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hydroPASS: a newly developed R package to go through the regional calibration of distributed catchment models

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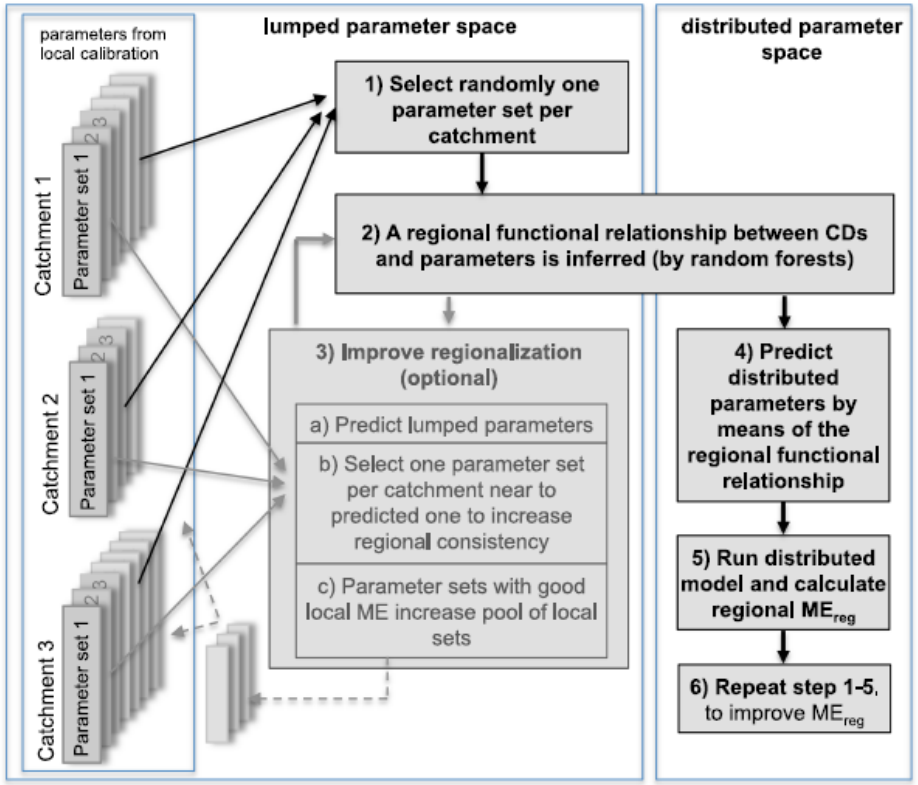
Where we started



Flowchart of PASS *(Merz et al.*, 2020).

PArameter Set Shuffling (PASS) procedure

Pros:

