RECONSTRUCTION OF A REALISTIC RAINFALL FIELD:
AN APPLICATION TO AN EXTREME EVENT IN ITALIAN PRE-ALPS

POLITECNICO MILANO 1863

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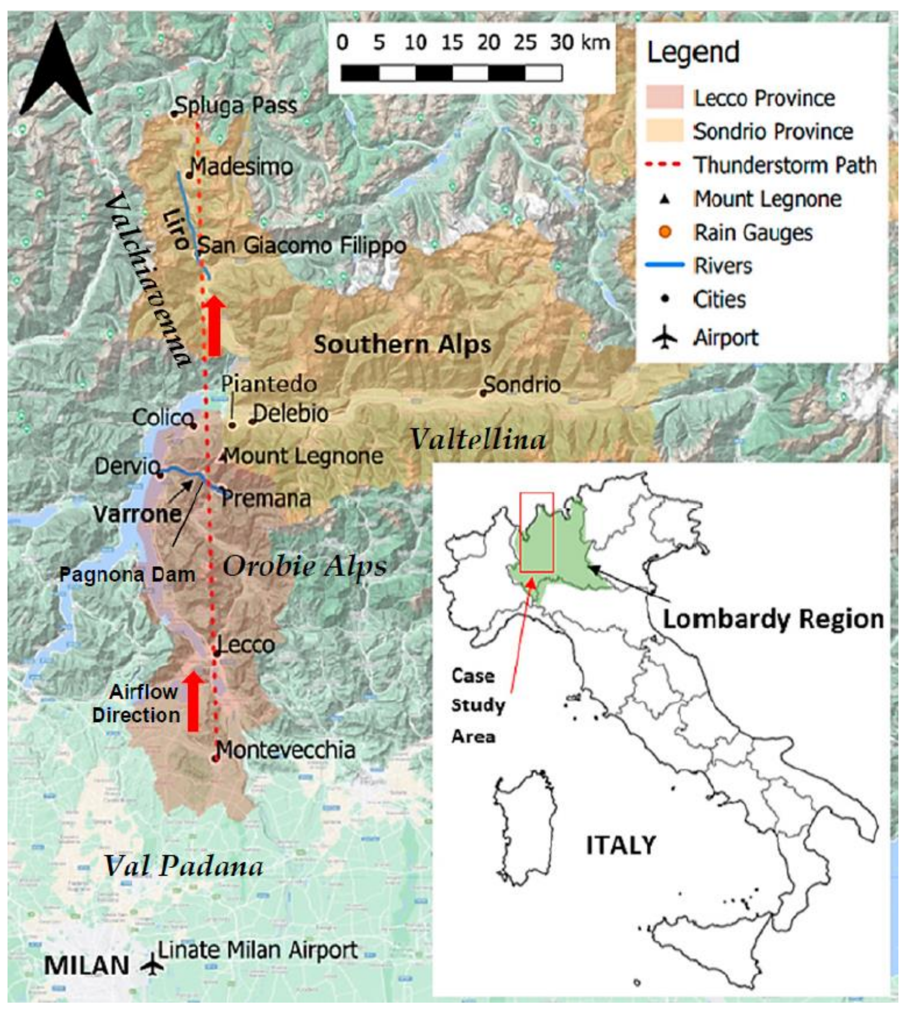
The Case Study of 11–12 June 2019

During the night between 11 and 12 June 2019, an **extreme convective rainfall event** occurred in the upper part of the Lake of Como, affecting the territory of the provinces of Lecco and Sondrio. Rather persistent and auto-regenerating thunderstorms started during the evening of 11 June around 8 p.m. and did not dissipate completely until 9 a.m. the following day. A huge amount of rainfall fell with an **average rainfall depth of 110 mm in 13 h**. The town of Premana experienced a total of **210 mm in 13 h** that corresponds to a precipitation with a return period of **200 years**.

