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STRENGTHENING THE RESEARCH CAPACITIES
FOR EXTREME WEATHER EVENTS IN ROMANIA

SUMMER SCHOOL ON AI USE FOR CLIMATE EXTREMES 2026

SEVERE WEATHER THROUGH HAIL PROBABILITY

Extreme precipitation contextualised as severe weather events and described by AI probabilistic models

Leonardo Aragão[1], Leone Cavicchia[2] & Silvio Gualdi[1]

CMCC Foundation - Euro-Mediterranean Center on Climate Change
[1]Earth SYstem modeling and Data Assimilation (ESYDA)
[2]CLImate VAriability and Predictions (CLIVAP)

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HAIL

// hāl // *noun*

Precipitation in the form of balls or irregular lumps of ice, always produced by convective clouds, nearly always cumulonimbus.

An individual unit of hail is called a hailstone. By convention, hail has a diameter of 5 mm or more, while smaller particles of similar origin, formerly called small hail, may be classed as either ice pellets or snow pellets. Thunderstorms that are characterized by strong updrafts, large liquid water contents, large cloud-drop sizes, and great vertical height are favorable to hail formation. The destructive effects of hailstorms upon plant and animal life, buildings and property, and aircraft in flight render them a prime object of weather modification studies.

AMS Glossary of Meteorology
https://glossary.ametsoc.org/wiki/hail/

HAIL MODELLING CHALLANGES

Tightly coupled processes across scales

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convective clouds
large cloud-drop sizes
5 mm diameter

strong updrafts
large liquid water contents
great vertical height

smaller particles
may be classed as
ice pellets or snow pellets

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Complex interactions in mixed-phase clouds bring key issues:

- Droplet size distributions
- Ice nucleation pathways
- Growth cycles

CLOUD MICROPHYSICS

strong updrafts
large liquid water contents
great vertical height

smaller particles
may be classed as
ice pellets or snow pellets

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Highly nonlinear and uncertain

Complex interactions in mixed-phase clouds bring key issues:

- Droplet size distributions
- Ice nucleation pathways
- Growth cycles

"State-of-the-art atmospheric models simplify it into bulk microphysics schemes."

CLOUD MICROPHYSICS

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CLOUD
MICROPHYSICS



STORM
THERMODYNAMICS

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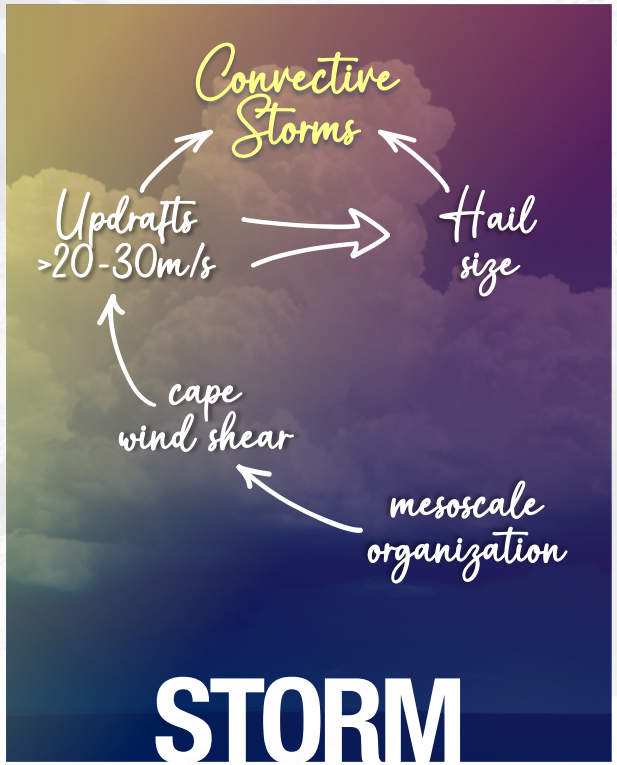
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Tightly coupled processes across scales

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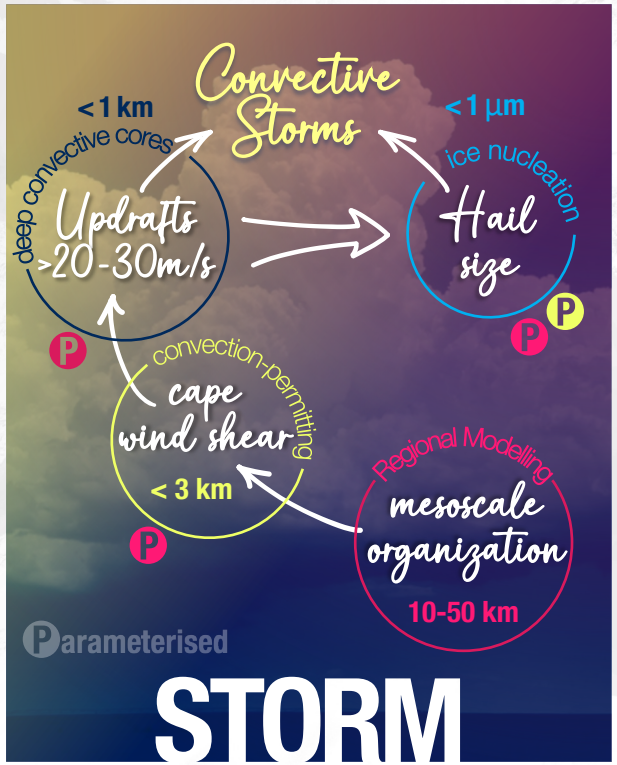
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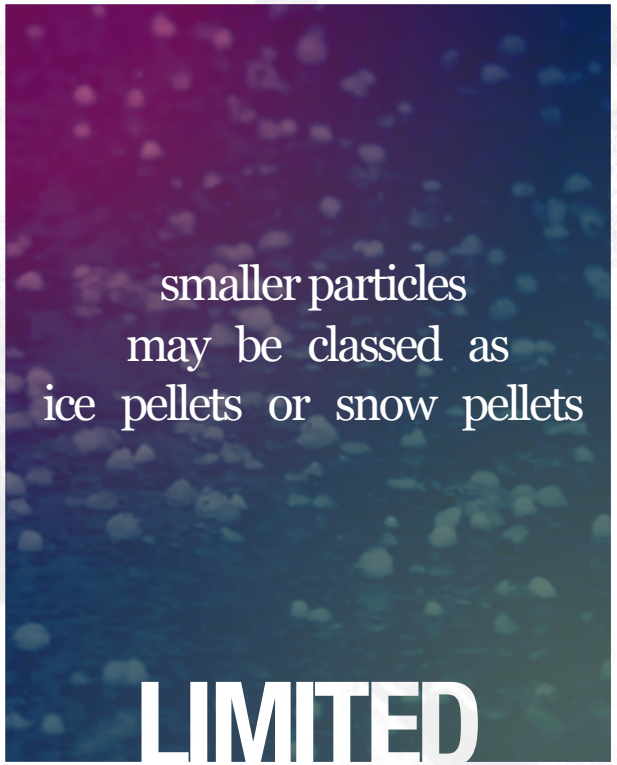
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CLOUD MICROPHYSICS



