Apport au Léman par précipitation directe

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Design Project n°34,

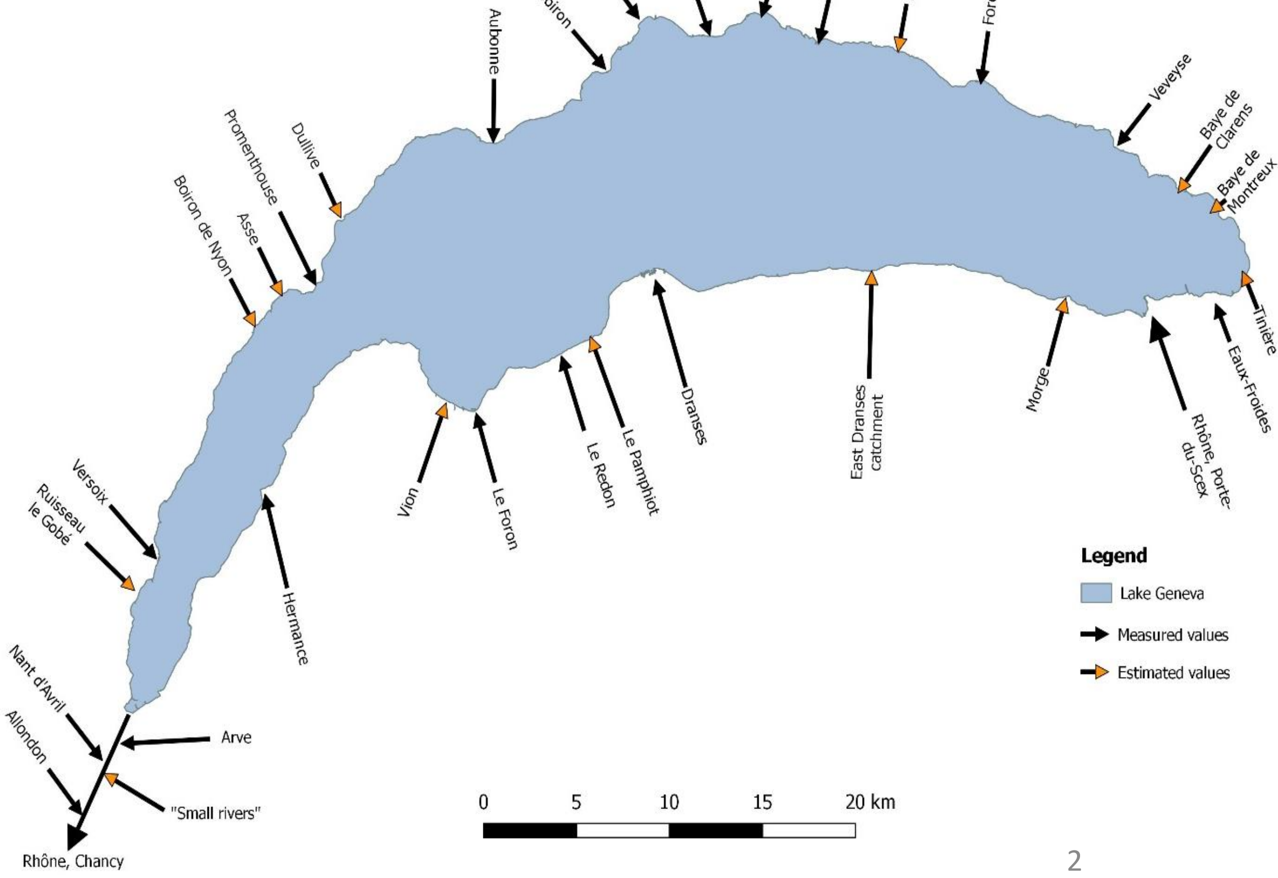
Karpushov Evgeny
Fourrier Alexandre

Supervised by:
Thomet Murielle and Dr. Mutzner Raphaël
Pr. Rinaldo Andrea and Dr. Giezendanner Jonathan

Project goals

- Determiniation of input and output river fluxes.
- Provide a correct estimation of discharge at the outlet of the Lake Geneva.
- Direct precipitation estimation.
- Evaporation determination.
- Determination of evaporation during raining event.