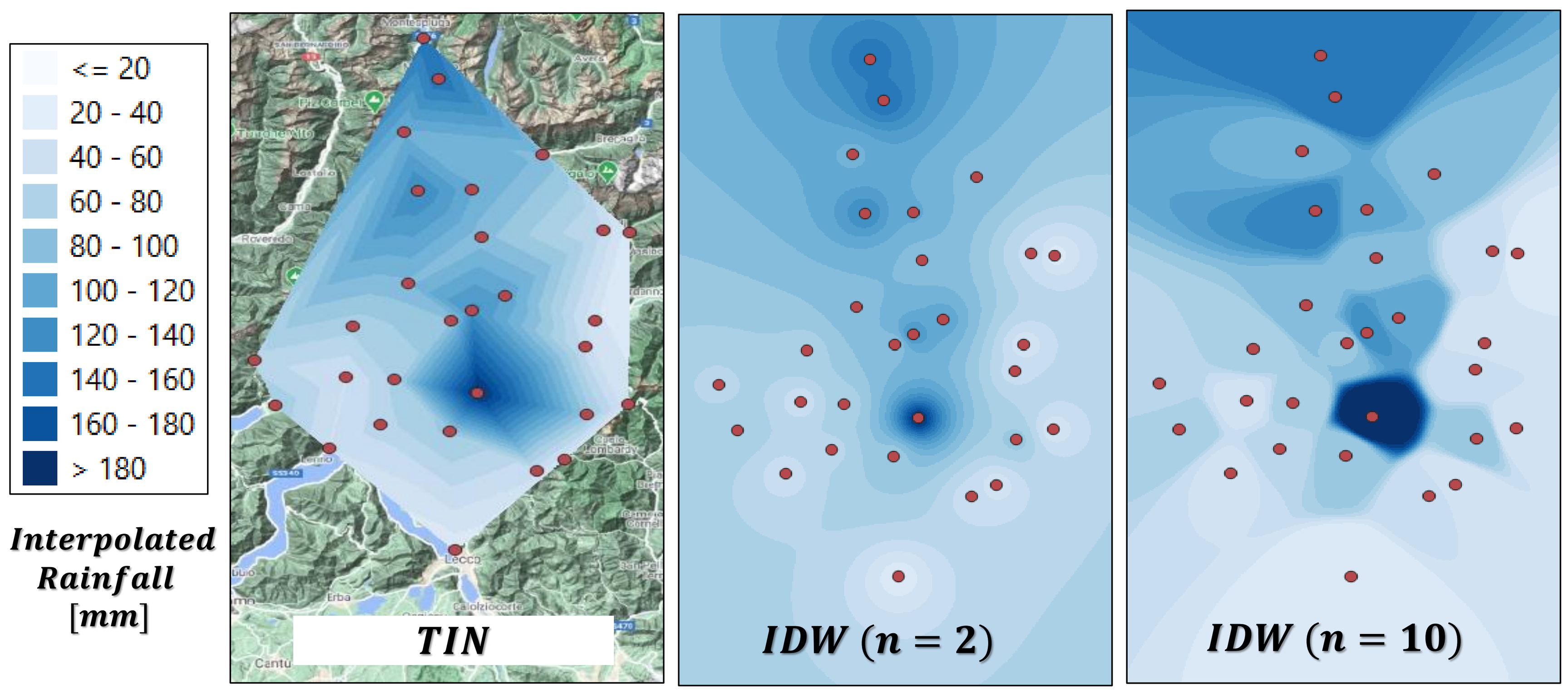
The Aim of our Study:
Reconstruction of the Event Rainfall Field

- *Geometrical Interpolation (TIN and IDW)*
- *Ordinary Kriging and PRISM Interpolation*
- *Linear Upslope Model of Orographic Rain*



Geometrical Interpolation: TIN and IDW

A rainfall field is reconstructed from a **station network**, applying automatic interpolation methods, such as the **TIN** or the **IDW**. The availability of a sufficiently dense network is necessary to obtain a reasonable interpolation however the dependence of the rainfall field on elevation is not taken into account.



Interpolated Rainfall [mm]

Ordinary Kriging and PRISM Interpolation

Geostatistical techniques, such as **Kriging External Driven (KED)** may be a viable solution: the classical Kriging could be conditioned (driven) considering an external drift, such as the **elevation**. KED yields good results when a strong relationship between a meteorological variable and elevation is present. This cannot be extended to precipitation. Here is therefore presented the **Ordinary Kriging (OK)** application.

Precipitation follows neither an additive error model nor a Gaussian distribution (typical of temperatures), which are both prerequisites for a rigorous application of most geostatistical methods. Instead, precipitation follows a multiplicative error model. Therefore, the **Kriging performances are low**, especially in the reconstruction of daily and sub-daily rainfall fields.

The **PRISM model** (Parameter Elevation Regressions on Independent slopes Models) is based on a **weighted climate–elevation regression function** that acknowledges the dominant influence of elevation on precipitation. To operate with PRISM, for each meteorological station are assigned weights that account for other **physiographical factors** in addition to elevation, such as the topographic exposure or coastal proximity, which affect the climate at a variety of scales.

