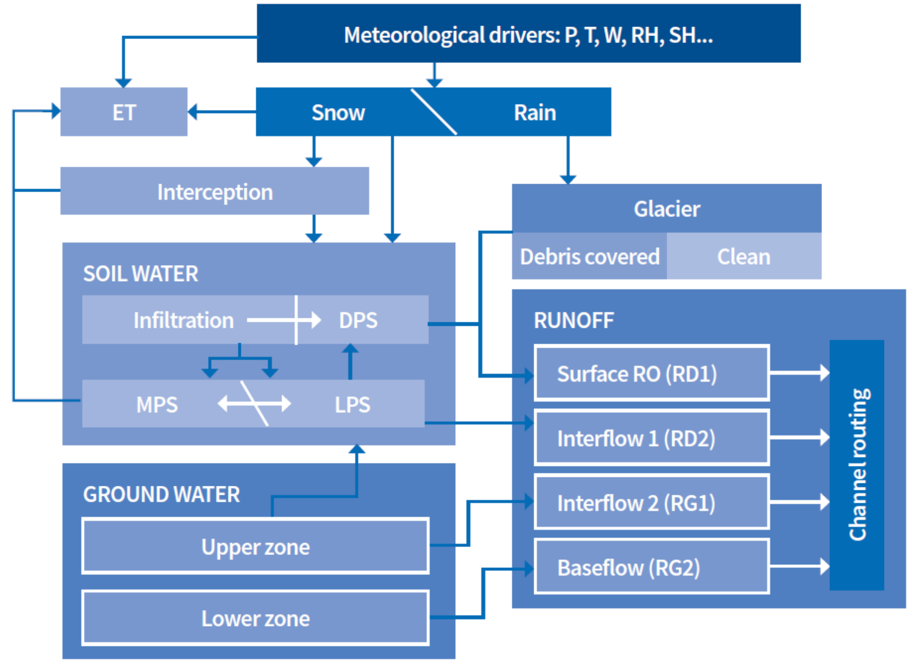
ALPGM
ALpine Parameterized Glacier Model

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?

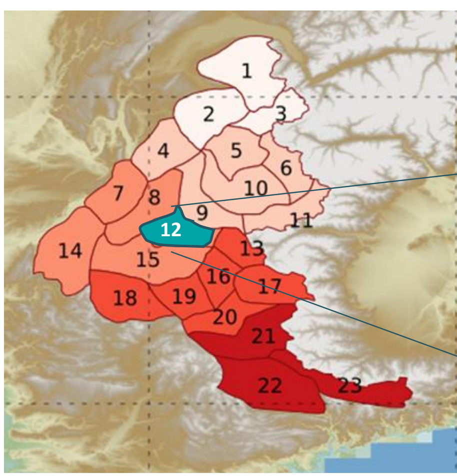
Data and methods

S2M meteorological reanalysis

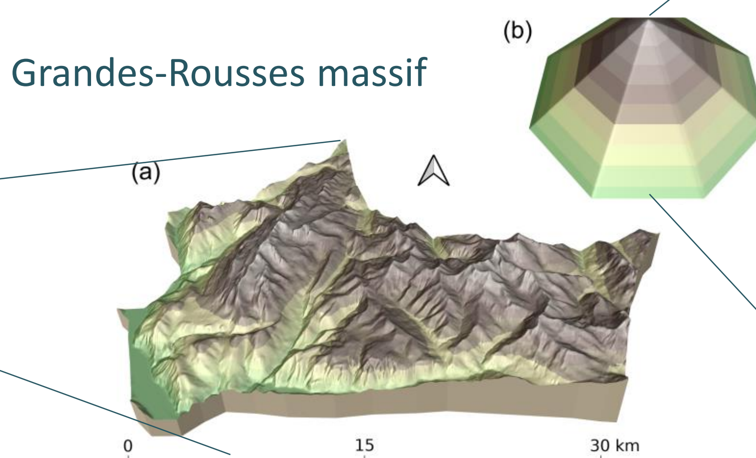
Durand et al., 2009 ; Vernay et al., 2022

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.

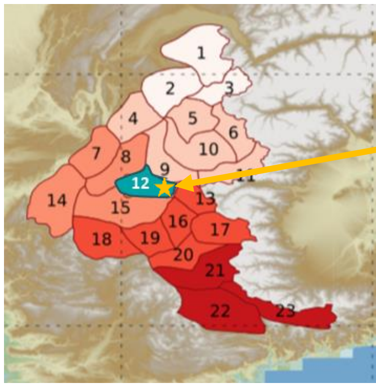


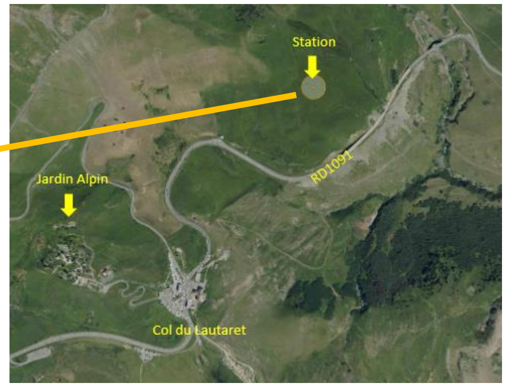
Vernay *et al.*, 2022



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

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

$f(\alpha, t_a, r_g, R_a)$; $f(alti, t_a)$; $f(alti, q_a)$; $f(t_a)$; $f(t_a)$; $f(alti)$; $f(u_a)$; $f(u_a)$