STORM THERMODYNAMICS



LIMITED OBSERVATIONS

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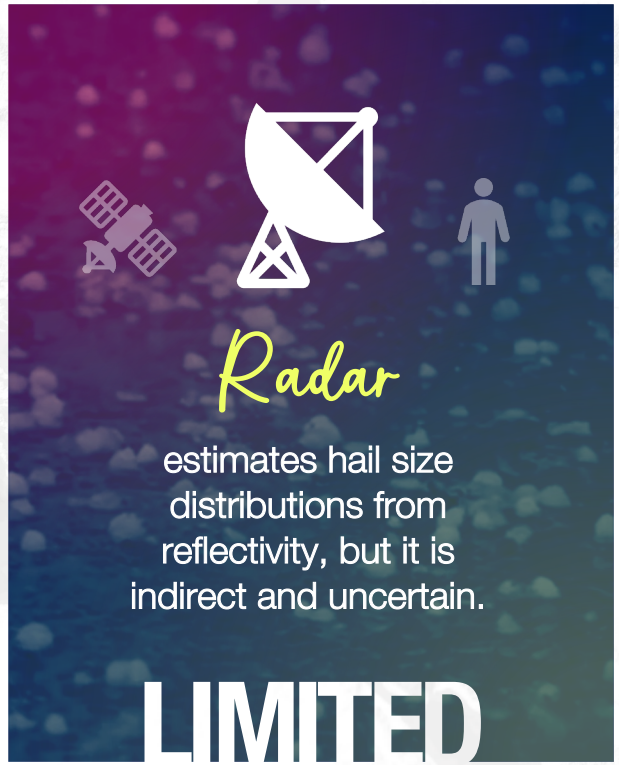
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CLOUD MICROPHYSICS



STORM THERMODYNAMICS



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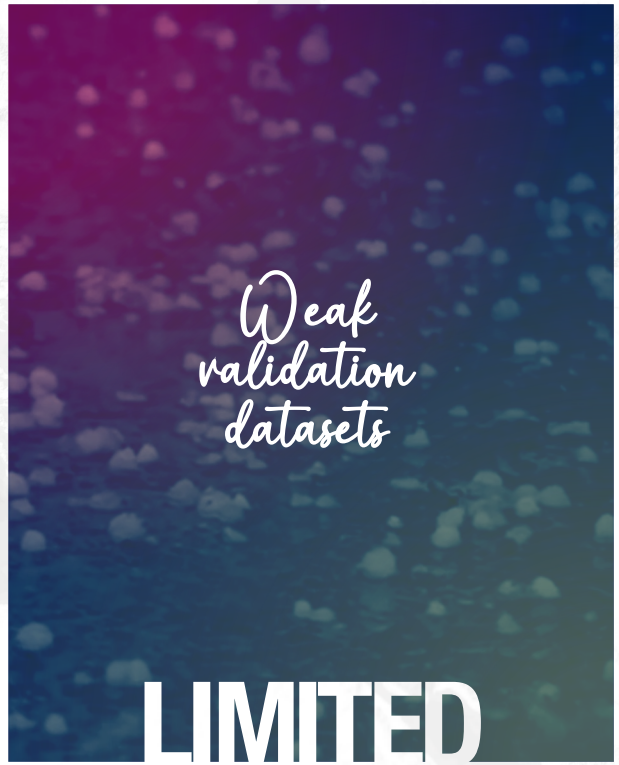
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CONTEXTUALISING

Large-scale meteorology enhancing local severe weather prediction

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Modelling hail hazard over Italy with ERA5 large-scale variables

Verónica Torralba [a,1,*], Riccardo Hénin [a,1,*], Antonio Cantelli [a,b], Enrico Scoccimarro [a], Stefano Materia [a], Agostino Manzato [c], Silvio Gualdi [a]

[a] Climate Simulations and Predictions Division, Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC), Bologna, Italy
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[c] Agenzia Regionale Per l'Ambiente (ARPA) Friuli Venezia Giulia – OSMER, Palmanova, Italy

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Italy
Genetic algorithm
ERA5
Extremes