Parameter Elevation Regression on Independent Slopes Model

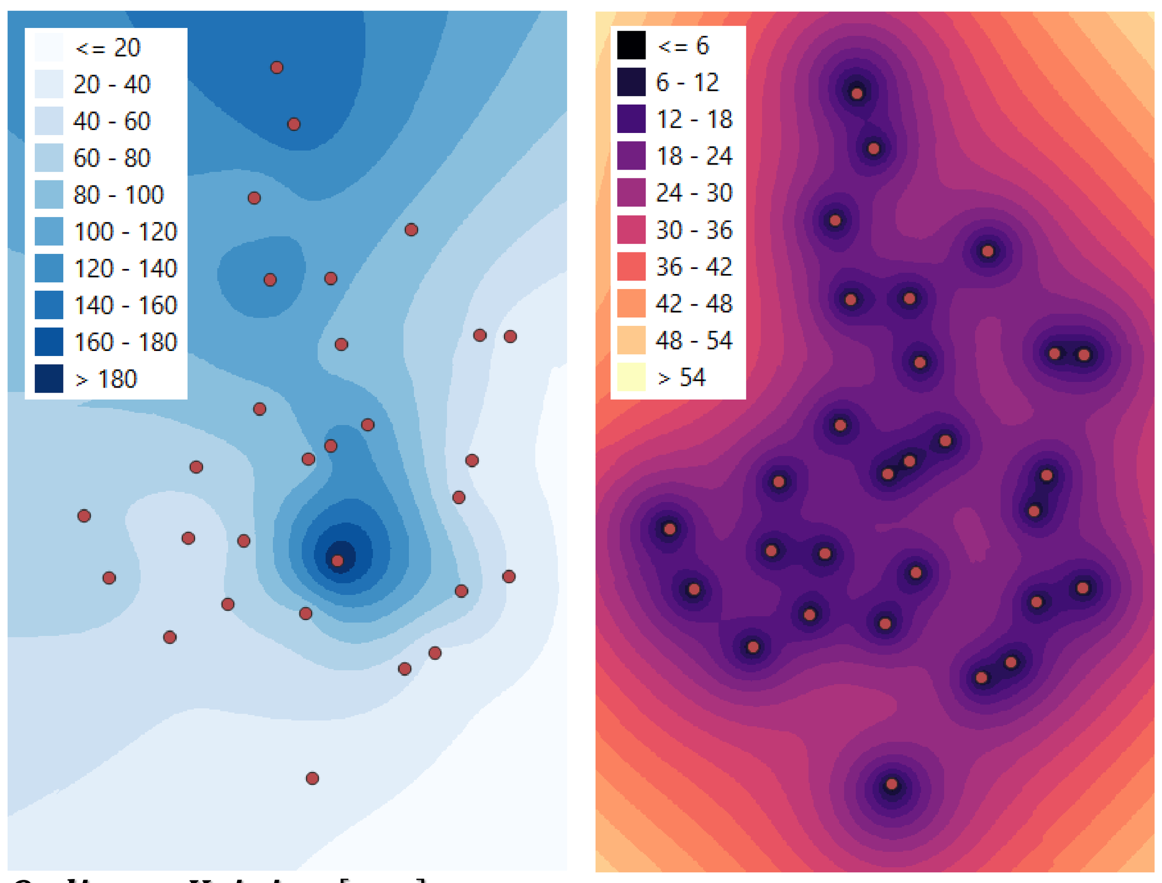
$$P = \beta_1 z + \beta_0 \qquad \text{linear regression function}$$

$$W = \left[F_d W_d^2 + F_z W_z^2\right]^{0.5} W_f \qquad \text{weight function}$$

- Fd = 0.8
- Fz = 0.2
- Wd = Distance weigh
- Wz = Elevation weigh
- Wf = Facets weigh

$$\hat{\beta}_1 = \frac{\sum_{i=1}^n W_i\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sum_{i=1}^n \left(x_i - \bar{x}\right)^2} \qquad \hat{\beta}_0 = \bar{y} - \hat{\beta}_1 \bar{x}$$

$$\bar{x} = \frac{\sum_{i=1}^n W_i x_i}{\sum_{i=1}^n W_i x_i}, \qquad \bar{y} = \frac{\sum_{i=1}^n W_i y_i}{\sum_{i=1}^n W_i}$$



Ordinary Kriging [mm] *O.K. Standard Deviation* [mm]

Mount Legnone Regression with PRISM: (Orange)