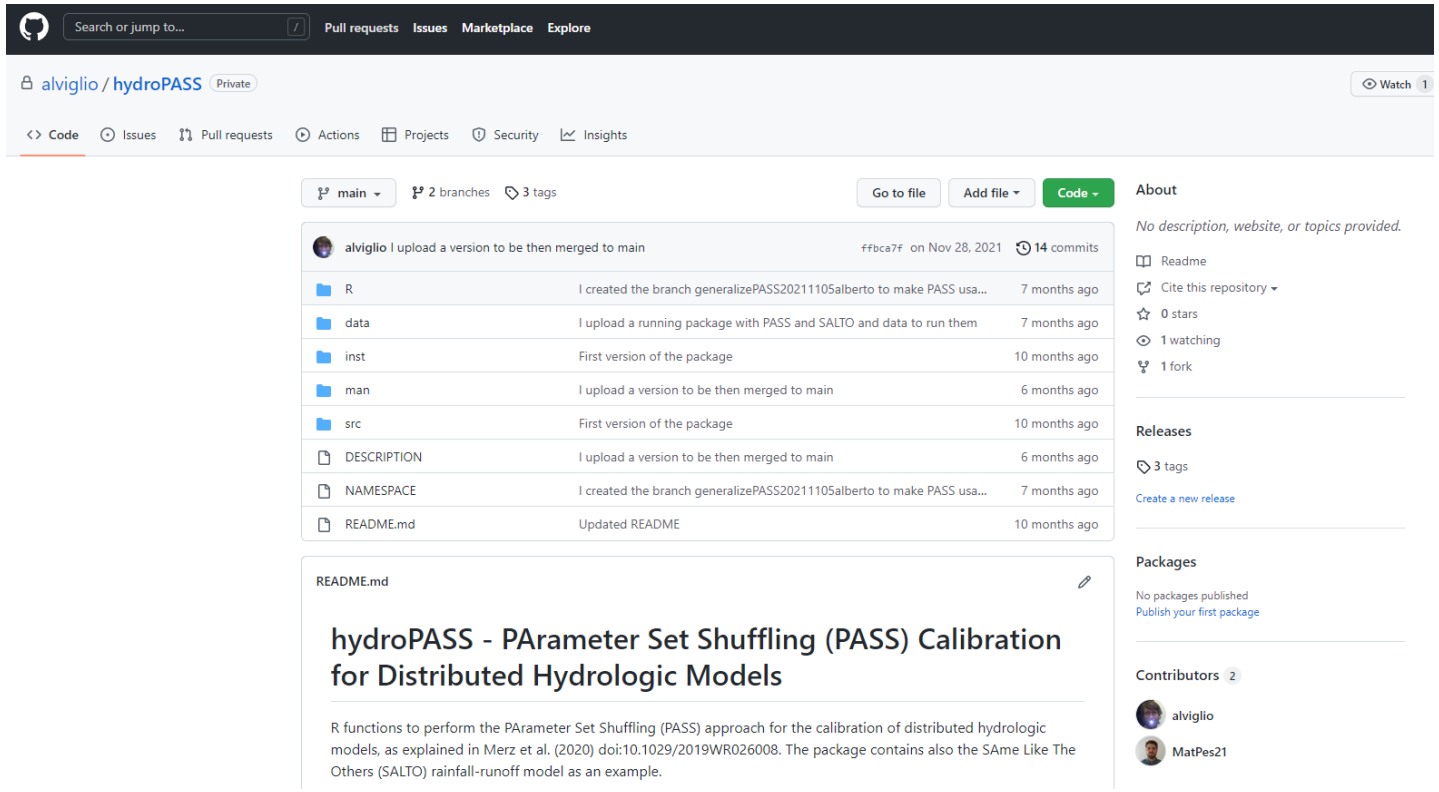
- It is **not required** any **a priori assumption** on the relationship between parameters and descriptors;
- Use of different **machine learning** algorithms (e.g., Random Forest, Decision Tree, Artificial Neural Network (ANN)).

Drawbacks:

- **Lack** of a **workflow** for a consistent and reproducible application of the method;
- **Limited application** to other study **areas**, having different physical characteristics (e.g., the Alpine Region), and with other **hydrologic models**.

Necessity of organizing code and data into a single framework

A new R package: hydroPASS



The source package contains:

- General information about the package (e.g., version, authors, etc.);
- The **src/** directory with the fortran code for the model SALTO;
- The **R/** directory with the R code for the functions SALTO, SALTOsetup, PASS;
- The **data/** directory with some data for the examples provided as help for each function;
- The **man/** directory with the help documents for all the code and data.

source package → **installation packages** for Windows, Linux and Mac operating systems

A new R package: hydroPASS

Actual Version: 0.0-beta.7

Function **load.Data**

Input :

- **NetCDF** files of precipitation, temperature, potential evapotranspiration, catchments descriptors and a digital elevation model;
- **Text** files of daily discharge;
- **Shapefile** of catchment boundaries.

Output:

- **.RData** file with all the data arranged for running the SALTOsetup function.

Function **SALTOsetup**

Input :

- **.RData** file produced with load.Data.