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

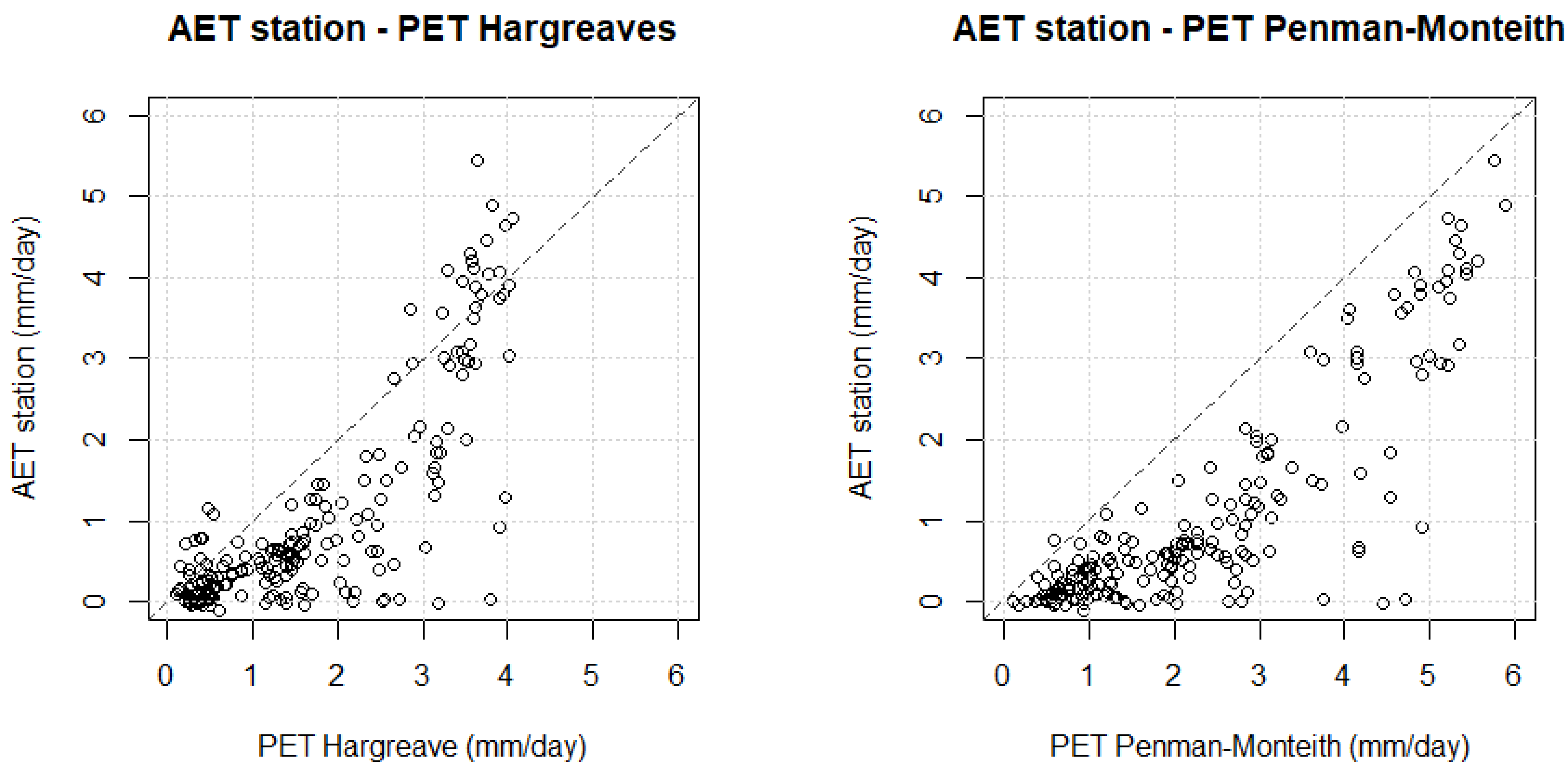
$f(lat)$; $f(t_a min, t_a max)$; $f(t_a)$