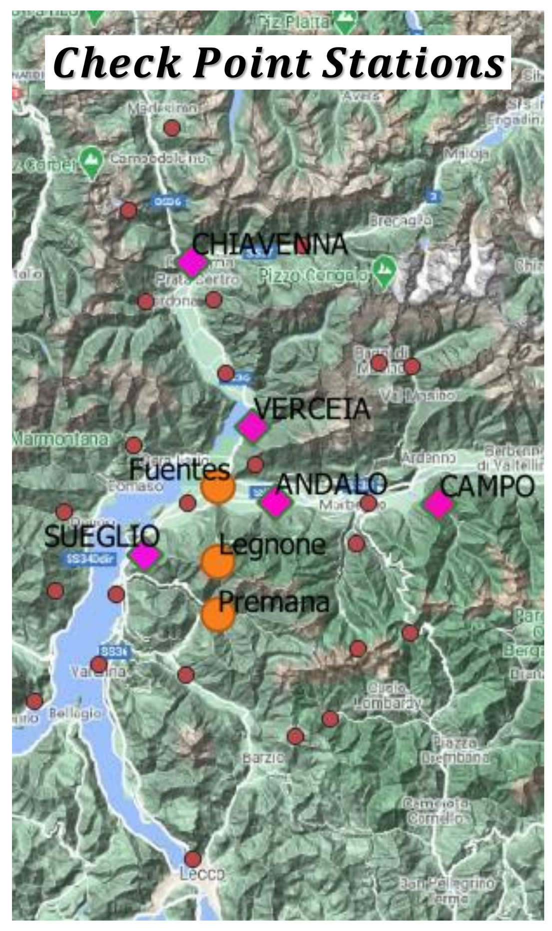
*The target point considered for the regression is the **highest mountain peak** in the area (2605 m). Following the PRISM methodology is shown **an appreciable dependance of rainfall on elevation [a]**. Considering surrounded stations of Fuentes (200 m) and Premana (950 m) the regression seems to follow a **Logarithmic function against elevation [b]**.*

5 Stations Regression with PRISM: (Pink)

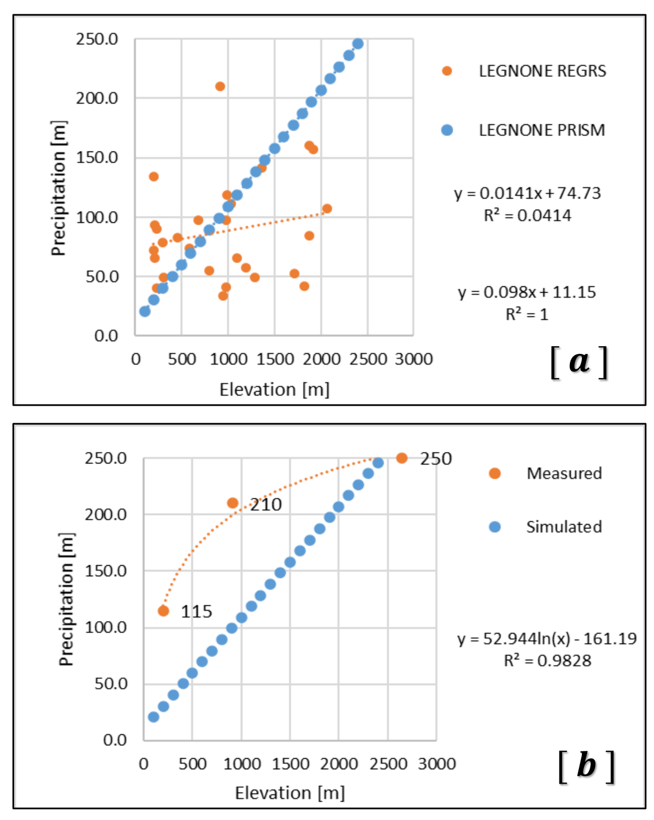
*5 additional station has considered as **Check-Points** for assessing the Performance of PRISM Regression. For that stations, the best predictor remains the **Distance Weight (W1)**, showing **no improvement in accuracy** considering also **Elevation (W2) and Facets Weights (W3)** in the regression **[c]**.*

$$W_1 = W_d \qquad W_2 = \left[F_d W_d^2 + F_z W_z^2\right]^{0.5} \qquad W_3 = W_2 W_f$$