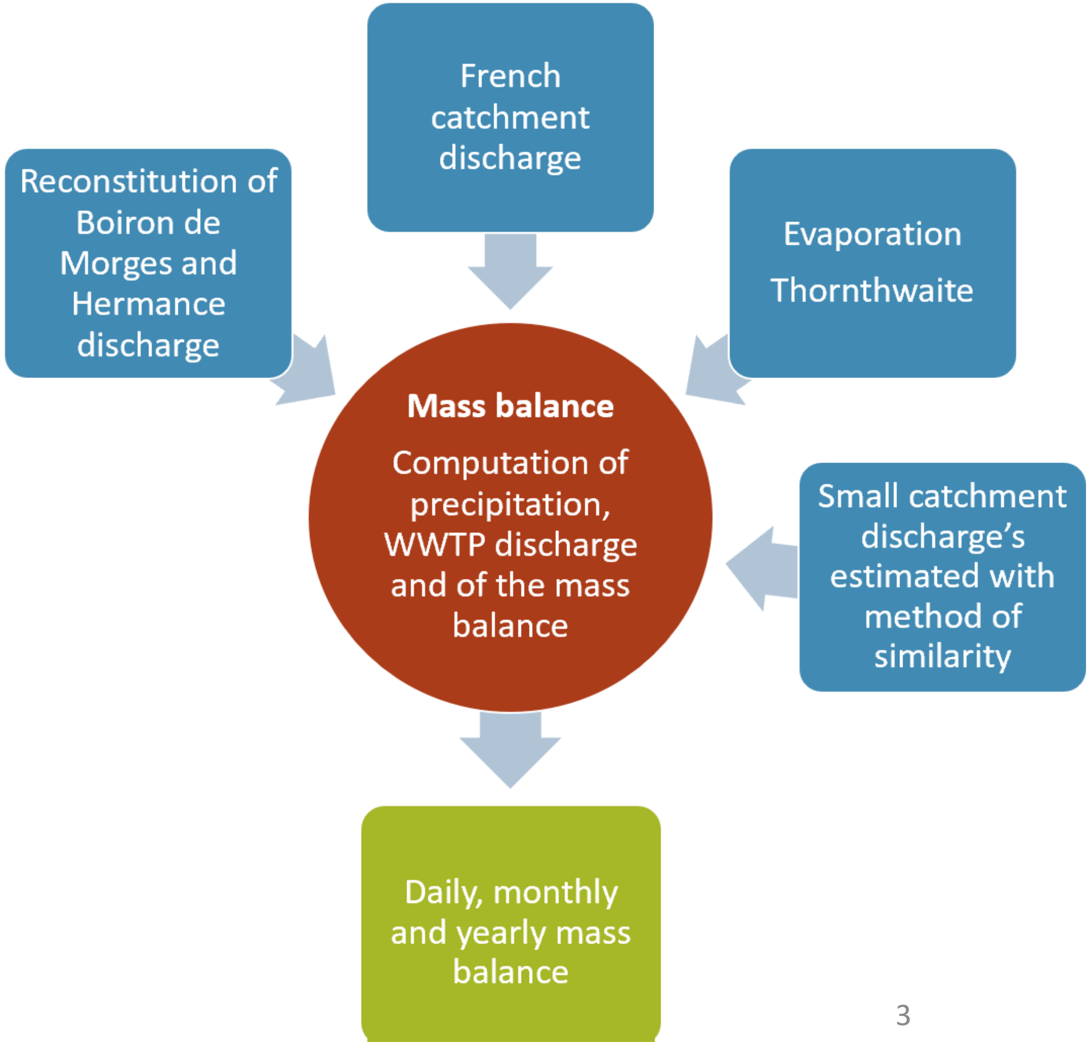
Main influent and effluent of Lake Geneva considered in the mass balance



Method overview

- Mass balance approach: *to determine river fluxes in and out of Lake Geneva.*
- Kriging with an External Drift: *to interpolate precipitation value over lake area.*
- Thornthwaite formula & Inverse Distance Weighting: *to estimate and interpolate evaporation.*

Structure of the MATLAB code:



Unmeasured discharge determination, similarity

- Based on two majors hypothesis:
  - Two catchments have the same specific discharge if they have similar:
    - area
    - mean precipitation
    - land cover
    - mean distance between any point of the watershed and the stream ($dist_{mean}$)
  - Linear relationship between precipitation and specific discharge.

$$q_{specific,j}(t) = \frac{Q_j(t)}{A_{catchement_i}}$$

- Indice J refers to the watersheds and river with a measuring station.
- Indice I refers to the watersheds and river without measurement.

Unmeasured discharge determination, similarity

- Attribute specific disharge $q_{spe,j}$ to a watersherds with a river i similar to the watersheds j
- Using a similarity index depending on land cover, watershed area and $dist_{mean}$, for catchment > 10 km^2.
- Using a similarity index depending on watershed area and $dist_{mean}$, for catchment < 10 km^2.
- Correction of calculated specific discharge multiplying by a ratio of mean precipitation fallen on watershed i divided by the mean precipitation fallen on water j.

- $Index_{simil,ij} =$

$$\Sigma_{k=1}^{N} \ min[f_i, f_j]_k * \frac{\min[A_i, A_j]}{\max[A_i, A_j]} * \frac{\min[dist_{mean,i}, dist_{mean,j}]}{\max[dist_{mean,i}, dist_{mean,j}]}$$

$$= \begin{cases} 0, \text{not similar.} \\ 1, \text{similar watershed.} \end{cases}$$

- $q_{spe,i,corr} = q_{spe,i} * \frac{P_i}{P_j}$

Unmeasured discharge determination, nearest neighbour

- Determine specific flows $q_{spe,i}$ stations from a linear combination of the specific discharges $q_{spe,j}$.
  - $q_{specific,i} = \sum_{i=1}^{n} \lambda_{ij} * q_{specific,j}$

- Based on one hypothesis :
  - Nearest streams show similar specific discharges.

- Weights : inversely proportional to the distance between the outlet of the watersheds i and j, with a sum of the weights equal to one :

$$\lambda_{ij} = \frac{\sqrt{\frac{1}{\left(X_i - X_j\right)^2 + \left(Y_i - Y_j\right)^2}}}{\sum_{k=1}^{n} \sqrt{\frac{1}{(X_i - X_k)^2 + (Y_i - Y_k)^2}}}$$