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

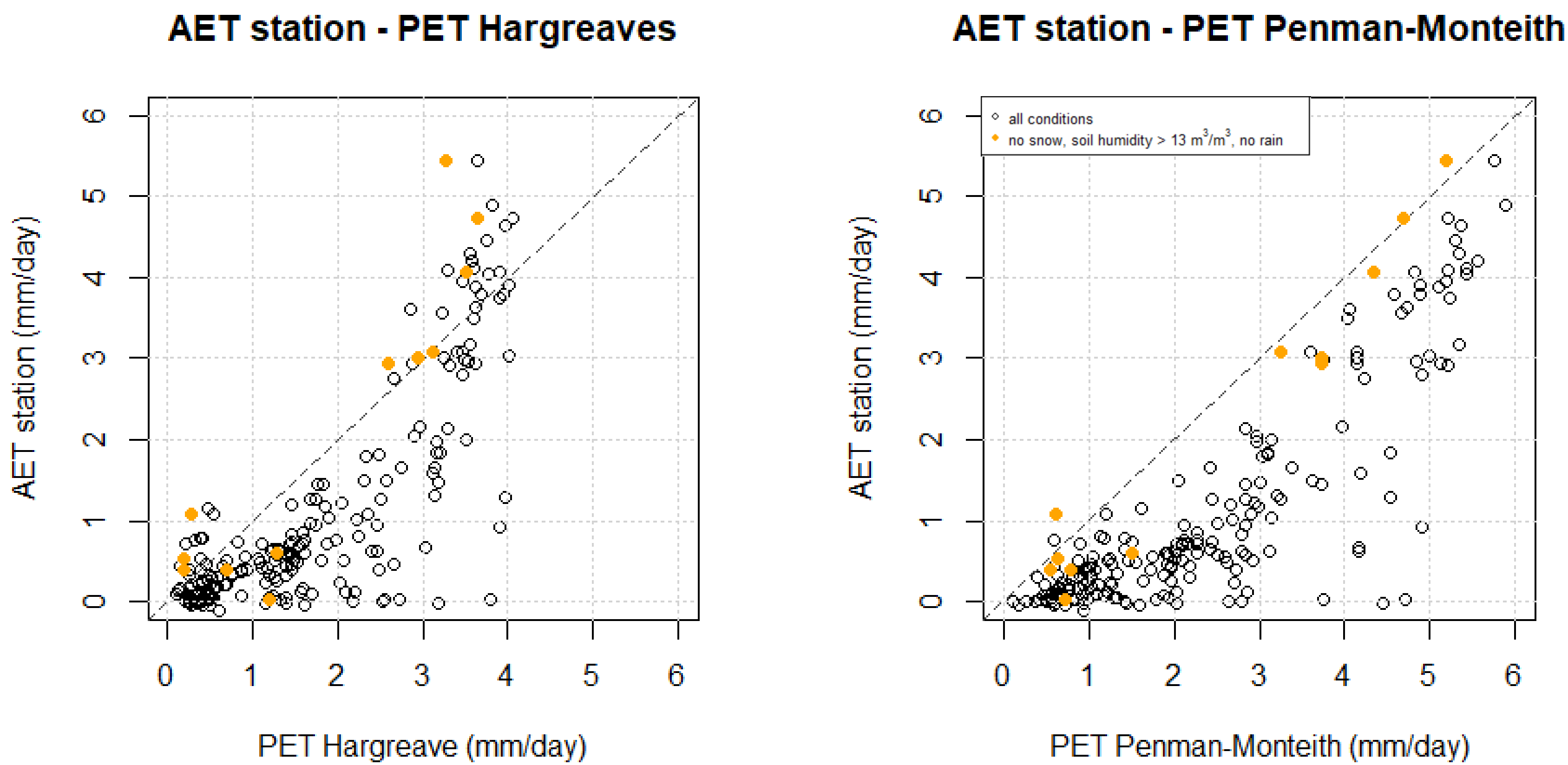
Correlation between AET and PET at Lautaret pass

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



Correlation between AET and PET at Lautaret pass

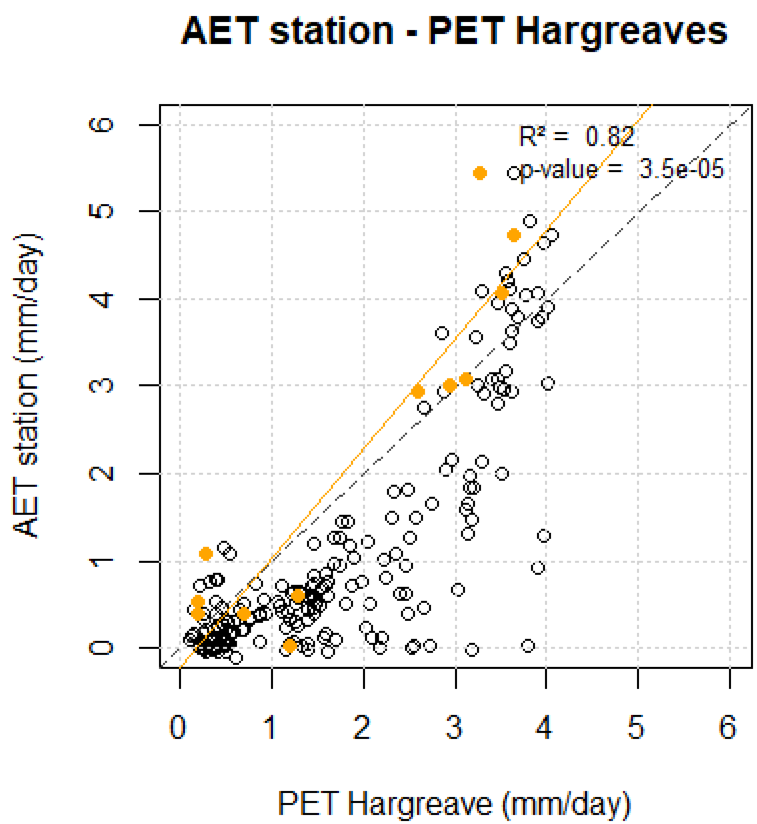
AET (station measurement), PET (formula with station data) in 2017