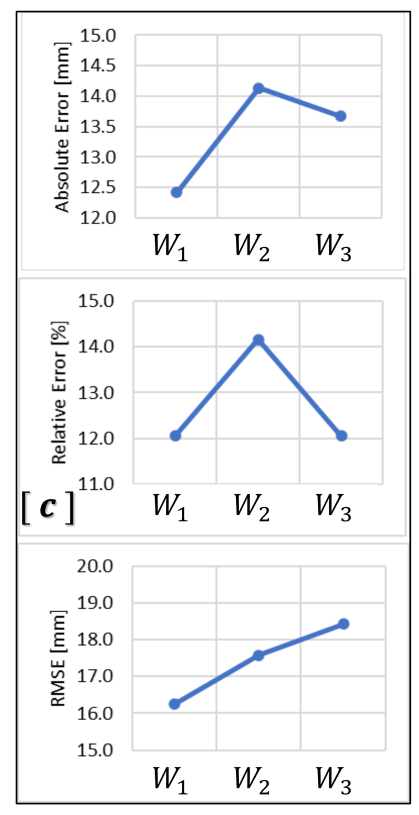
Check Point Stations



Mount Legnone PRISM Linear Regression



5 Stations PRISM Errors



NCEP Reanalysis Database and Linear Upslope Model 1D (LUM)

At regional scale, the position of air masses in [1] show a **low-pressure** centred on western France. This configuration was responsible of the **warm and humid air advection** coming from Mediterranean Sea in the direction of the Alps. The temporal **persistency of heavy rainfalls** was caused by the stationarity behaviour of the air masses. That **humid airflow was also sustained by the presence of intense jet streams** as reported in [2].

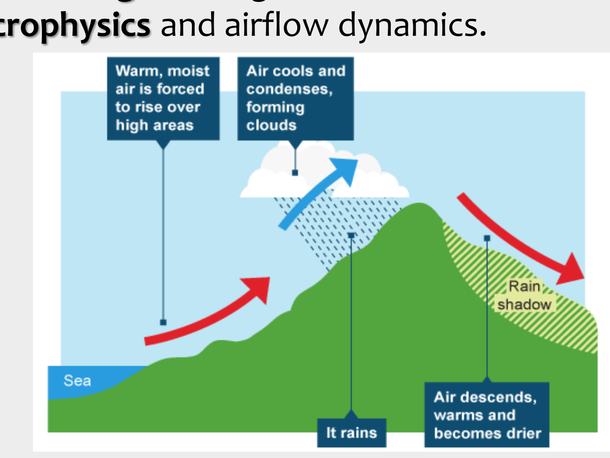
We tested the **Linear Upslope Model** designed for **estimating rainfall records in orographic precipitation.** This model explicitly addresses the dependence of **rainfall intensification caused by the terrain elevation** and evaluates the spatial evolution of a precipitation P (mm) triggered by the local orography h (m). The idea behind the model formulation is the following: when a **humid airflow rises** along a slope, it **starts to condense**, cooling adiabatically and triggering rainfall on the up-slope flank of the mountain range. Beyond the mountain peak, the airflow begins to **descend** and **dries out due to adiabatic warming**, causing a decrease in rainfall. This simple conceptualization **neglects all the cloud microphysics** and airflow dynamics.

1) $|WVF| = \int_0^\infty \rho q_v |\mathbf{U}(z)| dz,$

2) $\nabla \cdot WVF = P - E.$

3) $P(x) = H_{sat}^{-1} |WVF| \cdot \frac{dh(x)}{dx} \text{ when } \frac{dh(x)}{dx} > 0.$