ABSTRACT

Hail is a meteorological phenomenon with adverse impacts that affects multiple socio-economic sectors such as agriculture, renewable energy, and insurance. Nevertheless, the understanding of the favourable environmental conditions for hail formation and the models' inadequacy to represent these phenomena have been limited by the scarce temporal and spatial coverage of hail observations. This is a major concern for the mitigation of hail-related risk in sensitive regions such as Italy, which is one of the more hail-prone areas in Europe. In this work, we present a hail model that has been developed to describe the hail hazard over Italy. This model relies on several ERA5 large-scale meteorological variables and convective indices that are combined following the statistical method described in Prein and Holland (2018). The identification of the best set of variables to be used as predictors in the hail model has been performed by a systematic machine learning procedure based on a genetic algorithm. The hail model estimates the hail probability over Italy in the 1979–2020 period, on the ERA5 spatial grid resolution (~ 30 km). The output of the hail model has been used to characterize the seasonality and long-term variability of hail events in Italy. Furthermore, the categorical verification of the hail probability over the Friuli Venezia Giulia region has revealed that the hail model is able to effectively estimate the hail occurrences in specific Italian regions.

1. Introduction

Hail is a meteorological hazard affecting several industrial sectors (Martius et al., 2018; Changnon et al., 2009). For example, the agricultural industry suffers from the destruction of crops due to large hail stones (Sánchez et al., 1996) which has fostered the development of hail prevention and suppression techniques (Rogna et al., 2021; Rivera et al., 2020). Similarly, the electricity power supply market is impacted (Mohr et al., 2015b). Hail events are mainly produced by convective storms that have a local extent and a short duration, therefore the standard observational network often is inadequate (e.g., Mohr and Kunz, 2013). In addition, hail formation and growth are reproduced with some degree of uncertainty by numerical models due to the limitation introduced by the microphysics parameterization and convection schemes (Allen et al., 2015). Moreover, the simulation of these processes requires considerable computational resources (Gagne

RETRIEVE A PREVIOUS PROJECT

developed by some of our former colleagues

GENETIC ALGORITHM

to build hail probability functions based on observations

INCREASE HAIL RECORDS

from 2000–2020 (21 years) to 1940-2025 (86 years)
from Italian to the European domain

EXPAND ITS APPLICATION

from reanalysis to weather and seasonal forecast, up to climate projections

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MODELLING HAIL HAZARD

over Italy with ERA5 large-scale variables

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HAIL records

LARGE SCALE Conditions

GENETIC Algorithm

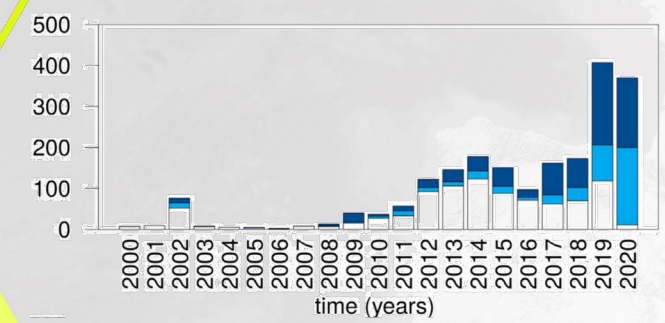
HAIL Probability

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HAIL
records

European Severe Weather Database (ESWD)

Hail records provided by European Severe Storms Laboratory (ESSL)

LARGE SCALE
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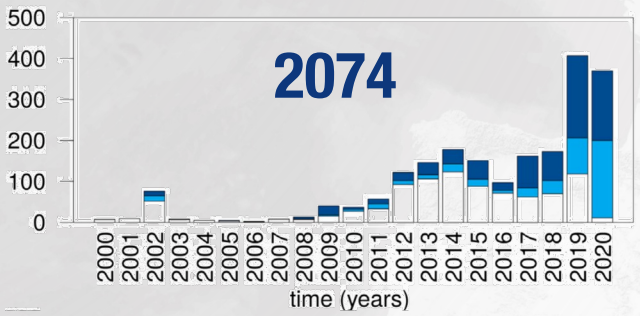
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2021	2022	2023	2024	2025
860	993	1453	685	779