Discharge estimation of Boiron de Morges, Hermance and French side

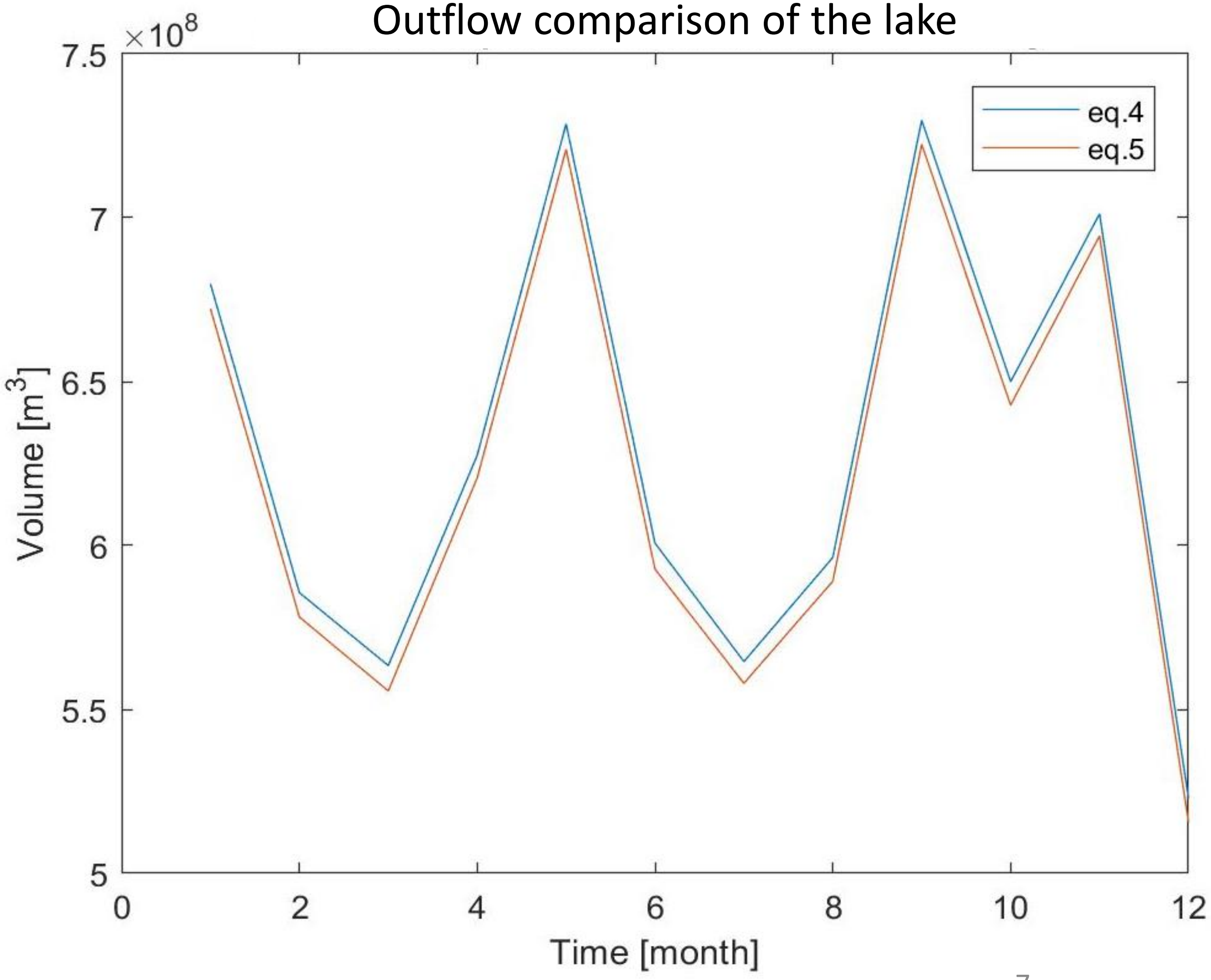
- Boiron de Morge and Hermance: discharge available since 2008 and 2009 only:
  - Reconstitution of 2003 to 2008/2009 discharge with a typical year.

- French side, estimation of Vion, Pamphiot and East Dranse Catchment discharge based on:
  - Values found in litterature (Qspec).
  - Similar size catchment with discharge measuring station.
  - Area ratio.

Mean output discharge of Lake Geneva

- Comparison of two methods:
  - $V_{outgoing,Lake\ Geneva}[m^3] = 97\% * V_{Chancy} - V_{Arve}$ (eq.4)
  - $V_{\ outgoing,Lake\ Geneva}[m^3] = \left(V_{Chancy} - \ V_{Arve} \ - \ V_{Nant\ d'Avril} - \cdots - V_{WWTP} - \ V_{\text{small rivers}} \right) * R$ (eq.5)
    - $R = \frac{A_{BVleman}}{A_{BVChancy} - A_{nant\ d'avril} - A_{small\ rivers} - A_{arve}}$
    - R = 0.9575

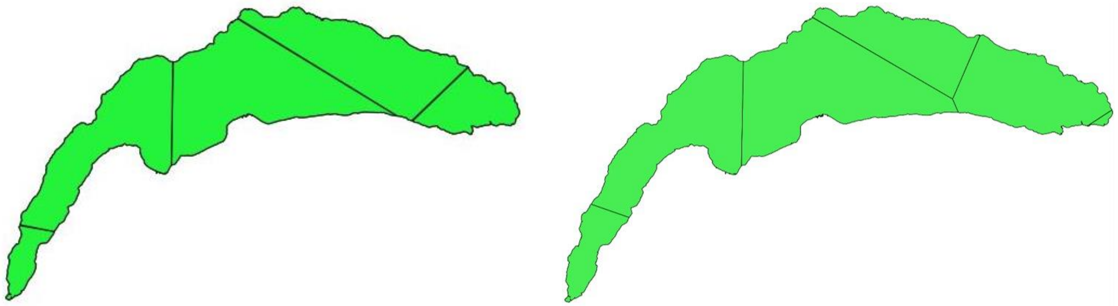
Outflow comparison of the lake



Determination of the direct precipitation over the lake

- Comparison of two interpolation methods:
  - Thiessen Polygon interpolation
  - Kriging (with an external drift) interpolation
- Using meteorological stations of Pully, Evian, Changins, Geneva, Aigle and Vevey (after 2010).
- Estimated at 951mm/year by MétéoSuisse.