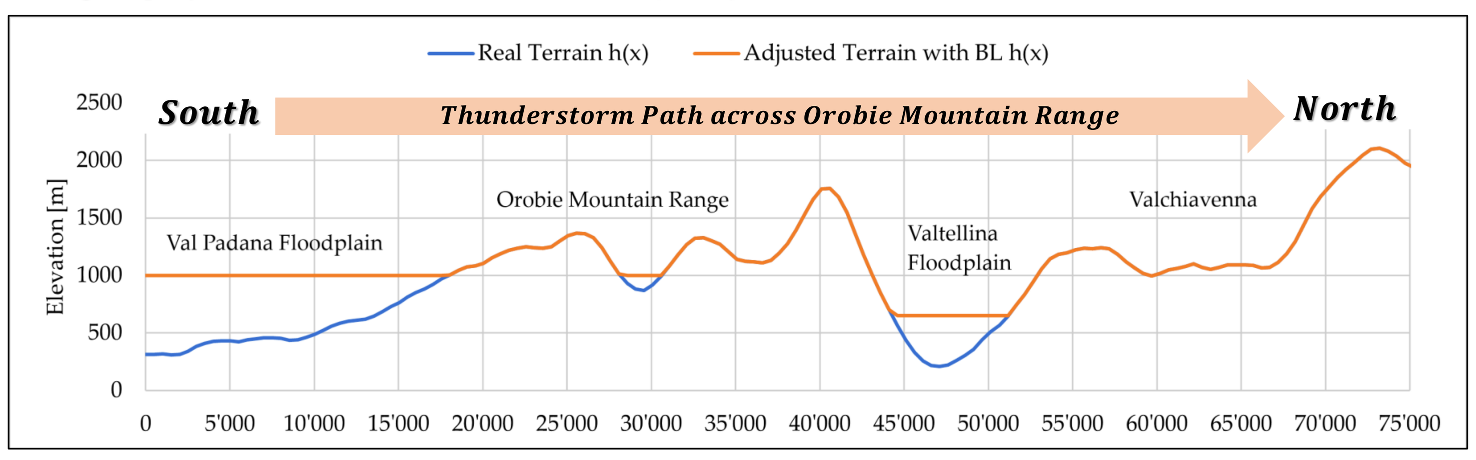
4) $E(x) = H_{sat}^{-1} |WVF| \cdot \frac{dh(x)}{dx} \text{ when } \frac{dh(x)}{dx} < 0.$



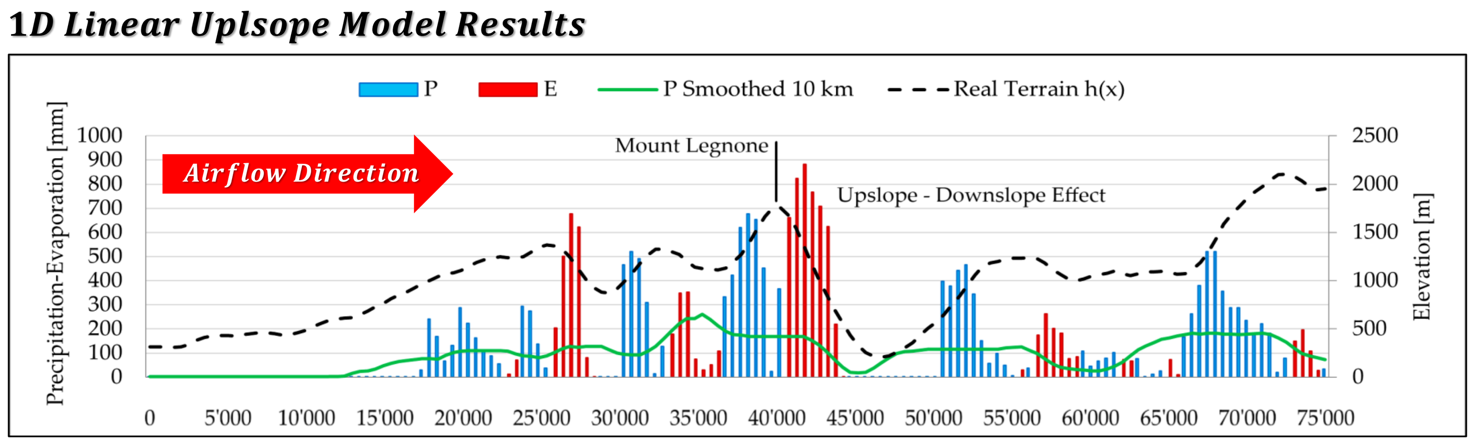
P is expressed as a function of only two terms: the continuity equation of ***Water Vapour Flux*** (1) - (2) and the local terrain slope ***h(x)***. Water Vapour Flux (**WVF**) is an indicator of the airmass moisture and is depleted by ***Precipitation*** (3) and refilled by ***Evaporation*** (4).

HPs adopted:
Steady State | 1D Airflow directed along positive x-axes (Northward) | Boundary layer correction