+4770
hail records
in the last 5 years

LARGE SCALE
Conditions

GENETIC
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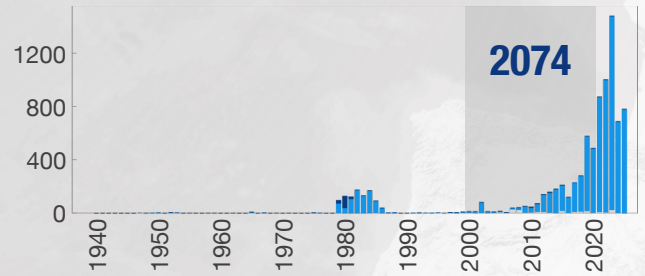
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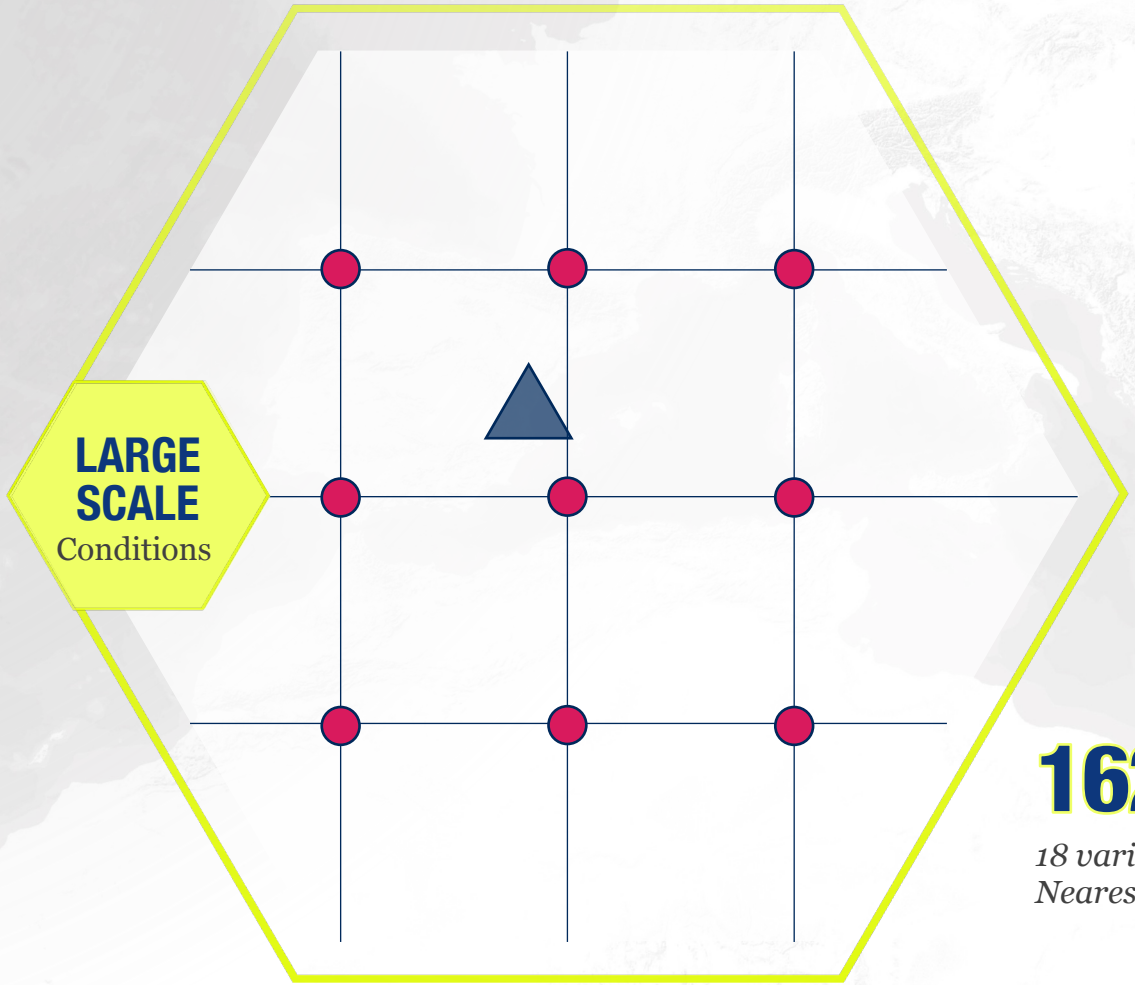
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HAIL
records

LARGE SCALE
Conditions



GENETIC
Algorithm

HAIL
Probability

162 predictors from ERA5 (Daily at 0.25°)

18 variables collected at the daily maximum CAPE hour
Nearest + 8 surrounding gridpoints

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MODELLING HAIL HAZARD

over Italy with ERA5 large-scale variables

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HAIL
records

LARGE SCALE
Conditions

PRE GASWE™

ERA5 (Daily at 0.25°)
18 variables collected at the daily maximum CAPE hour
Nearest + 8 surrounding gridpoints

+ any NetCDF training set

+ any extreme event record

+ any daily or higher resolution

+ new diagnostics variables

GENETIC
Algorithm

HAIL
Probability

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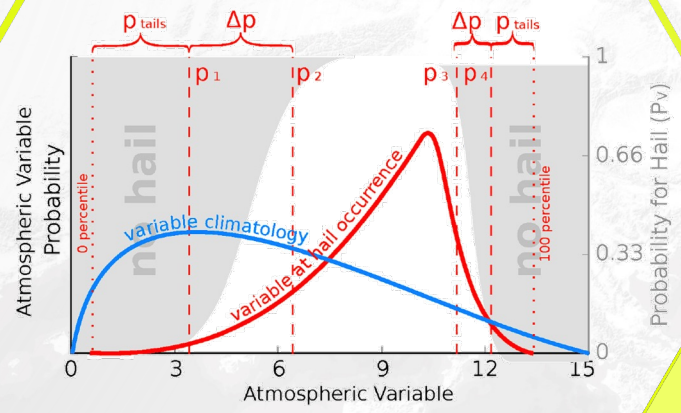
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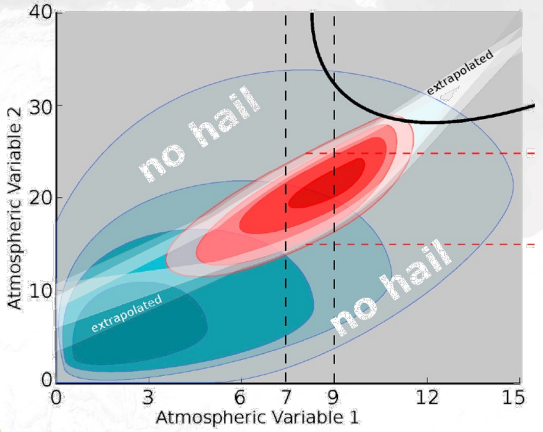
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HAIL records