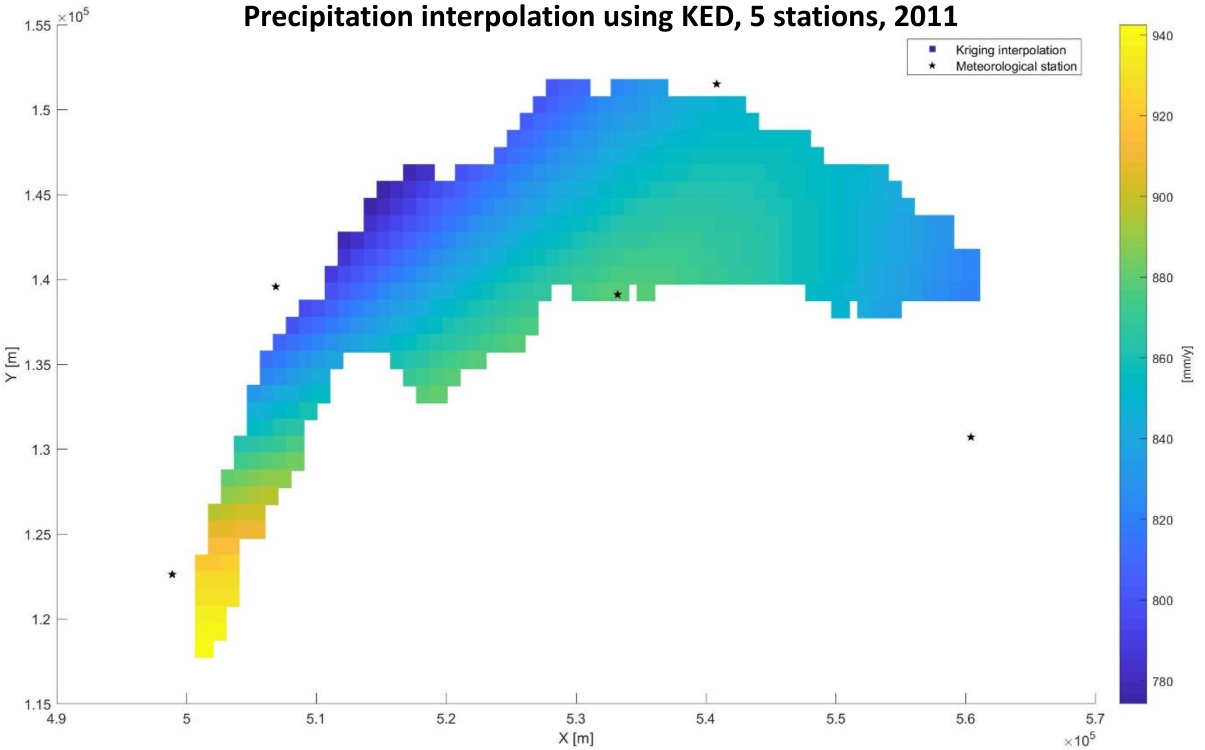
Thiessen polygons



- Beginning of precipitation measurements in Vevey in 2010. Before 31.12.2009: use of 5 Thiessen polygon's, after 01.01.2010: use of 6 Thiessen polygon's.
- Mean yearly Precipitation estimation : **919.7** mm/year .
  - $Precipitation_{on\ lake} = \frac{\Sigma_{j=1}^{n} Precipitation_j * A_j}{\Sigma_{j=1}^{n} A_j}$

Kriging with an external drift (KED)