Output:

.RData file containing:

- Climate data, discharge and catchment descriptors, arranged for running SALTO or other models;
- Topology of catchments (see SALTO function).

```
List of 4
 $ prec: num [1:21915, 1:500] 0.945 2.84 2.016 12.965 0.331 ...
  ..- attr(*, "dimnames")=List of 2
  .. ..$ : chr [1:21915] "1961-01-01" "1961-01-02" "1961-01-03" "1961-01-04" ...
  .. ..$ : chr [1:500] "1" "2" "3" "4" ...
 $ temp: num [1:21915, 1:500] 2.81 3.63 5.09 2.98 1.96 ...
  ..- attr(*, "dimnames")=List of 2
  .. ..$ : chr [1:21915] "1961-01-01" "1961-01-02" "1961-01-03" "1961-01-04" ...
  .. ..$ : chr [1:500] "1" "2" "3" "4" ...
 $ pet : num [1:21915, 1:500] 0.59 0.666 0.802 0.606 0.51 ...
  ..- attr(*, "dimnames")=List of 2
  .. ..$ : chr [1:21915] "1961-01-01" "1961-01-02" "1961-01-03" "1961-01-04" ...
  .. ..$ : chr [1:500] "1" "2" "3" "4" ...
 $ qobs: num [1:21915, 1:117] NA NA NA NA NA NA NA NA NA NA ...
  ..- attr(*, "dimnames")=List of 2
  .. ..$ : chr [1:21915] "1961-01-01" "1961-01-02" "1961-01-03" "1961-01-04" ...
  .. ..$ : chr [1:117] "1" "2" "3" "4" ...
```

```
$ cat: num [1:117, 1:79] 4.41 4.13 3.5 2.53 3.07 2.56 2.56 2.62
 ..- attr(*, "dimnames")=List of 2
 .. ..$ : chr [1:117] "1" "2" "3" "4" ...
 .. ..$ : chr [1:79] "CL_dRD2D" "CL_MAP" "CL_MAT" "CL_PET" ...
$ grd: num [1:500, 1:79] 2.91 2.91 2.91 2.92 2.92 ...
 ..- attr(*, "dimnames")=List of 2
 .. ..$ : chr [1:500] "1" "2" "3" "4" ...
 .. ..$ : chr [1:79] "CL_dRD2D" "CL_MAP" "CL_MAT" "CL_PET" ...
```

```
'data.frame':   7 obs. of  4 variables:
 $ grd    : num  142 143 166 167 168 192 193
 $ effarea: num  0.3758 0.0102 0.0415 0.6628 0.2725 ...
 $ flowto : num  168 168 192 193 193 193 -99
 $ level  : num  1 1 1 1 2 2 3
```

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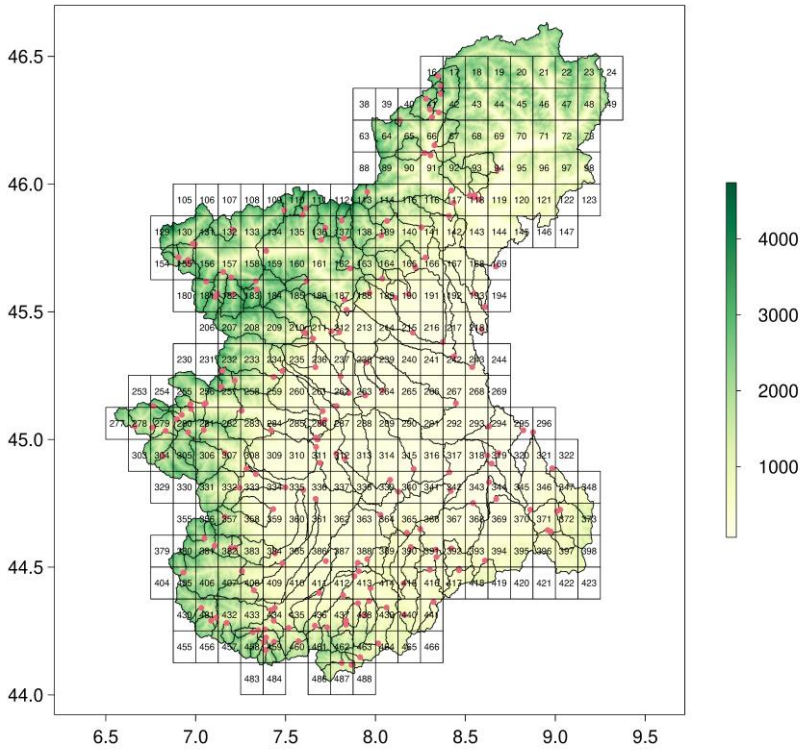
PASS — Model Efficiency Function — SALTO, TUWmodel, ….