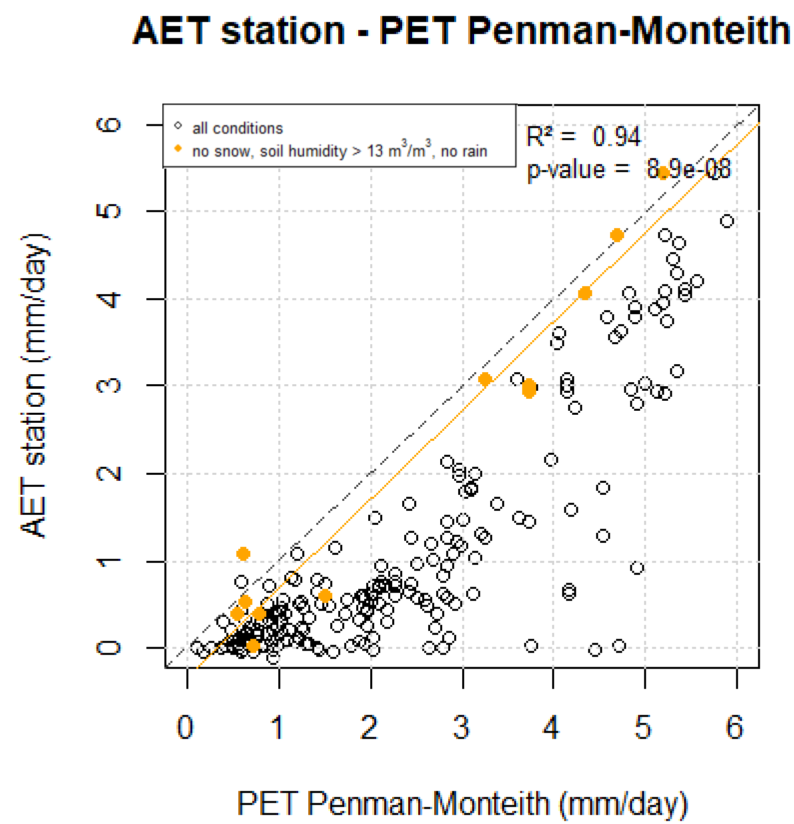


- PET equivalent to AET with : no snow on the ground, water saturated soil and no rain.

Correlation between AET and PET at Lautaret pass

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

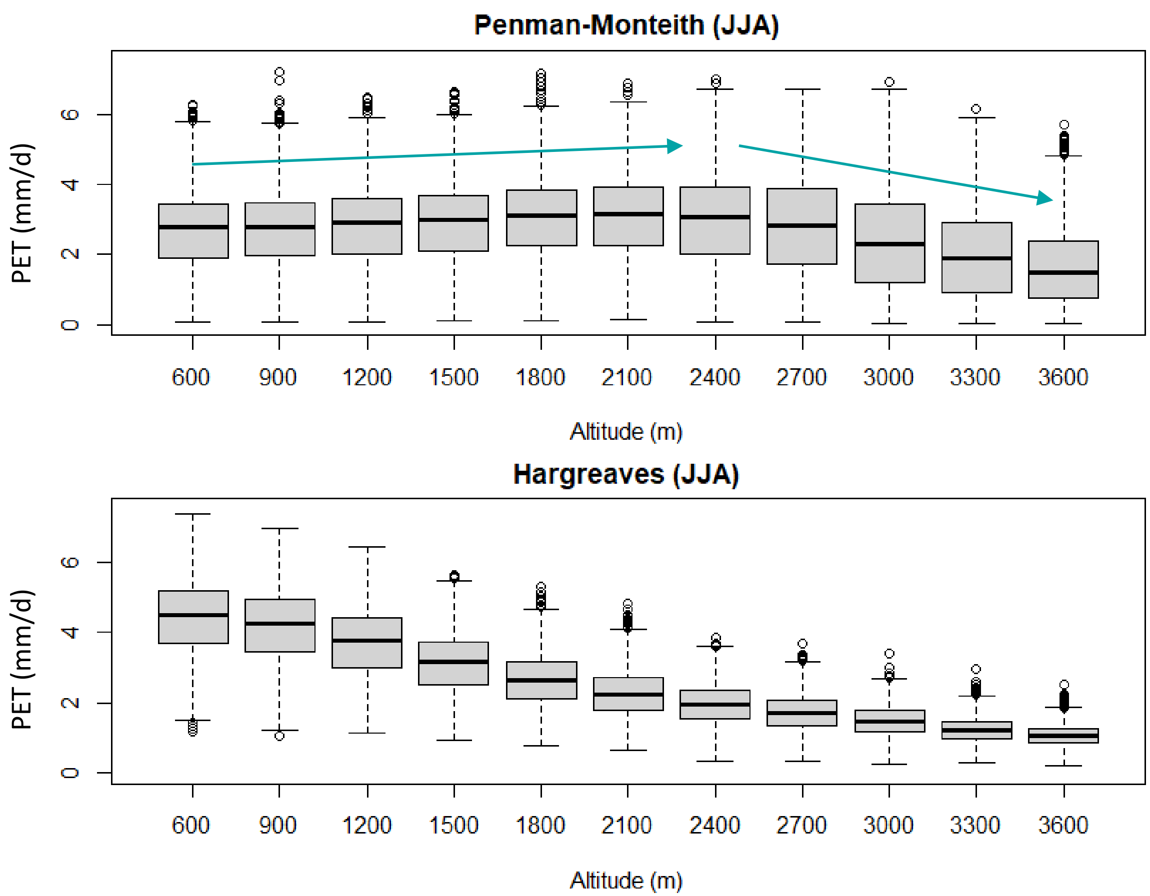




→ PET calculated with P-M gives a stronger correlation than with Hargreaves formula.