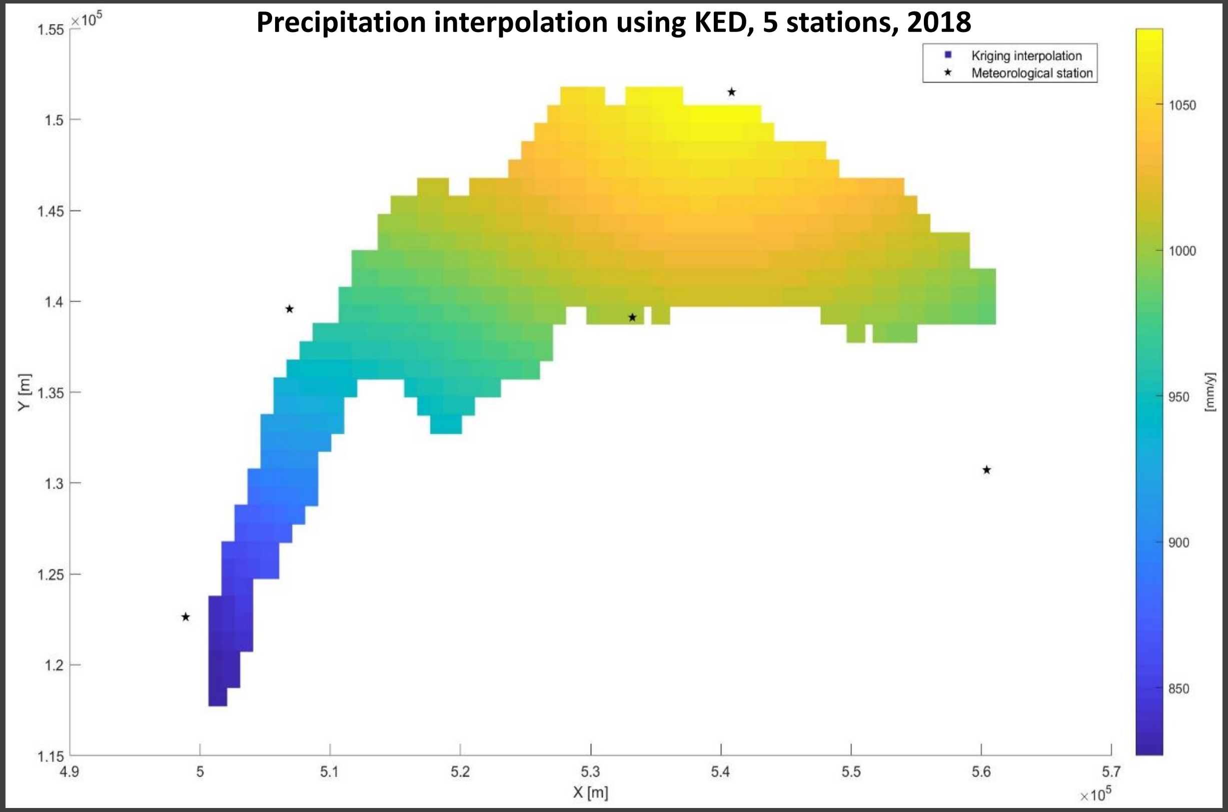
- Variogram model determination (Atkinson and al, 1998):
  - $\gamma(h,\theta) = c_1 * \left(1 - e^{-\left(\frac{h}{a_1(\theta)}\right)^2}\right) + c_2 * \left(\frac{3}{2} * \frac{h}{a_2(\theta)} - \frac{1}{2}\left(\frac{h}{a_2(\theta)}\right)^2\right) \; if \; h < a_2(\theta)$
  - $\gamma(h,\theta) = c_1 * \left(1 - e^{-\left(\frac{h}{a_1(\theta)}\right)}\right) + c_2 \; if \; h > a_2(\theta)$
- Linear relationship between the altitude and the precipitation :
  - $P(x_1, y_1) \approx a_1 * Alt(x_1, y_1) + a_0 = a_1 * S_1^1 + a_0 * S_1^0$
- Weights determination for precipitation interpolation:
  - $P_i = \Sigma_{j=1}^{n} \lambda_{ij} * P_j$
- Mean yearly Precipitation estimation: **985.5**mm/year