Application to real case studies

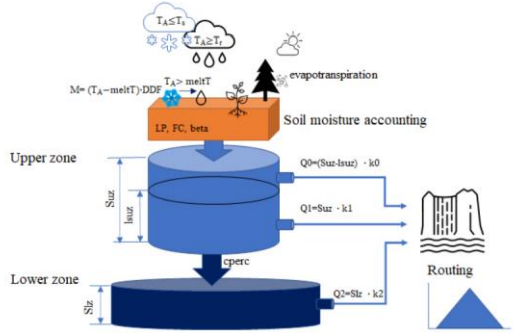


Stream gauges, catchment boundaries and pixels with climate inputs of Piemonte and Valle d'Aosta. The background shows elevation (m.a.s.l.).

```
> library(TUWmodel)
> ?TUWmodel


> # Model efficiency function (i.e., objective function)
> ME.TUWmodel <-
+   function(param,      # vector or matrix parameters for catchment i
+            cat.number, # number of catchment i
+            grdname,    # list of grid names associated to all catchments
+            prec,       # matrix of precipitation data for all grids
+            airt,       # matrix of air temperature data for all grids
+            ep,         # matrix of potential evapotranspiration...
+            area,       # list of proportion of catchment area contained
+                        #  in each grid for all catchments
+            disc,       # matrix of runoff discharge for all rivers
+            snow,       # matrix of snow cover for all grids
+            iwarmup=303) {
+   GRDNAME <- grdname[[cat.number]]

+   AREA <- area[[cat.number]]
+   PREC <- prec[, as.character(GRDNAME)]
+   AIRT <- airt[, as.character(GRDNAME)]
+   EP <- ep[, as.character(GRDNAME)]
+   DISC <- disc[, cat.number]
+   SNOW <- snow[, as.character(GRDNAME)]
+   if (!is.null(dim(param))) param <- t(param)
+   # global variables are in the function
+   simu <- TUWmodel(prec=PREC, airt=AIRT, ep=EP,
+                    area=AREA, param=param)
+   swesim <- (simu$swe > 1)[-c(1:iwarmup),]
+   sweobs <- (SNOW > 10)[-c(1:iwarmup),]
+   # Snow Cover Efficiency
+   SC <- mean(1 - apply(abs(swesim - sweobs), 1, mean, na.rm=T), na.rm=T)
+   # Runoff Kling-Gupta Efficiency
+   simu <- simu$q[-c(1:iwarmup)]  # remove the warming period
+   simu[is.na(simu)] <- -999
+   obse <- DISC[-c(1:iwarmup)]  # remove the warming period
+   r <- cor(simu, obse, method='pearson', use='pairwise.complete.obs')
+   beta <- mean(simu)/mean(obse, na.rm=TRUE)
+   gamma <- (sd(simu)/mean(simu))/(sd(obse, na.rm=TRUE)/mean(obse, na.rm=TRUE))
+   kgeQ <- 1 - sqrt((r - 1)^2 + (beta - 1)^2 + (gamma - 1)^2)
+   me <- 0.5*kgeQ + 0.5*SC  # mean of Runoff Kling-Gupta Efficiency
+                            #  and Snow Cover Efficiency
+   if (is.na(me)) me <- -999
+   return(me)
+ }
```