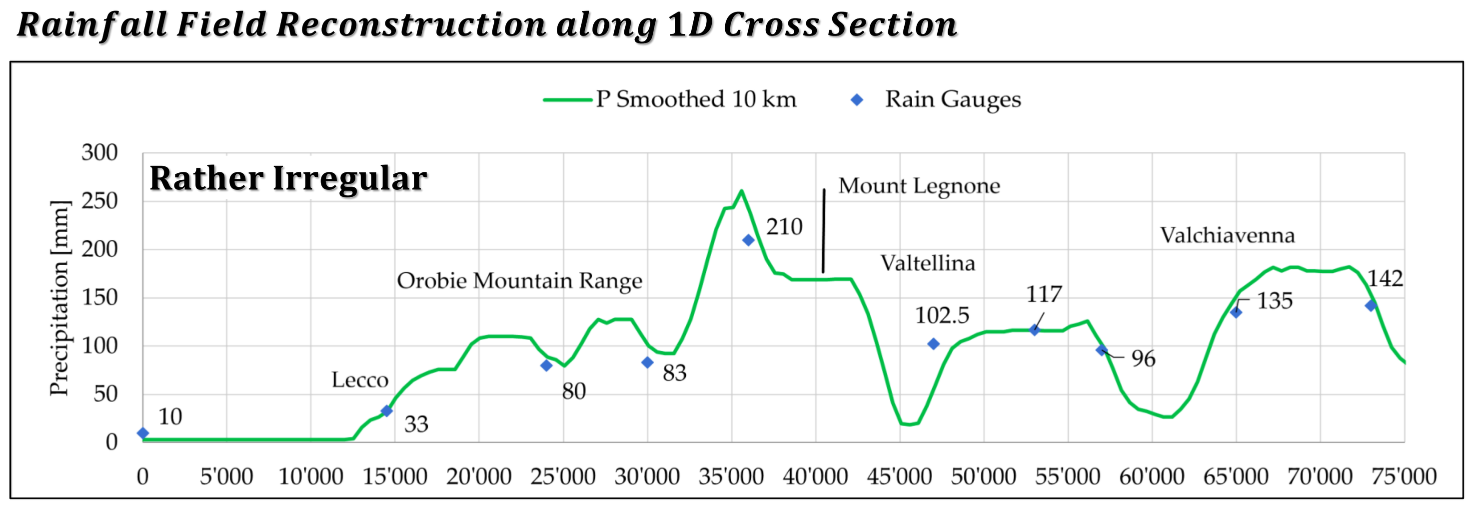
Orography correction with Boundary Layer