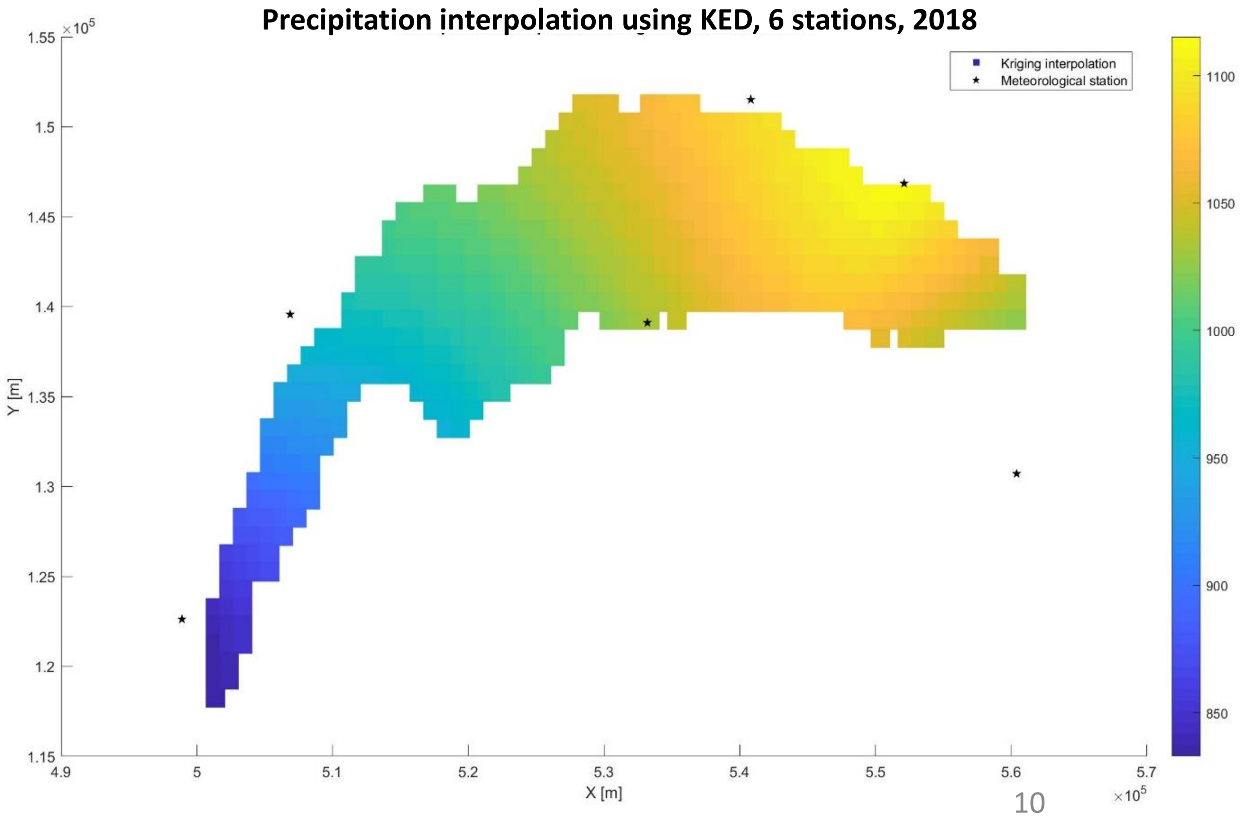


$$
\begin{bmatrix}
\gamma_{11}^Y & \gamma_{12}^Y & \dots & \gamma_{1N}^Y & 1 & S_1^1 & \dots & S_1^L \\
\gamma_{21}^Y & \gamma_{22}^Y & \dots & \gamma_{2N}^Y & 1 & S_2^1 & \dots & S_2^L \\
\vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\
\gamma_{N1}^Y & \gamma_{N2}^Y & \dots & \gamma_{NN}^Y & 1 & S_N^1 & \dots & S_N^L \\
1 & 1 & \dots & 1 & 0 & 0 & \dots & 0 \\
S_1^1 & S_2^1 & \dots & S_N^1 & 0 & 0 & \dots & 0 \\
\vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\
S_1^L & S_2^L & \dots & S_N^L & 0 & 0 & \dots & 0
\end{bmatrix}
\begin{bmatrix}
\lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_N \\ -\nu_0 \\ -\nu_1 \\ \vdots \\ -\nu_L
\end{bmatrix}
=
\begin{bmatrix}
\gamma_{10}^Y \\ \gamma_{20}^Y \\ \vdots \\ \gamma_{N0}^Y \\ 1 \\ S_0^1 \\ \vdots \\ S_0^L
\end{bmatrix}
$$

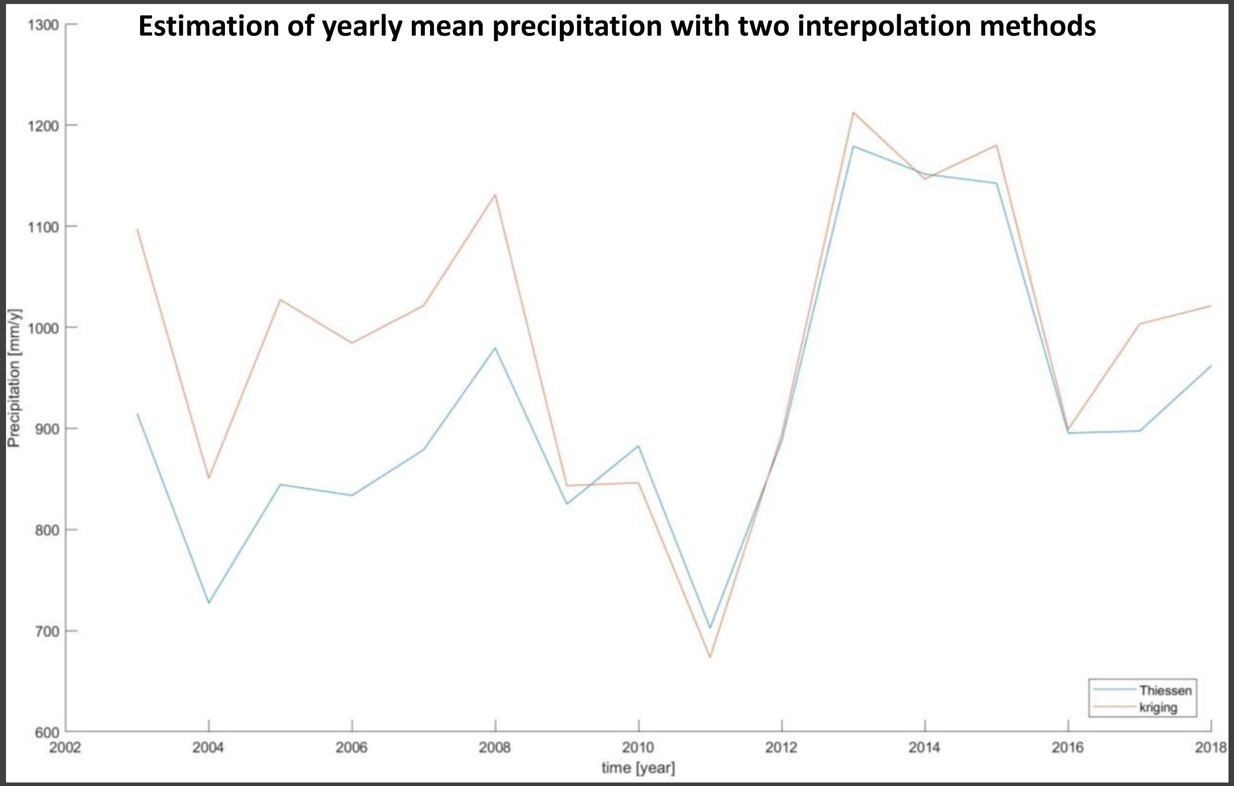
Influence of measurements station in Vevey (Kriging)

- $Yearly\ differences\ for\ a\ point = 0.45\ \frac{mm}{year}$ between 5 and 6 measuring station with Kriging.