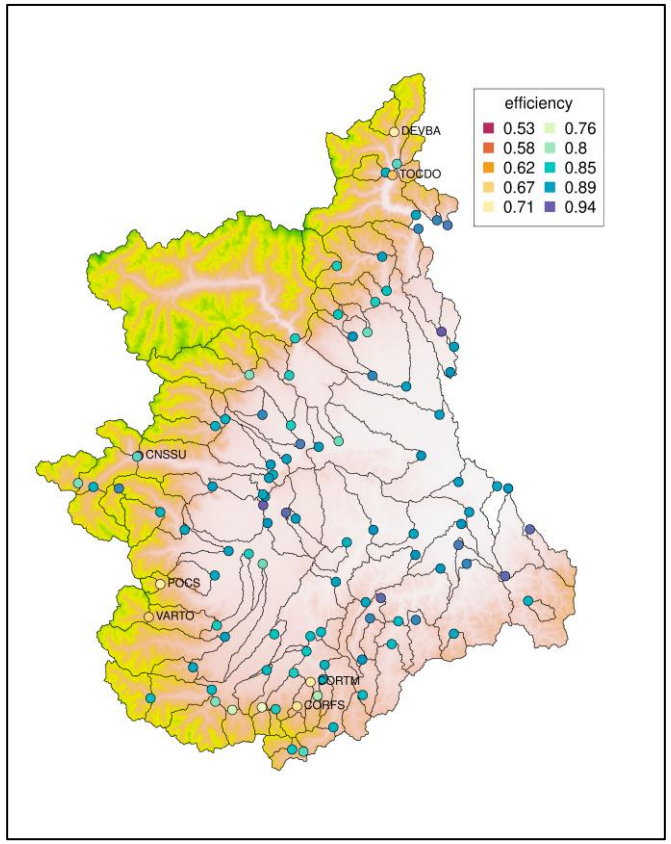
Conceptual description of TUWmodel *(Tong et al.*, 2021).

```
> # Running PASS
> run01 <- PASS(Y=train.parameters,
+               X.cat=cat.CD,
+               X.grd=grd.CD,
+               grd2cat=sapply(topology, function(x) x$grd.name),
+               model.eff.fn=ME.TUWmodel,
+               lower=c(SCF=0.9, DDF=0.0, Tr=1.01, Ts=-3.0, Tm=-2.0,
+                       LPrat=0.0, FC=0.0, BETA=0.0, k0=0.0, k1=2.0, k2=30.0,
+                       lsuz=1.0, cperc=0.0, bmax=0.0, croute=0.0),
+               upper=c(SCF=1.5, DDF=5.0, Tr=3.0, Ts=1.0, Tm=2.0,
+                       LPrat=1.0, FC=600.0, BETA=20.0, k0=2.0, k1=30.0, k2=250.0,
+                       lsuz=100.0, cperc=8.0, bmax=30.0, croute=50.0),
+               options=PASS.options(maxLoops=100, nGroups=10,
+                                    REGloops=5, sampling='random'),
+               prec=data118cat305px1$prec,
+               airt=data118cat305px1$tmean,
+               ep=data118cat305px1$pet,
+               area=sapply(topology, function(x) x$grd.weightCat),
```