LARGE SCALE Conditions





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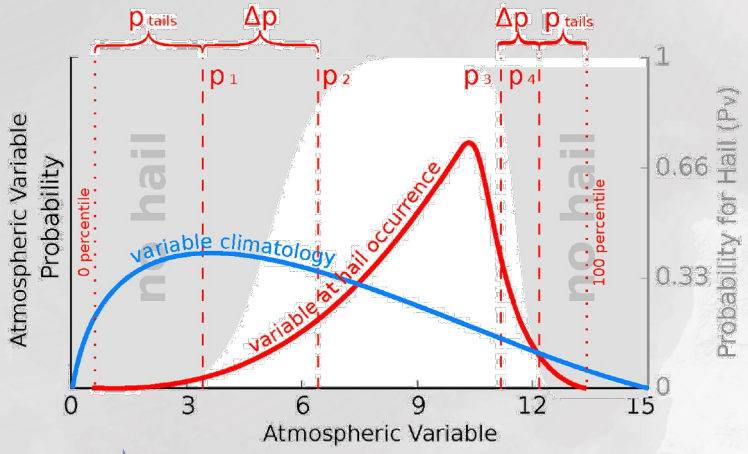
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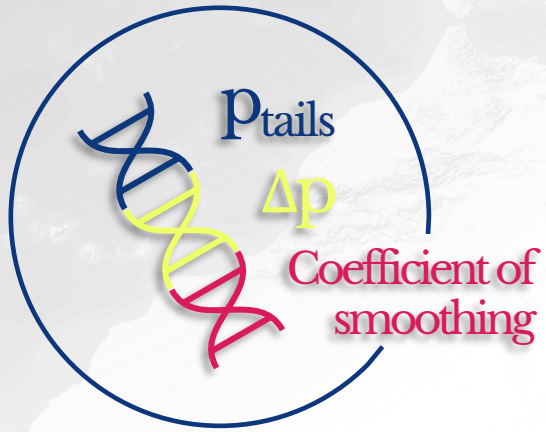
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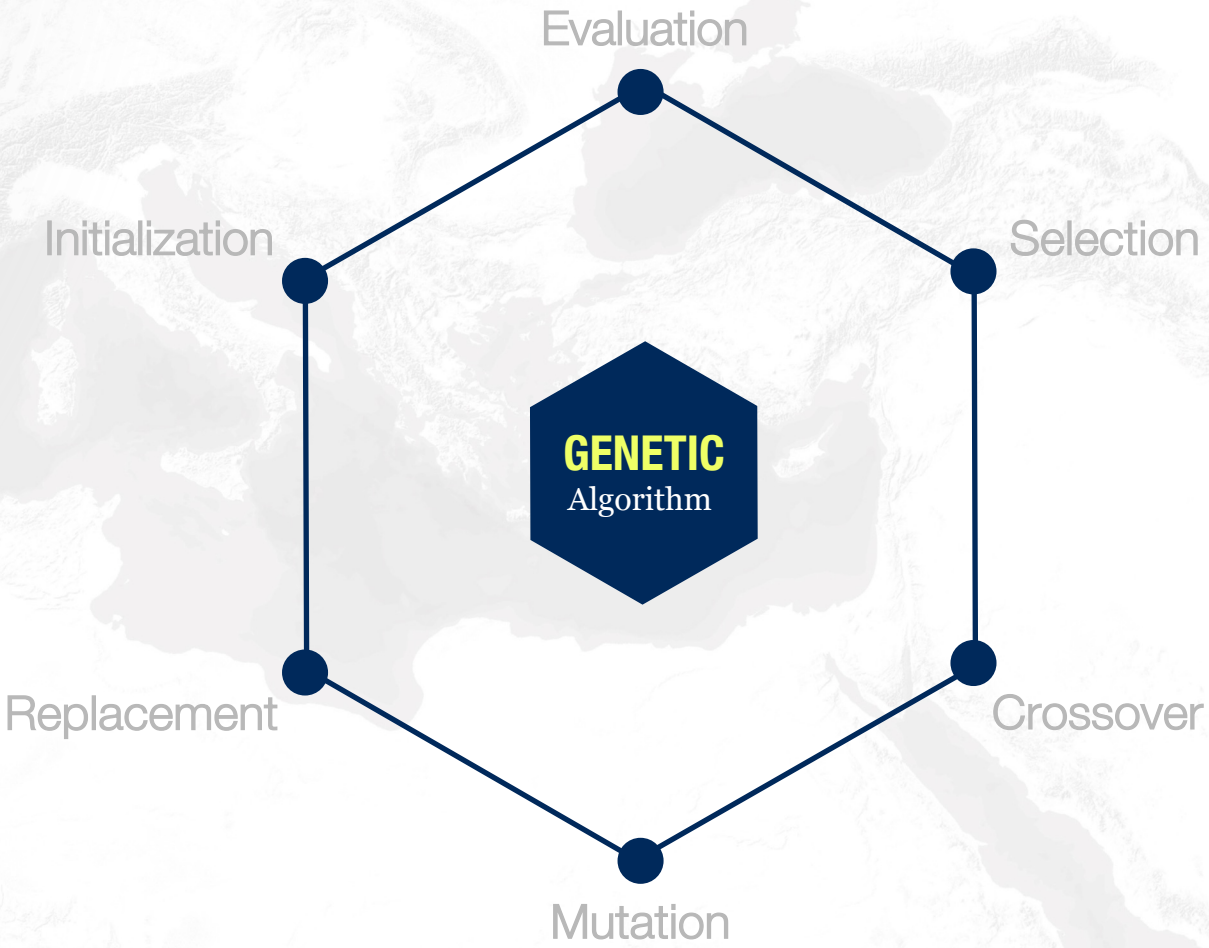
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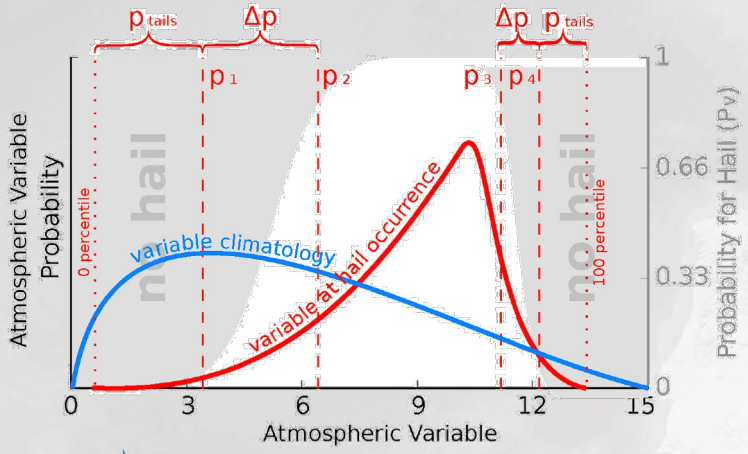


