STATISTICAL ESTIMATION OF PRECIPITATION OVER FRENCH MOUNTAIN RANGES

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Abstract: The estimation of snow storage and precipitation, essential for managing hydroelectric reservoirs of EDF, still remains subject to considerable uncertainties. EDF-DTG currently seeks to develop some tools for robust interpolations, able to provide a reliable estimate of precipitation and snow water equivalent at any point in mountainous areas. The developed tools are essentially based on the ground sensor network of DTG, which measures precipitations, snow depth and water equivalent over French mountains. In the long term, these tools should make it possible to progress towards a better spatial vision of the daily or "event" precipitation, as well as of the snow cover on the ground, based on measurements taken all over the basins requiring an operational hydrological forecast.

To develop this model, a very large database was collected for the main mountainous areas, gathering precipitation data from France but also Switzerland, Italy and Spain. This tool makes use of a Digital Elevation Model with a mesh of 1×1 km. Since the orographic effect is dominant in the explanation of precipitations in mountain, a linear relation is considered for each pixel to connect precipitation to elevation. This procedure takes into account a specific distance between the target pixel and the measurement points located in its vicinity, whose mode of selection and weighting conditions the quality of the results.

The use of a cross validation made it possible to evaluate the level of accuracy of the model for the Alps, the Pyrenees, and the Central mountains. One can regard the results as very encouraging taking into consideration those obtained by other methods, which is undoubtedly the fact of the local character of this mode of reconstitution.

Keywords: *Precipitation, spatialisation, orographical effect, mountainous areas*

1. DOMMAIN OF STUDY AND DATABASE

The hydropower production concerns of EDF are essentially concentrated in the French mountainous areas. So our approach is developed for the Alps, the Pyrenees and the Massif Central, which are equipped with many hydroelectric facilities. We consider independently these three geographical sub-regions for which we have a DEM (Digital Elevation Model) with a 1 km mesh. The mapping of precipitation will be developed on this DEM, with this resolution scale.

The database is especially derived from the EDF's network, centered on the EDF's facilities. The EDF's network is the densest and the highest network in the French mountainous areas (some stations are higher than 2000 m). This database is supplemented by series of Météo France, as well as Spanish, Italian and Swiss series, in order to limit border effects. The whole of the collected series are daily measurements.

Despite the rather good spatial density of our network, high elevation mountain zones are not actually instrumented. And we know that in this zones precipitations are very variable. To improve precipitation information in mountain zones, we included into this network the snow-rain totalizers NPT (Nivo-Pluviomètres Totalisateurs) operated by EDF in high mountain over the years 1950 to 1975. These stations have measured monthly and seasonal precipitation totals, which could bring crucial information about precipitation distribution at high elevation.

The current available database is composed by 603 series (1948-2005) from EDF, 286 from Météo France, 213 from Meteo Swiss, 383 from ARPA Piemonte (Italy) and 131 from INM (Spain), which are completed with 216 NPT (1957-1973 only).

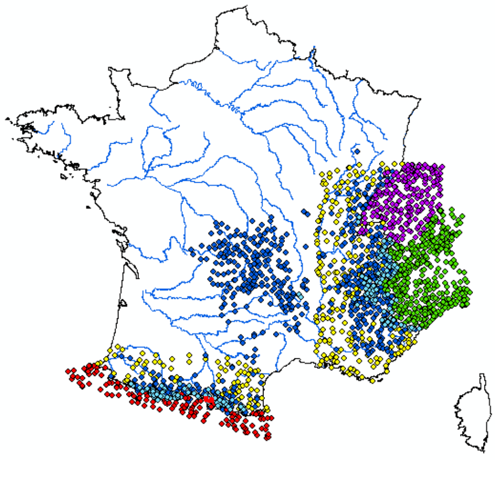


Figure 1: Network of precipitation measurements used

2. THE DEVELOPPED MODEL OF INTERPOLATION OF THE PRECIPITATIONS

Our interpolation model of precipitations has been inspired by PRISM (Precipitation-elevation Regressions on Independent Slopes Model), a model developed by DALY et al. (1994) at Oregon State University for areas of average latitude with dominant orographic effect. This analytical model seeks to estimate monthly and annual precipitations on pixels of a DEM representing the domain at hand. The estimation is based on ground measurement, which provide an actual precipitation on some pixels of the DEM. Orographic precipitations are then analysed through a combination of climatological and statistical considerations, in order to estimate precipitations on all the non-instrumented pixels of the DEM.

2.1 The orographic effect

Generally, precipitations increase with altitude, due to the orographic effect. The developed model tries to approach this relation between precipitations and altitude through a local linear approximation. We seek first for annual or seasonal precipitations P, a relation like:

$$\boxed{P(Z) = A_z . Z + B}$$

where A_z and B are functions of space coordinates $\begin{cases} a = a(X,Y) \\ b = b(X,Y) \end{cases}$

Indeed the orographic gradient of precipitation A_z has significant variations with the place (X,Y) where the approximation is made, according for example with the mountainous area, the slope or the orientation considered. For example, the edges of a mountainous area correspond often to stronger gradients ("barrier" effect on the weather flow), and the inside to weaker gradients, because weather flows are well attenuated.