PET of Penman-Monteith and Hargreaves

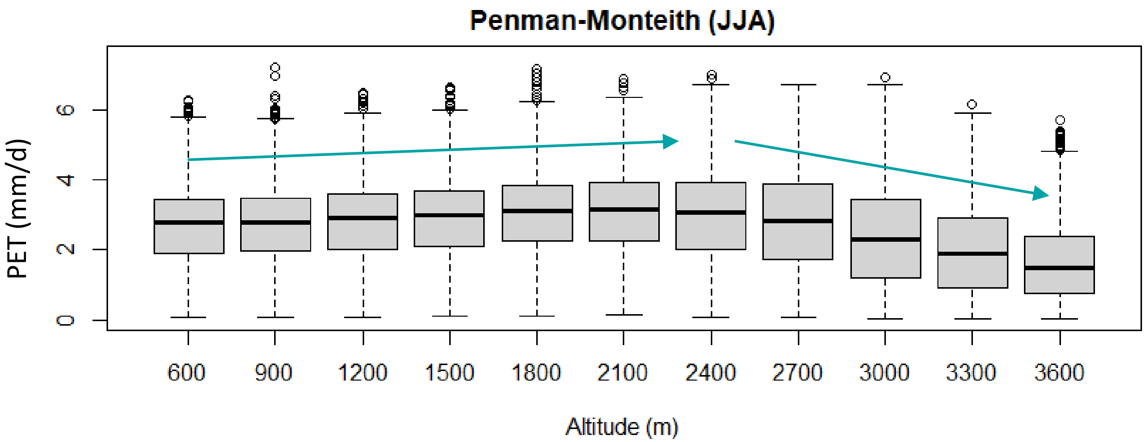
Evolution by altitude bands over 1958-2018 (summer)

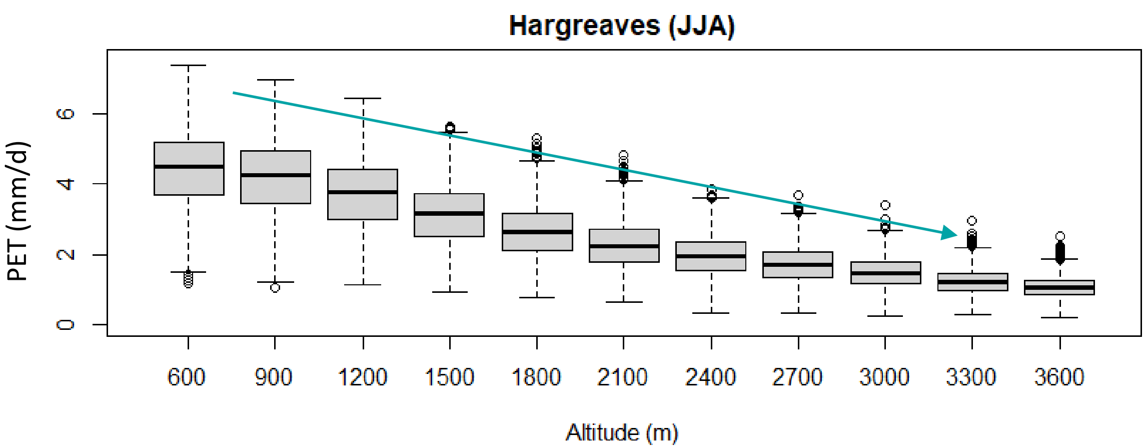


- P-M: mean PET increase from 600 m.a.s.l to 2100 m.a.s.l and then decrease.
- Hargreaves : decrease of PET with altitude.
- At 600 m.a.s.l, 3 mm/d (P-M) and 4.5 mm/d (Hargreaves) for PET average.
- At 2100 m.a.s.l, 3.5 mm/d (P-M) and 2.5 mm/d (Hargreaves) for PET average.
- For PET Hargreave, dispersion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

PET of Penman-Monteith and Hargreaves

Evolution by altitude bands over 1958-2018 (summer)