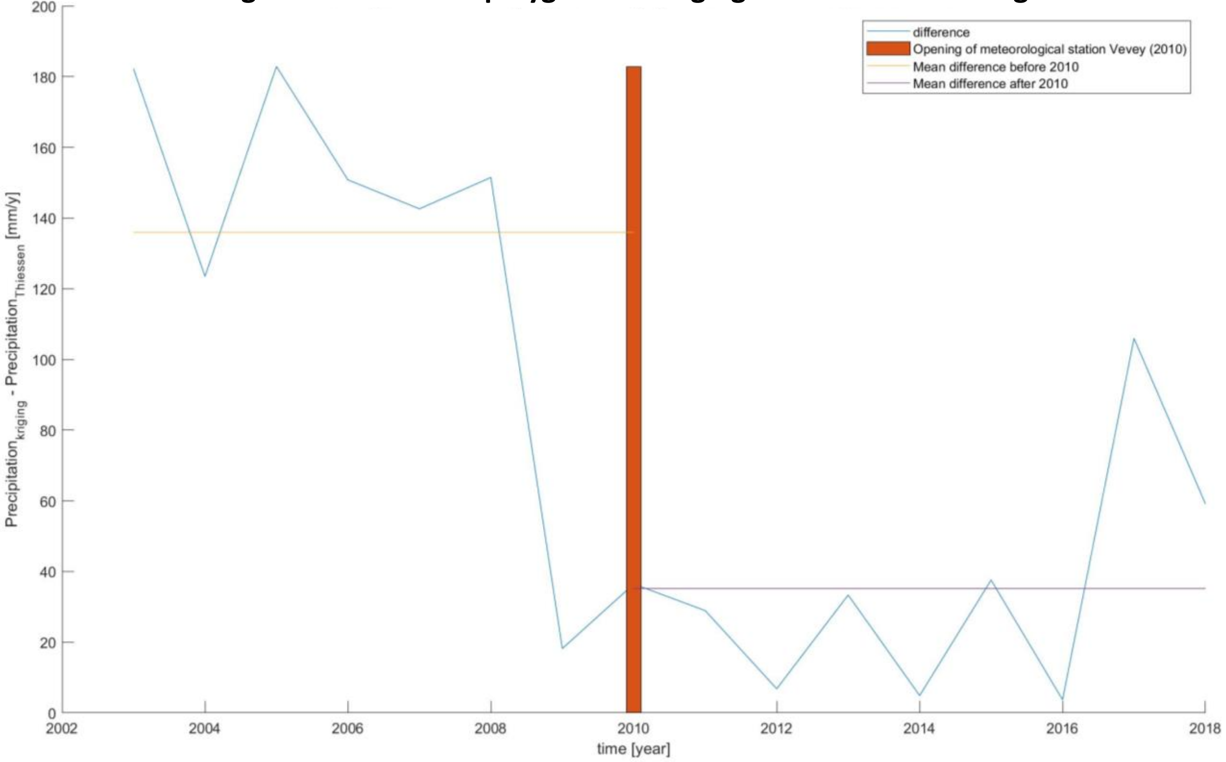




Influence of precipitation measurements in Vevey (2009)



Convergence of Thiessen polygon and kriging with 5 & 6 meteorogicals stations



Precipitation errors estimations

- Each device in the stations has its own incertitudes. In the stations there is two type of rain gauges
- The yearly error on each station is determined.
  - $Error_j = Incertitude_j * (number\ of\ measurement_j > 0.0\ mm)$
- The mean yearly errors precipitation for the lake is calculated for each method :
  - Thiessen :
    - $Error = \frac{\Sigma_{j=1}^{n} Error_j * A_j}{\Sigma_{j=1}^{n} A_j}$
  - Kriging :
    - $Error_i = \Sigma_{j=1}^{n} |\lambda_{ij}| * Error_j$
    - $Error = < Error_i >$

Rain gauges used in each station:

Station	Rain gauges
Genève	Pluvio2
Changins	Lambrecht
Pully	Lambrecht
Vevey	Pluvio2
Aigle	Lambrecht
Evian	Unknown

Rain gauges incertitude ($Incertitude_j$):

Rain gauges	Incertitude
Pluvio2 (OTT HydroMet, 2019)	+/-0.05 mm/ hourly measurement
Lambrecht (Raig, 2020)	+/-0.1mm/hourly measurement or 1% if hourly measurement > 10mm