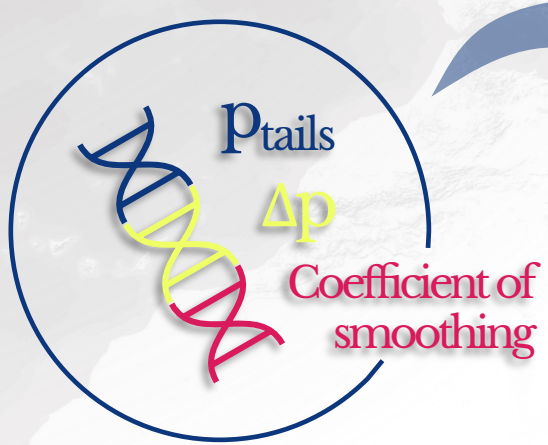
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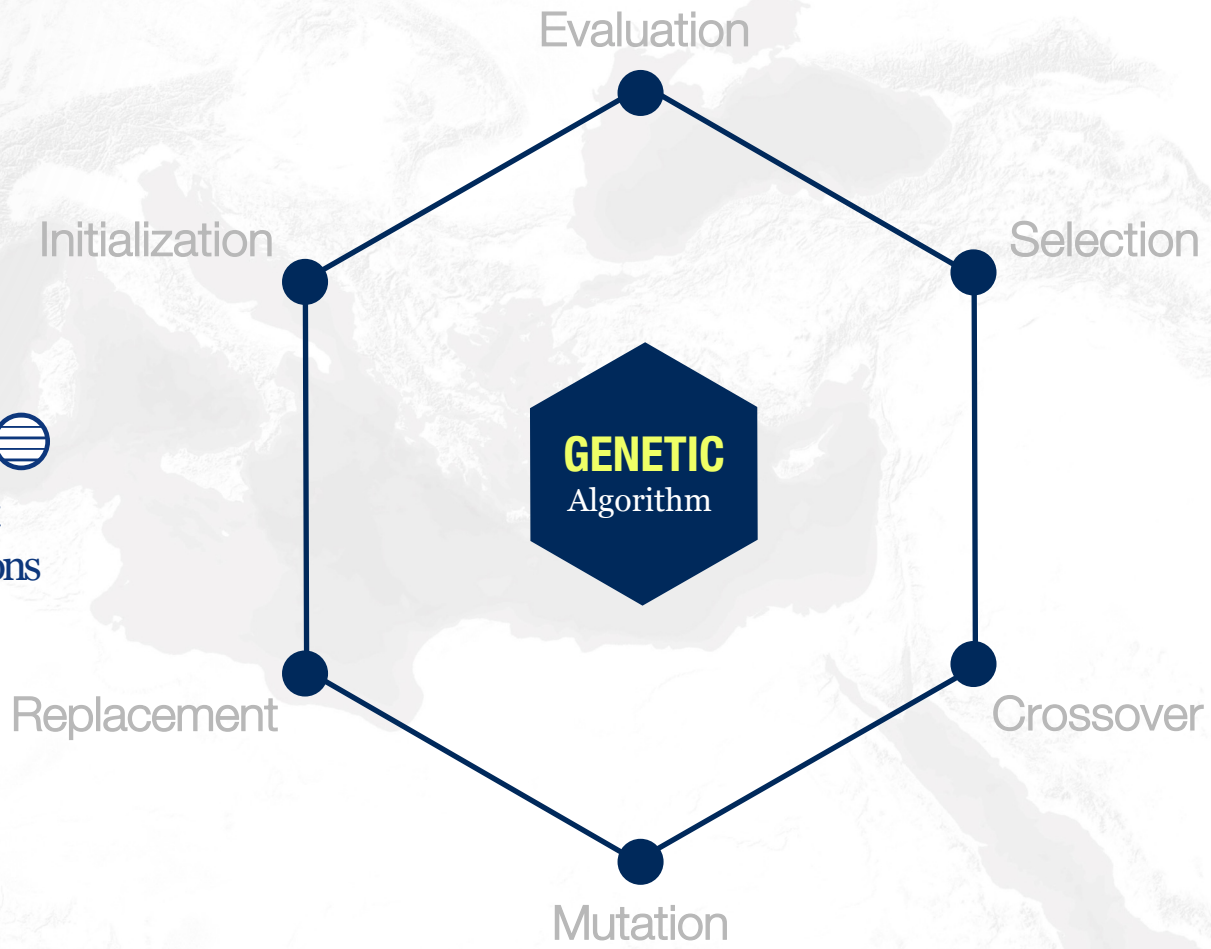
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Different Combinations