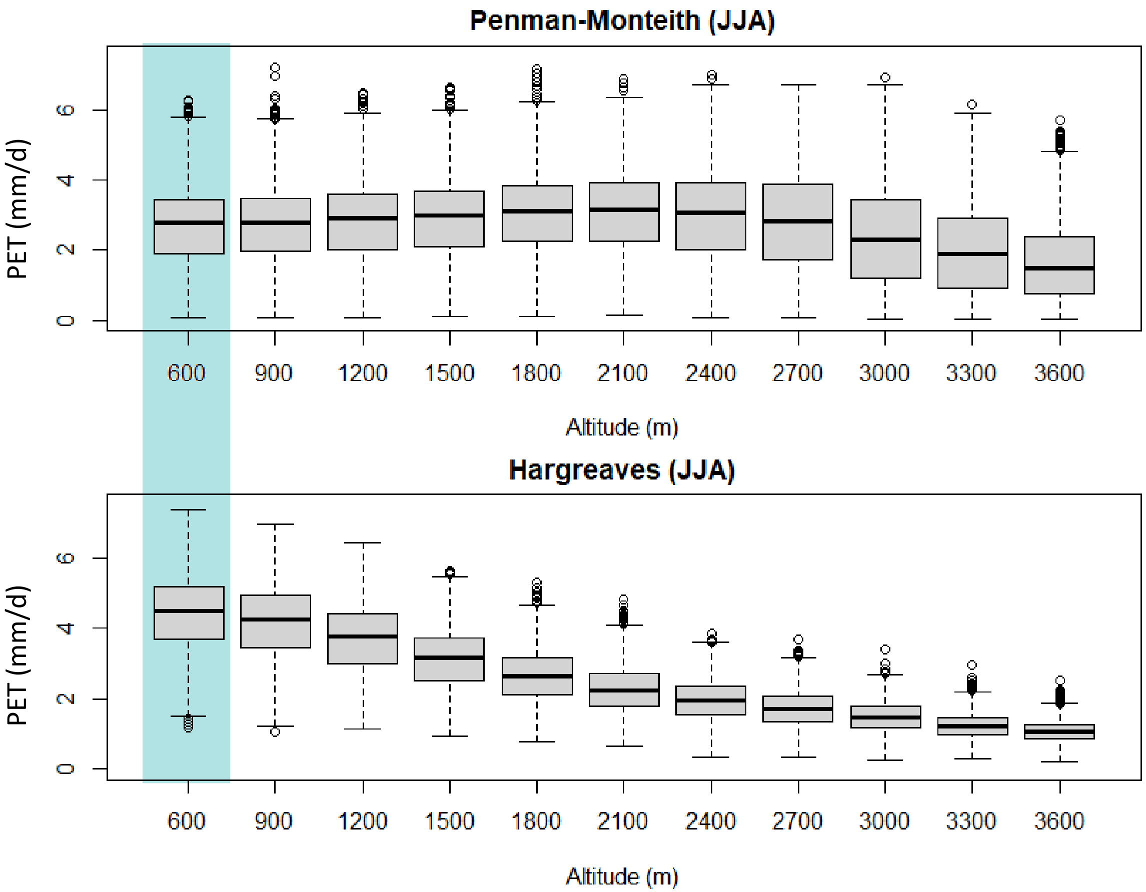




- P-M: mean PET increase from 600 m.a.s.l to 2100 m.a.s.l and then decrease.
- Hargreaves : decrease of PET with altitude.
- At 600 m.a.s.l, 3 mm/j (P-M) and 4.5 mm (Hargreaves) for PET average.
- At 2100 m.a.s.l, 3.5 mm/j (P-M) and 2.5 mm (Hargreaves) for PET average.
- For PET Hargreave, dispersion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

PET of Penman-Monteith and Hargreaves

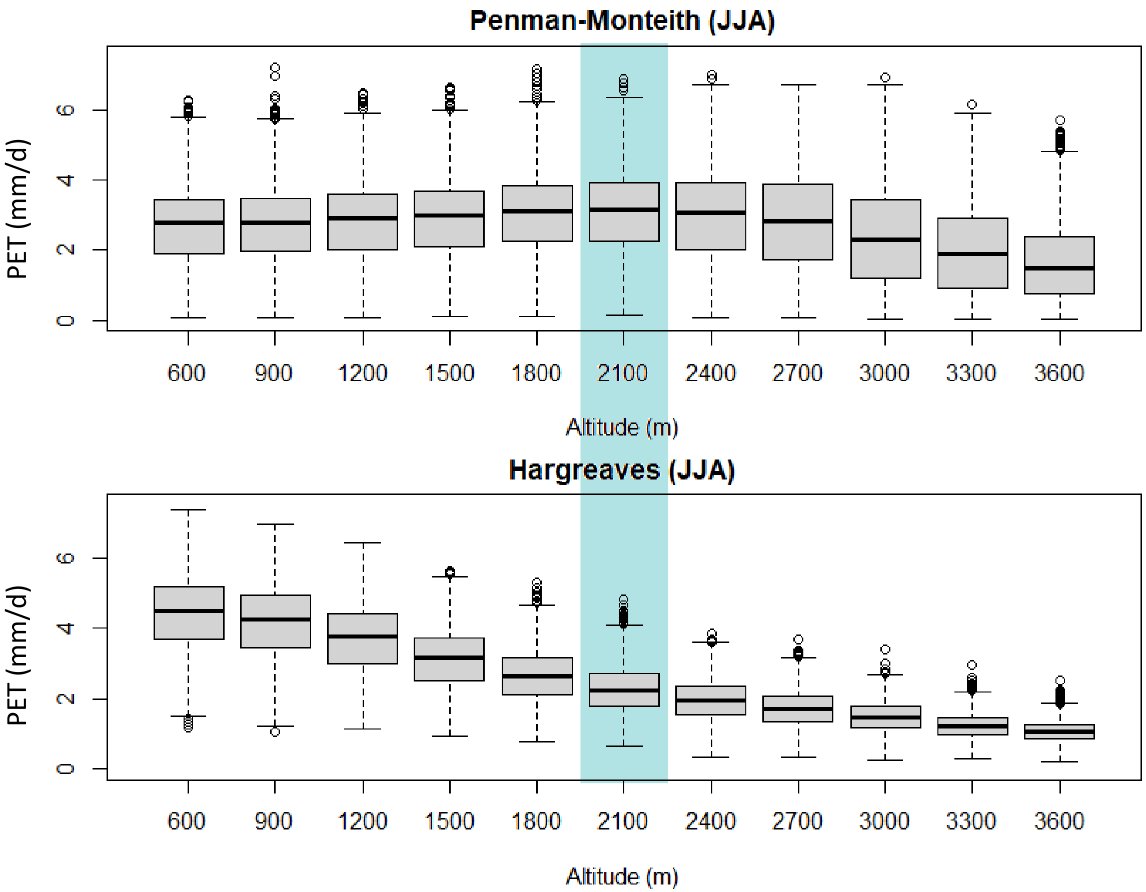
Evolution by altitude bands over 1958-2018 (summer)



- 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 Hargreaves, dispersion decreases with altitude.