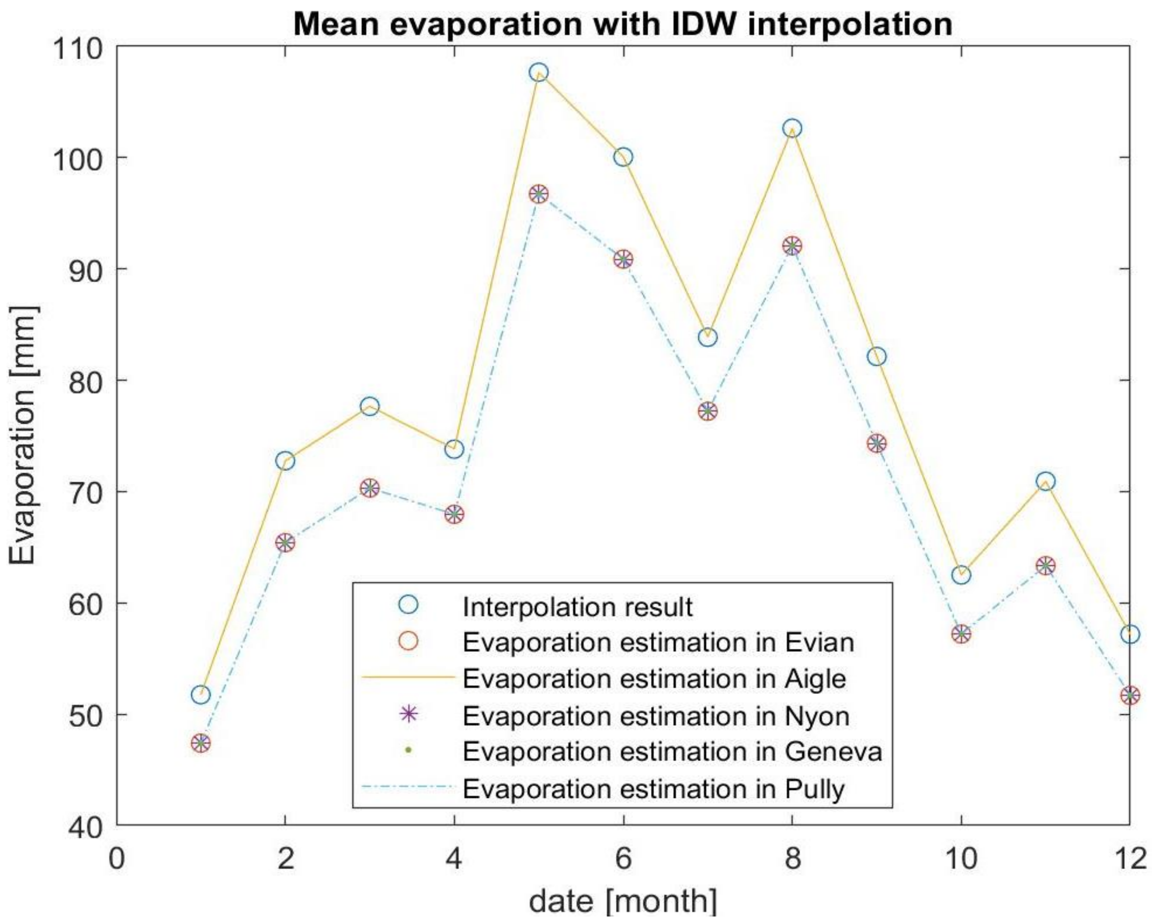
Yearly errors for each method:

Methods	Error
Thiessen	109.26 mm/year
Kriging with an external drift	123.19 mm/year

Methods	Interval for the true value
Thiessen	[866.3; 1112.7]
Kriging with an external drift	[810.4; 1029.0]

Evaporation determination and interpolation

- Using Thornthwaite equation:
  - $ET_0(m) = \frac{16}{12} N_m (\frac{10T_m}{I})^a$
  - $ET_{Lake}(m) = 1.61 * ET_0(m)$
- Interpolated according to Inverse Distance Weighting.
- Mean yearly evaporation estimation: **938** mm/year.
- Estimated at: 950mm/year by Hydrological atlas of Switzerland.



- Mass Balance:
  - $\frac{dV(t)}{dt} * \frac{1}{A_{lake}} = \frac{Q_{out}(t) - Q_{in}(t)}{A_{lake}} - Prec(t) + ET(t)$

Model use	Mass balance closure [mm/y]
Nearest neighbour	113.56
Similitude	9.28

Evaporation during rainfall event

- Based on 4 precipitation events (> 24h & > 0.1mm/h): summer 2012, fall 2015, spring 2017 and winter 2018.
- Comparison of 3 methods: Rohwer, Primault and FAO-Penman.
- Determined in Pully.

- Rohwer:
  - $E_{mm/h} = 0.484(1 + 0.6v)(e_s - e_a)$
- Primault:
  - $E_{mm} = \frac{103 - H_r}{100}(N + 2 * 1/24)$
- FAO-Penman:
  - $ET_0\left[\frac{mm}{h}\right] = \frac{0.408 * \Delta * (R_n - G) + \gamma * \frac{900}{T+273} * u_2 * (e_s - e_a)}{\Delta + \gamma * (1 + 0.34 * u_2)}$

Evaporation during rainfall event

- Ratio $= \frac{Evaporation\ [mm]}{Precipitation\ [mm]} * 100\ [\%]$

- Seasonal trend for all methods.

- Evaporation is:
  - Negligeable: Fall and Winter
  - Important: Spring and Summer

Ratio [%]	Winter	Spring	Summer	Autumn
Rohwer	2.589+/- 0.165	**5.683**+/- 0.294	**15.867**+/- 0.389	7.2107+/- 0.184
Primault	0.818+/-10^{-3}	1.215+/-10^{-3}	3.151+/-10^{-3}	1.913+/-10^{-3}
Penman	0.4719+/- 0.192	**20.247**+/- 1.957	**37.816**+/- 2.822	5.281+/- 0.294

Error estimation

- From measurement:
  - Discharge: $\delta \epsilon\ [5\%\ ;20\%]$

- Propagation of error measurement:
  - Precipitation: $\delta \epsilon\ [12\%\ ;12.5\%]$
  - Evaporation: $\delta \epsilon\ [7.5\%\ ;40\%]$

- From missing data: smoothing effect of interpolation methods.

- From the position of the measuring station: missing catchment area of 172 km^2.

Results

- Mass balance closure: 10mm/y, < 10% of evaporative volume.
- Direct precipitation: 986 mm/y, ~4% difference with MétéoSuisse measurements.
- Evaporation: 938 mm/y, ~1.3% difference with Hydrological Atlas of Switzerland.

Conclusion:

- Coherent inflow and outflow model of Lake Geneva.
- Two models to determine direct precipitation. KED more adapted to the data.
- Rough yearly evaporation estimation.
- Evaporation during a precipitation event:
  - Negligeable in Fall and Winter
  - Important in Spring and Summer

Thank you for your attention !

« La Terre avait été un musée sublime. Par malheur, l'homme n'était pas conservateur. », Sylvain Tesson