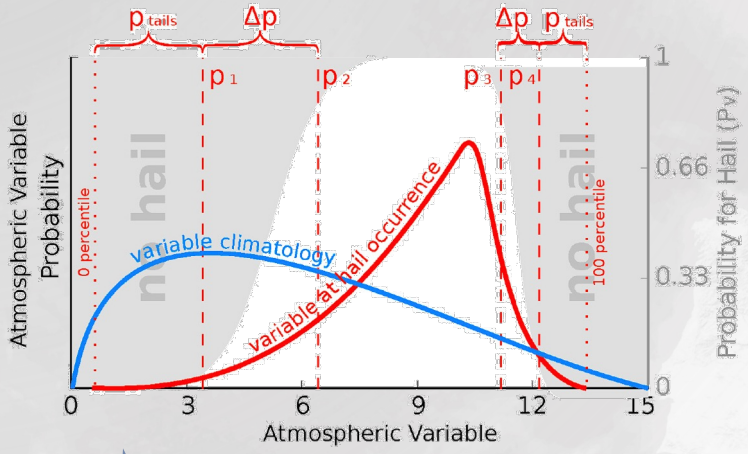


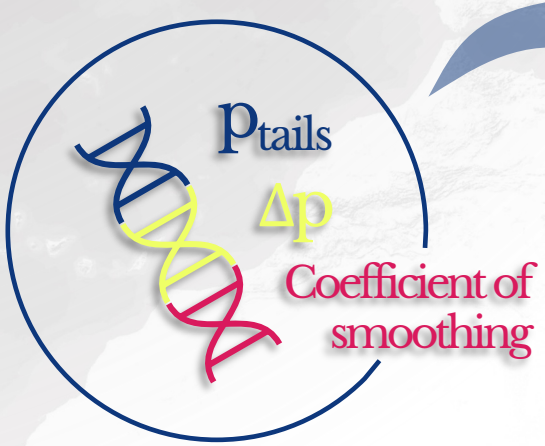
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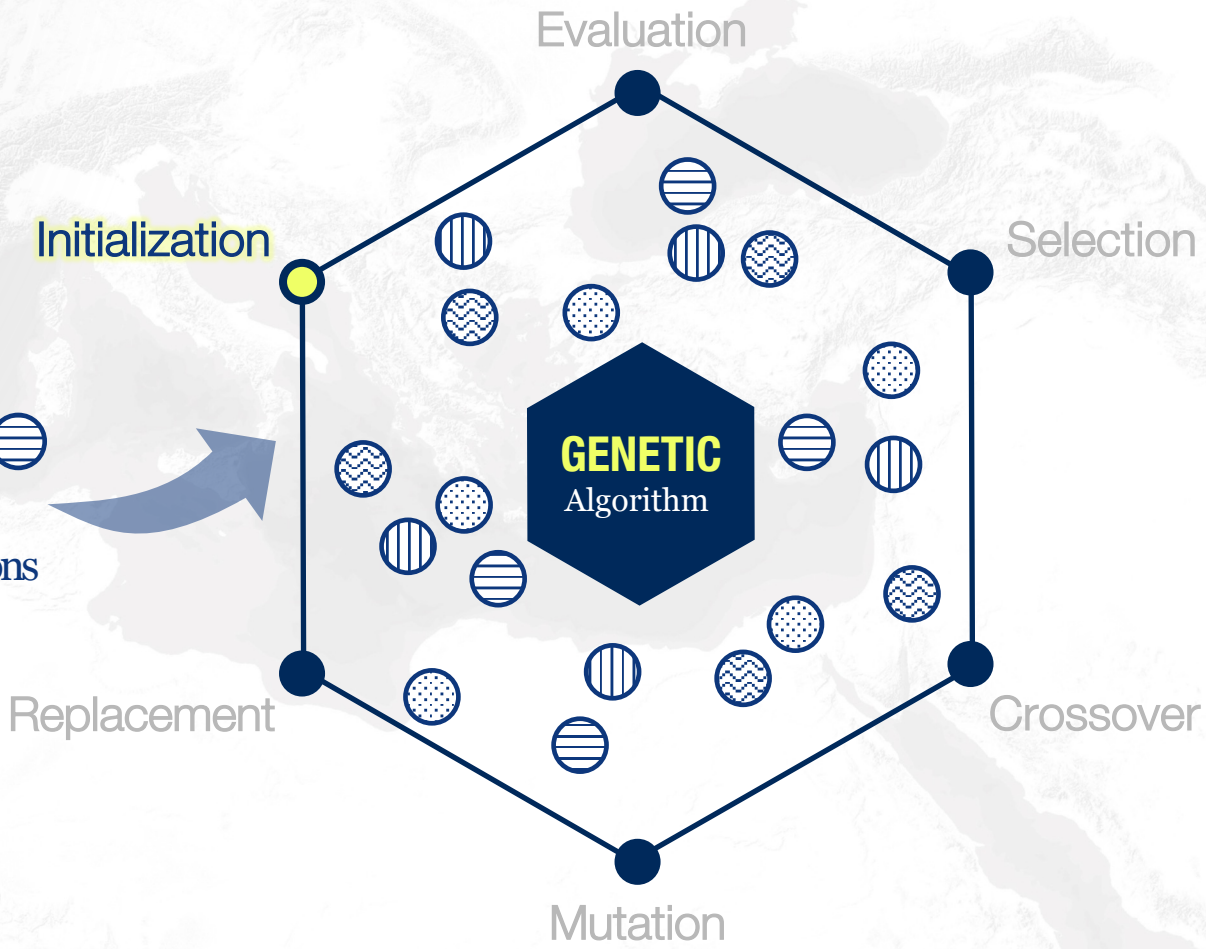
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Different
Combinations