PET of Penman-Monteith and Hargreaves

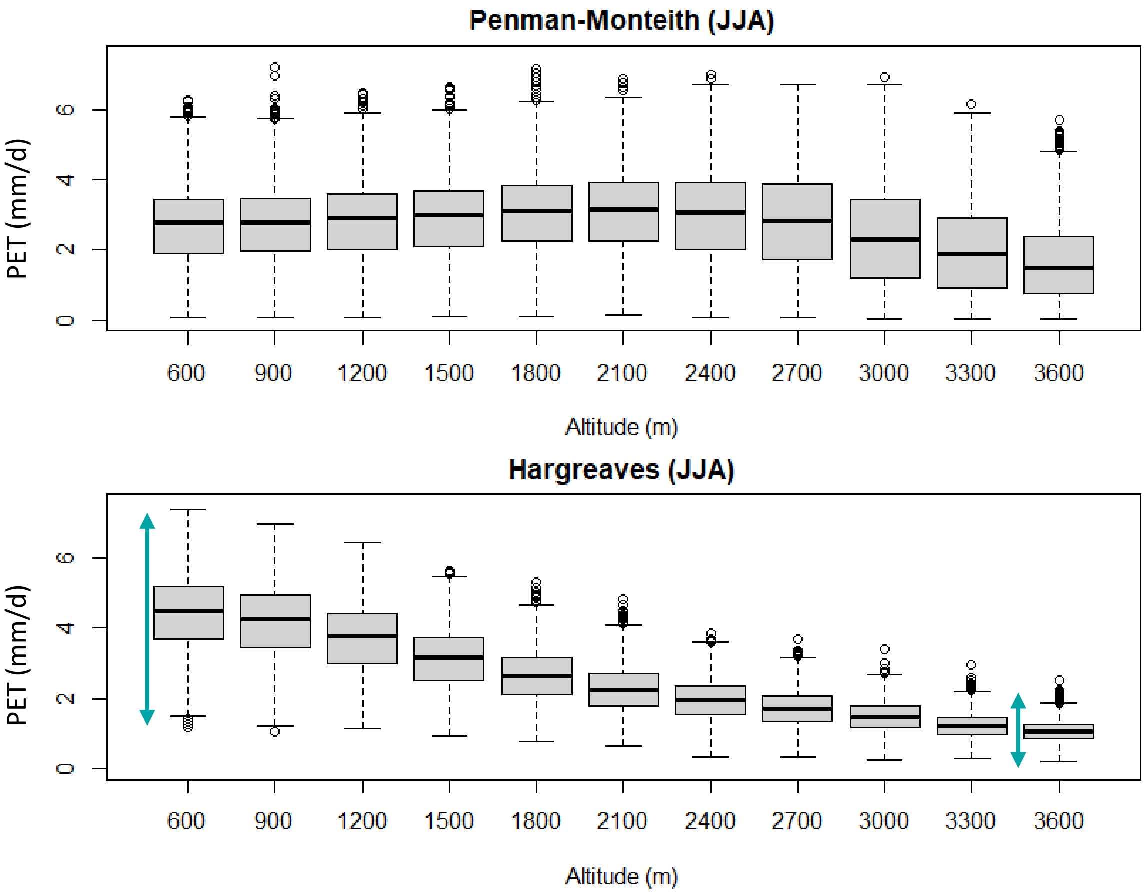
Evolution by altitude bands over 1958-2018 (summer)



- 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 Hargreaves, dispersion decreases with altitude.

PET of Penman-Monteith and Hargreaves

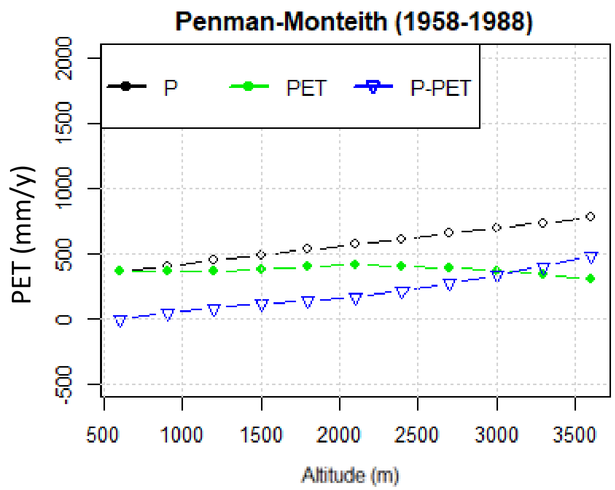
Evolution by altitude bands over 1958-2018 (summer)