It is obviously impossible to obtain an analytical expression of the functions A_z and B, taking into account the very significant number of parameters brought into play, and of the complexity of the weather phenomena considered. The relation is thus discretized on the DEM, and the model propose a numerical expression of the precipitation estimated PE_{ij} in any point (i,j) of the DEM :

$$\boxed{PE_{ij} = a_{ij} . Z_{ij} + b_{ij}}$$

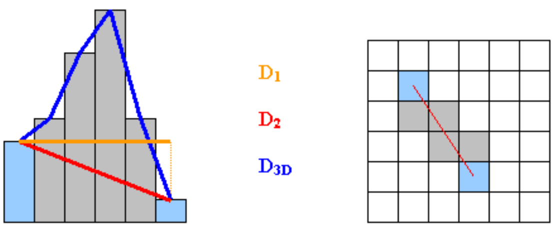
Where Z_{ij} is the altitude of the DEM,

a_{ij} the local orographic gradient and b_{ij} the local intercept value.

The goal of the model is to determine the coefficient a_{ij} and b_{ij} with local linear regression, on a judicious selection of a part of the measured precipitations PO_{kl} located around and closed to the pixel (i,j) considered.

2.2 Selection and weighting method for the neighbouring stations

A subset of neighbouring stations of proximity are selected in the vicinity of each pixel (i,j) on the DEM in order to estimate the coefficients a_{ij} and b_{ij}. The stations are selected according to a "crossing distance" d_{3D} that separates them from the target pixel. This "crossing distance" takes in consideration the horizontal Euclidian distance station-to-pixel, but also a vertical component related to the crossing of crests and valleys. An exhaustive definition of the "crossing distance" is given on the Figure 2.



$$d_1 = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$$

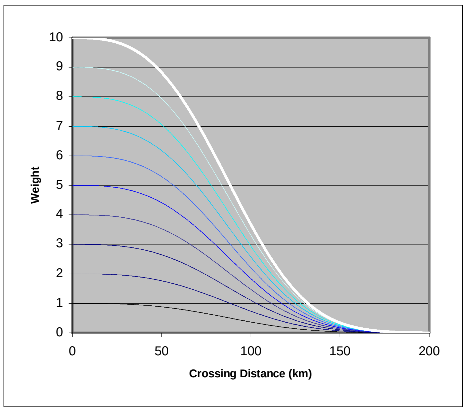
$$d_2 = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2}$$

$$\boxed{d_{3D} = \sum_{\text{crossed pixels } i} \sqrt{(\Delta x_i)^2 + (\Delta y_i)^2 + (ech \times \Delta z_i)^2}}$$

Where *Ech* is a scaling factor of amplification on the elevation

Figure 2: The Crossing Distance and different ways to estimate a distance between two pixels.

A station is selected and considered as explanatory if the crossing distance, which separates it from the pixel, is lower than a fixed limit d_{lim}. When the station is selected, it receives a weight W, in order to give it more or less weight in the linear regression. The weight of the station is given by the entire part of the function f, the "bell of selection".



The selection and weighting operation are carried out in practice into the same step using that we called a "bell of selection" of equation:

$$f(d_{3D}) = \lambda.\exp\left(\left(\frac{d_{3D}}{d_0}\right)^{\alpha}\right)$$

λ, α and d_0 are adjustment parameters :

- λ to adjust the range of the values of weightings,
- α to adjust the form of weighting
- d0 to determine the limit of the distance of the selection

Figure 3: The bell of selection with different values of λ (α and d0 fixed).

2.3 Validation of interpolations

The cross validation is used to estimate the quality of the interpolations of the model. Thus we have for each observed precipitation P_{obs} an interpolated precipitation P_{int} independently from P_{obs}. If n is the total number of observed and cross-validated precipitation, one is able to define these three coefficients, which quantify the quality of an interpolation:

The Bias B

$$B = \frac{\mu_{P_{int}(n)}}{\mu_{P_{obs}(n)}}$$

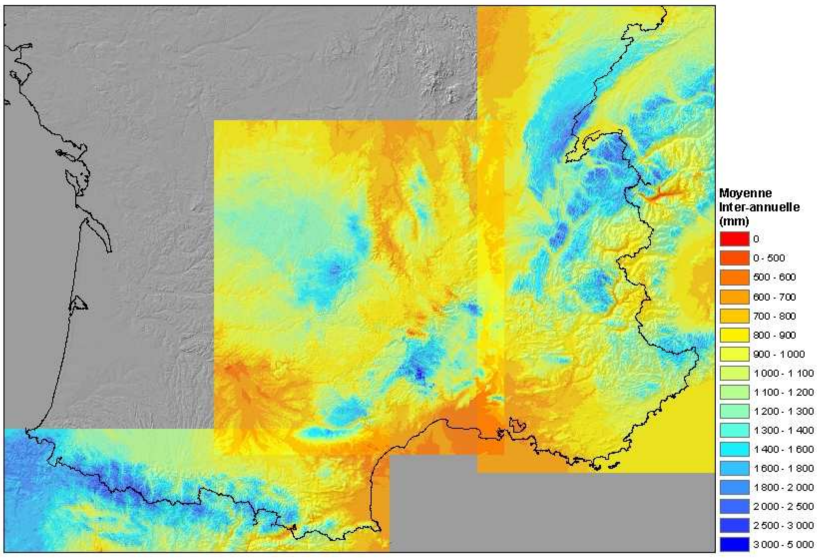
The RMSE

$$E^2 = \frac{\sum_{i=1,n}\left(P^i_{obs} - P^i_{int}\right)^2}{n}$$

The coefficient of NASH

$$D^2 = 1 - \frac{\sum_{i=1,n}\left(P^i_{obs} - P^i_{int}\right)^2}{\sum_{i=1,n}\left(P^i_{obs} - \mu_{P_{obs}(n)}\right)^2}$$

3. MAP OF INTERANNUAL MEANS OF PRECIPITATION ON THE 1957-1973 PERIOD



<u>Cross Validation</u>

The Alp

B	=	0.99
E	=	141 mm
D²	=	0.75

The Pyrenees

B	=	1.01
E	=	254 mm
D²	=	0.62

The Massif Central

B	=	0.99
E	=	167 mm
D²	=	0.73

Figure 4: Inter-annual means of precipitation (1957-1973) for the Alp, the Pyrenees and the Massif Central.

4. DAILY INTERPOLATION

4.1 Perspectives: guess fields and weather types

The final objective is to reach the daily time step, in order to produce daily maps for the historical datas but also for every day in real time. The spatial density of the measurement network available on the French mountainous areas is very variable over the last fifty years. The 1957-1973 years seems to display a maximum of density. Today, the network has been reduced, and it appears unrealistic to generate precipitation maps using only the existing observations.

The introduction of guess fields is necessary. The idea is to use the daily structure of the precipitation field identified on a better-instrumented period, to try as well as possible a reconstitution of the current day by wrapping this structure on observed precipitations. A layer of residual kriging is then carried out to correct the variations between the observed point and their counterpart on the guess field:

$$P_{\text{int}}^{ij} = P_{otl}^{ij} + \sigma_{P\,krg}^{ij}$$

Where P_{int}^{ij} is the interpolated precipitation of the pixel (i,j), P_{otl}^{ij} is the estimated precipitation with the guess field and $\sigma_{P\,krg}^{ij}$ the kriged residual.

In order to produce these guess fields, we are considering a classification into daily weather patterns. The classification retained is that established at EDF (PAQUET et al. 2006) because of it is used in other applications of EDF, and was developed specifically for the needs of DTG. This classification contains eight weather patterns identified by the shape of the 700 hPa and 1000 hPa geopotential fields:

- Class 1: Atlantic wave
- Class 2: Stationary Atlantic flow
- Class 3: Circulation of Southwest
- Class 4: Circulation of South
- Class 5: Circulation of Northeast
- Class 6: Westward
- Class 7: Central low-pressure
- Class 8: Anticyclone

It allows generating eight maps of inter-annual mean of precipitation for each weather pattern. These maps have a specific daily mean structure and can be used as a guess once scaled or distorted appropriately. Each day is associated with a weather pattern and the associated outline.

4.2 First results

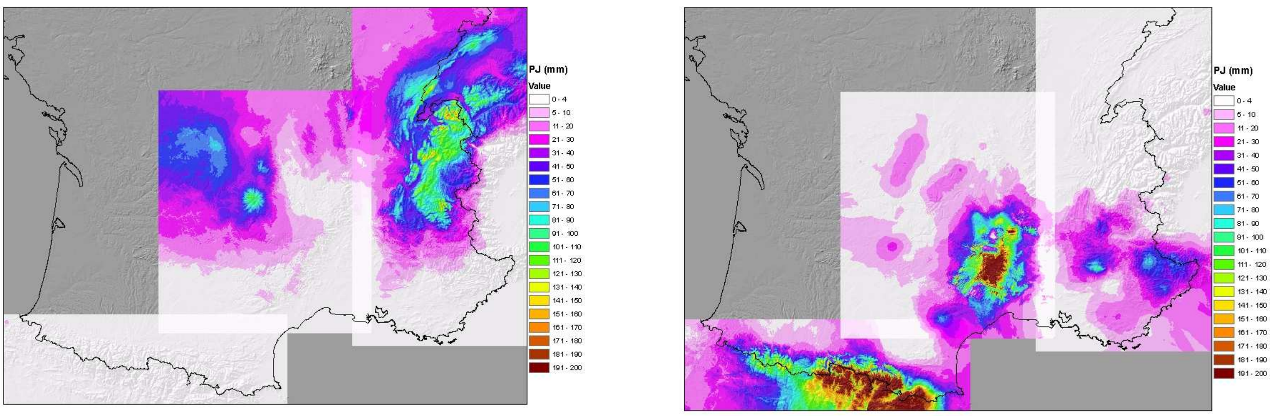


Figure 4: Daily map: the 26th November 1983 (Class 2) on the left and the 7th November 1982 on the right (Class 4).

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