Key point: flexibility

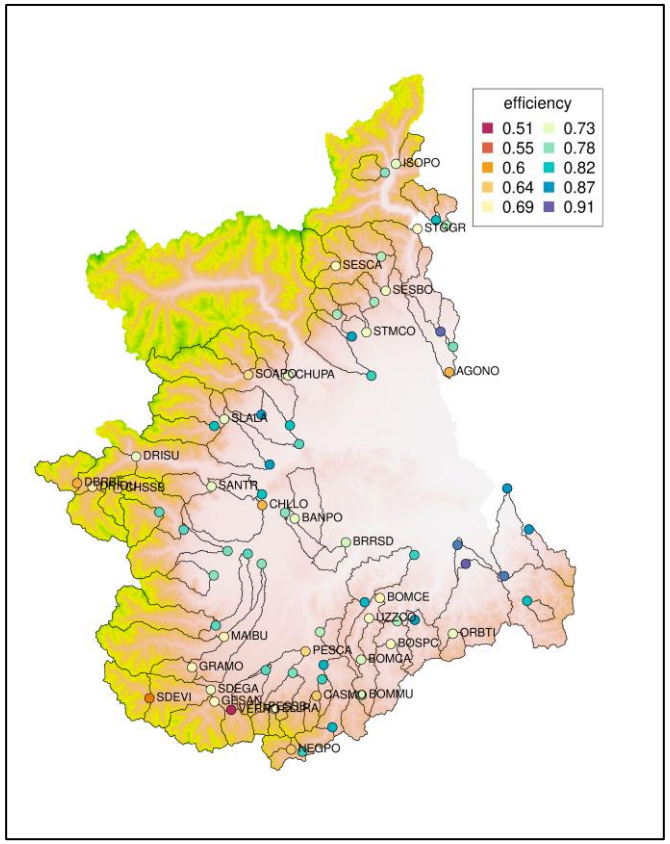
PASS in Northwestern Italy

Local calibration (2000-2010)

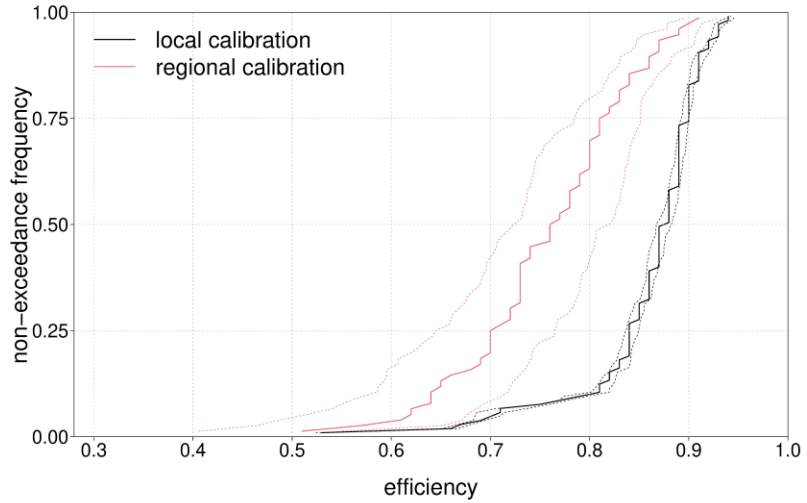


Local model efficiency for **104 sites**. The codes of sites where ME < 0.75 are indicated.

Regional calibration (2000-2010)



Regional model efficiency for **75 sites**. The codes of sites where ME < 0.75 are indicated.



Cumulative **frequency function** of model efficiencies (black: **locally calibrated parameters** for 104 sites, red: **regionalised parameters** with PASS for 75 sites).

References

- Merz, R., Tarasova, L. & Basso, S. Parameter's Controls of Distributed Catchment Models - How Much Information is in Conventional Catchment Descriptors?, Water Resources Research, 2020, 56 (2), e2019WR026008.

- Tong, R., Parajka, J., Salentinig, A., Pfeil, I., Komma, J., Széles, B., Kubáň, M., Valent, P., Vreugdenhil, M., Wagner, W. & Blöschl, G. The value of ASCAT soil moisture and MODIS snow cover data for calibrating a conceptual hydrologic model, Hydrology and Earth System Sciences, 2021, 25, 1389–1410.

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