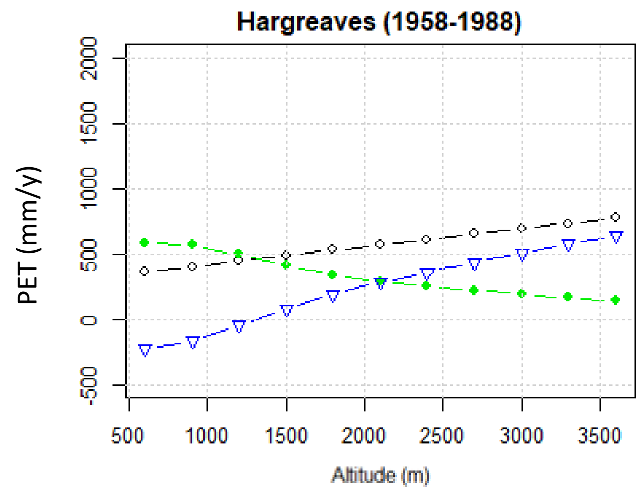


- P-M: mean PET increase from 600 m.a.s.l to 2100 m.a.s.l and then decrease.
- Hargreaves : decrease of PET with altitude.
- At 600 m.a.s.l, 3 mm/d (P-M) and 4.5 mm/d (Hargreaves) for PET average.
- At 2100 m.a.s.l, 3.5 mm/d (P-M) and 2.5 mm/d (Hargreaves) for PET average.
- For PET Hargreaves, dispersion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

Water balance: precipitations, PET, P-PET

Mean values over 30 years



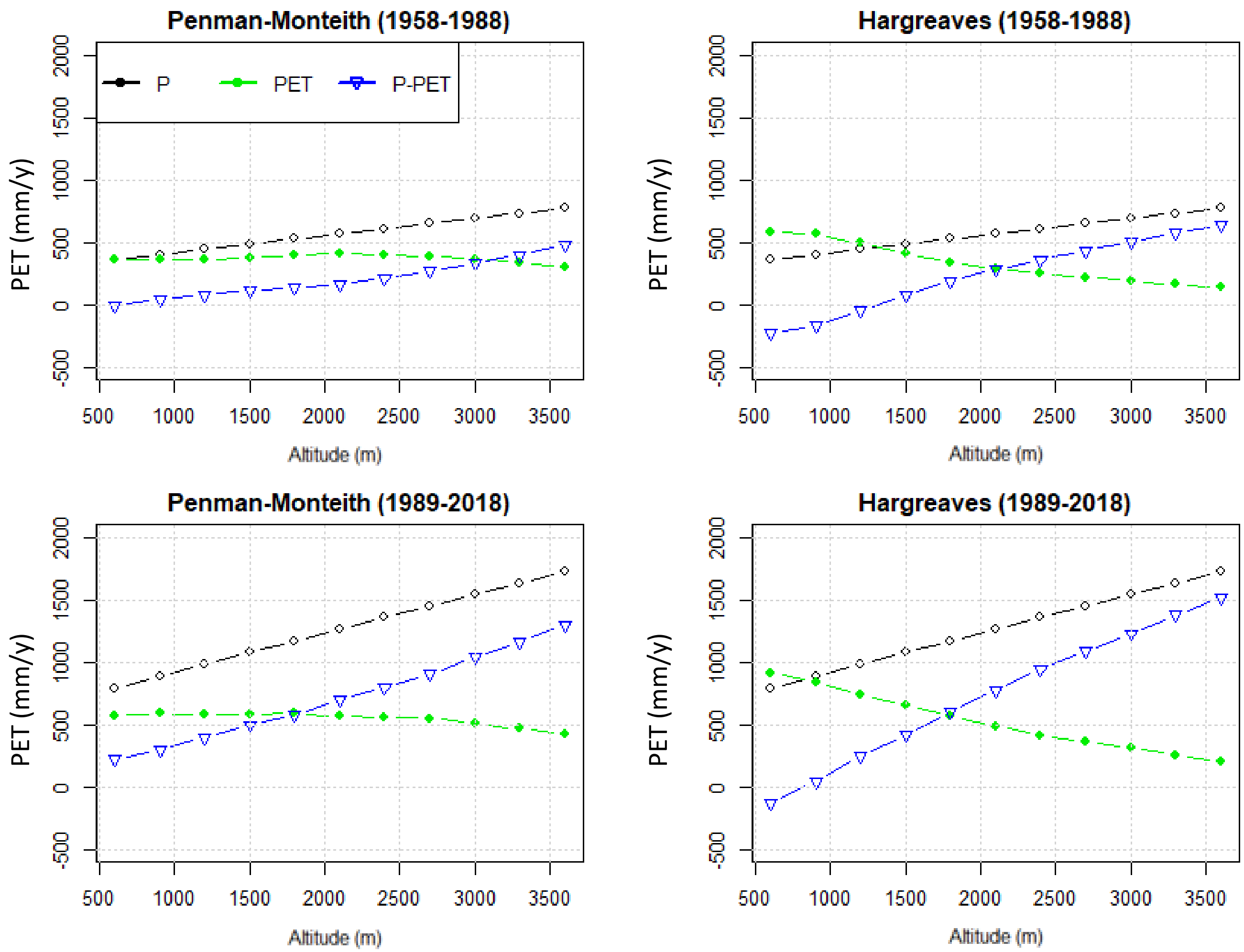


- With Hargreaves, PET stronger at low altitudes than P-M and it is the opposite for high altitudes.
- At low altitudes, there is a water deficit with the Hargreaves formulation.

- 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

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 Hargreaves.

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.

This work is funded by the project BERGER, which is part of Pack Ambition Recherche supported by the Auvergne-Rhône-Alpes region.

La Région
Auvergne-Rhône-Alpes

INRAE

UGA
Université Grenoble Alpes

IGE

METEO FRANCE

CNRM