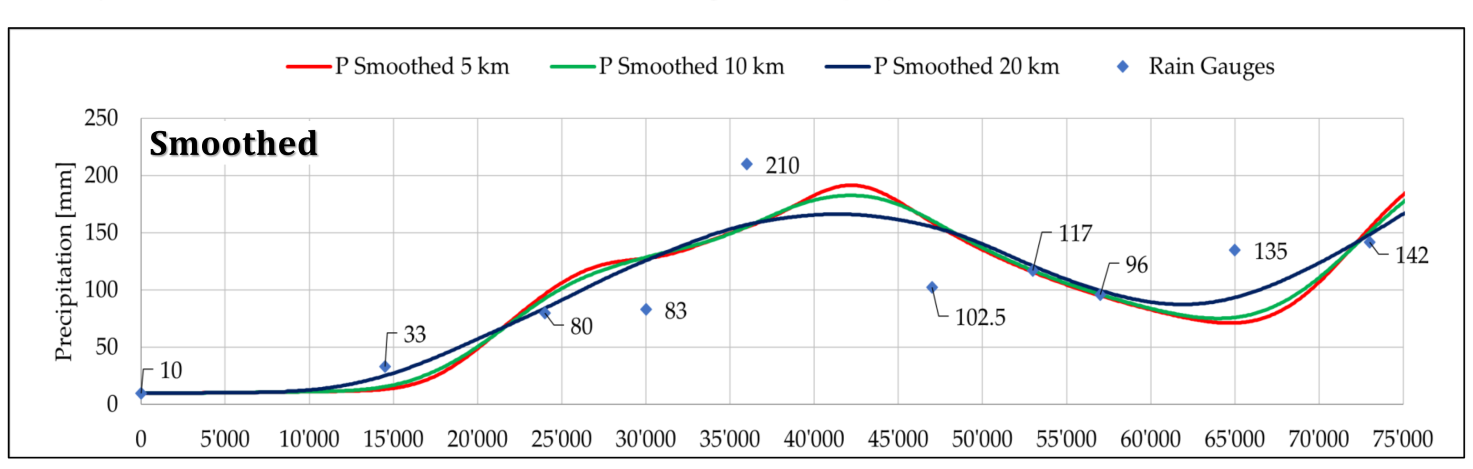
1D Linear Uplsope Model Results



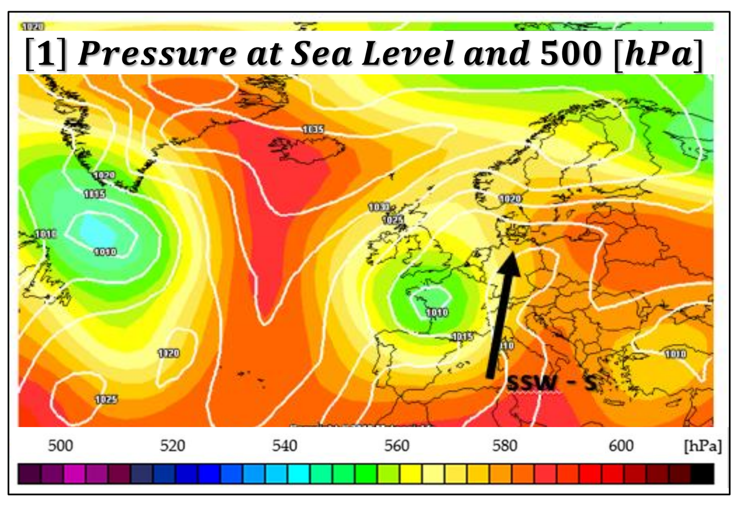
Rainfall Field Reconstruction along 1D Cross Section



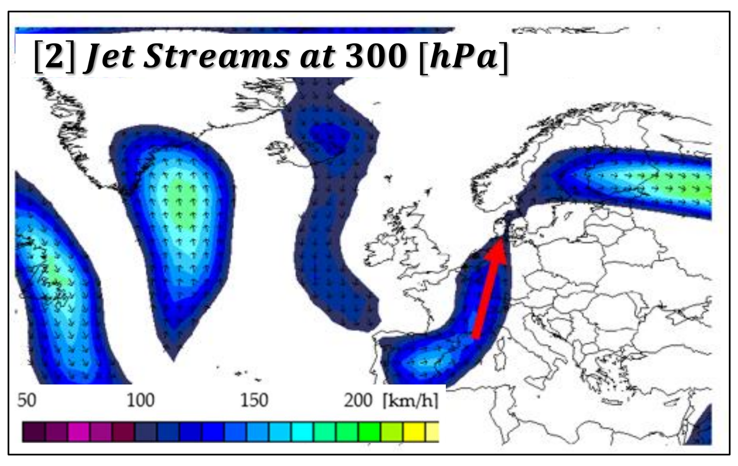
Rainfall Field Reconstruction including Microphysics



[1] Pressure at Sea Level and 500 [hPa]



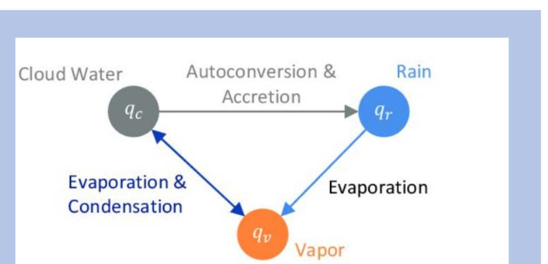
[2] Jet Streams at 300 [hPa]



Linear Upslope Model with Microphysics

$$\mathbf{U} \cdot \nabla q_c = S(x, y) - \frac{q_c}{\tau_c} \qquad P(x, y) = q_s(x, y)/\tau_f.$$

$$\mathbf{U} \cdot \nabla q_s = \frac{q_c}{\tau_c} - \frac{q_s}{\tau_f}, \qquad S(x, y) = S_\infty + C_w \mathbf{U} \cdot \nabla h(x, y),$$



A pair of steady-state advection equations describing the vertically ***integrated cloud water density qc(x, y)*** and **hydrometeor density *qs(x, y)***. where **τc** is the time constant for ***conversion*** from cloud water to hydrometeors (i.e., rain or snow) and ***τf*** is the time constant for hydrometeor ***fallout***. The model is vertically integrated, we use average values of the time constants, range from **200 to 2000 s**, representative of the whole column.

Results and Conclusions

Mean Absolute Error [mm]			
Ordinary K.	PRISM	LUM	LUM + Micro
20-30	14.0	14.02	18.3

Using the Linear Upslope Model a realistic Rainfall Profile has been obtained with a sensible reduction of errors in respect to the other techniques tested. This analysis allowed us to increase our understanding of this type of complex meteorological phenomena. Furthermore, the application of the Linear Model with Microphysics seems to further improve the simulation of the studied event.

Bibliography

Abbate, A.; Papini, M.; Longoni, L. Extreme Rainfall over Complex Terrain: An Application of the Linear Model of Orographic Precipitation to a Case Study in the Italian Pre-Alps. Geosciences **2021**, 11, 18. https://doi.org/10.3390/geosciences11010018