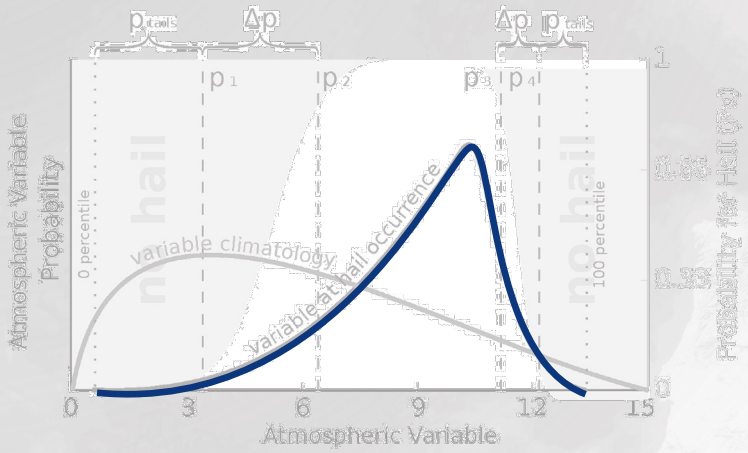


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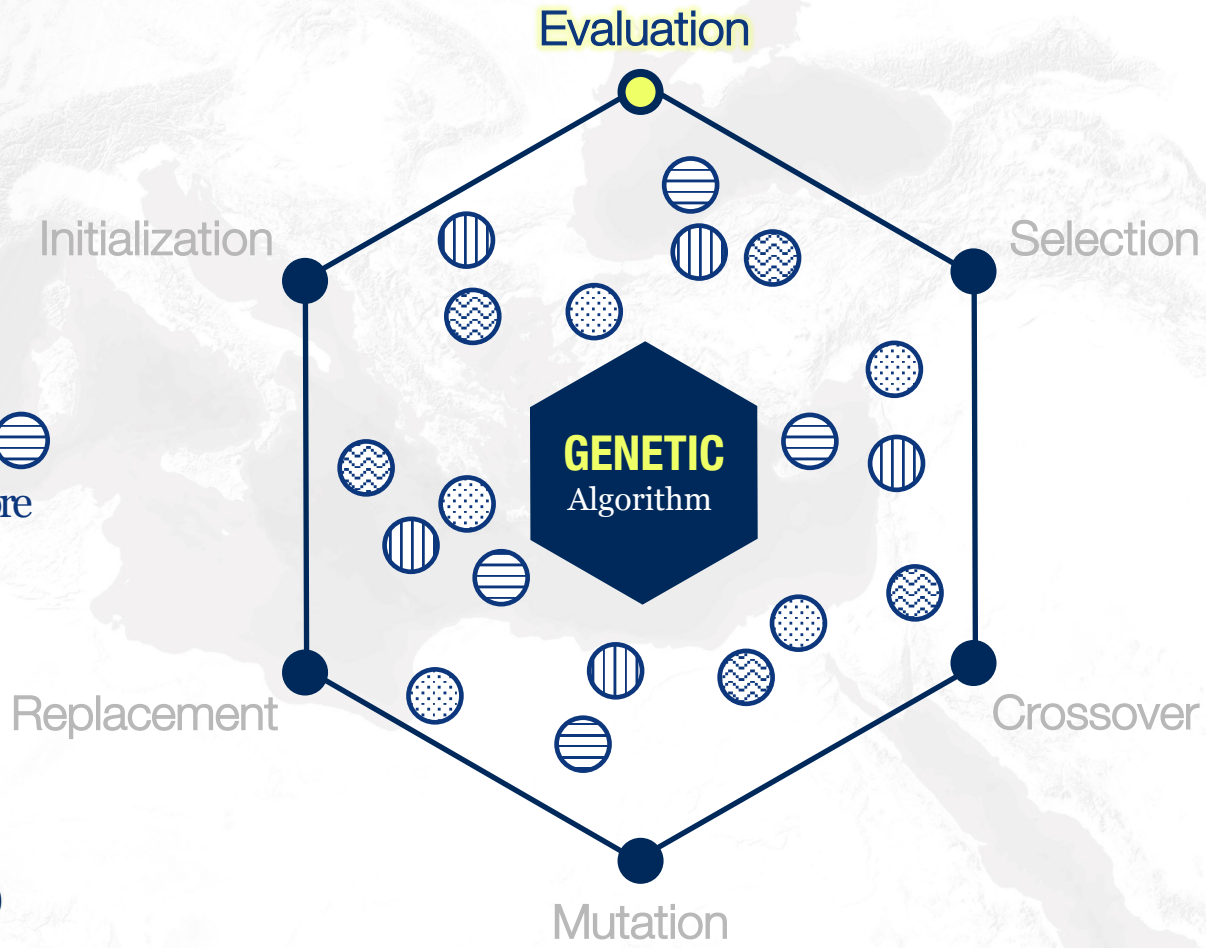


Fitness Score

Matthews Correlation Coefficient

$$MCC = \frac{a \cdot d - b \cdot c}{\sqrt{(a+b)(a+c)(d+b)(d+c)}}$$

a = Hits (T+)
b = False Alarms (F+)
c = Misses (T-)
d = Correct Negatives (F-)

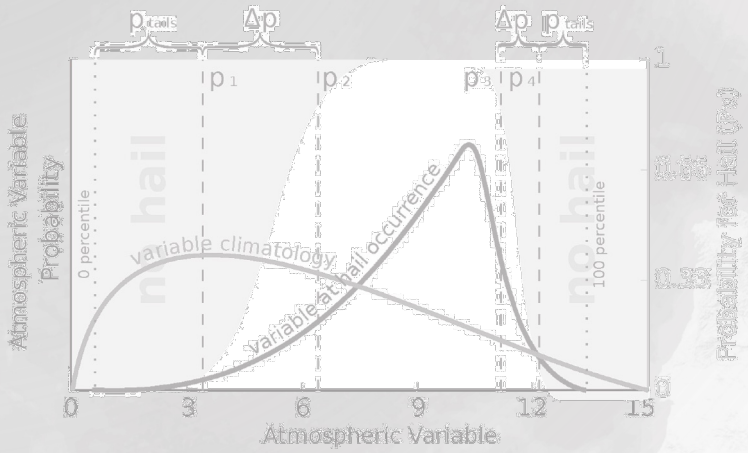


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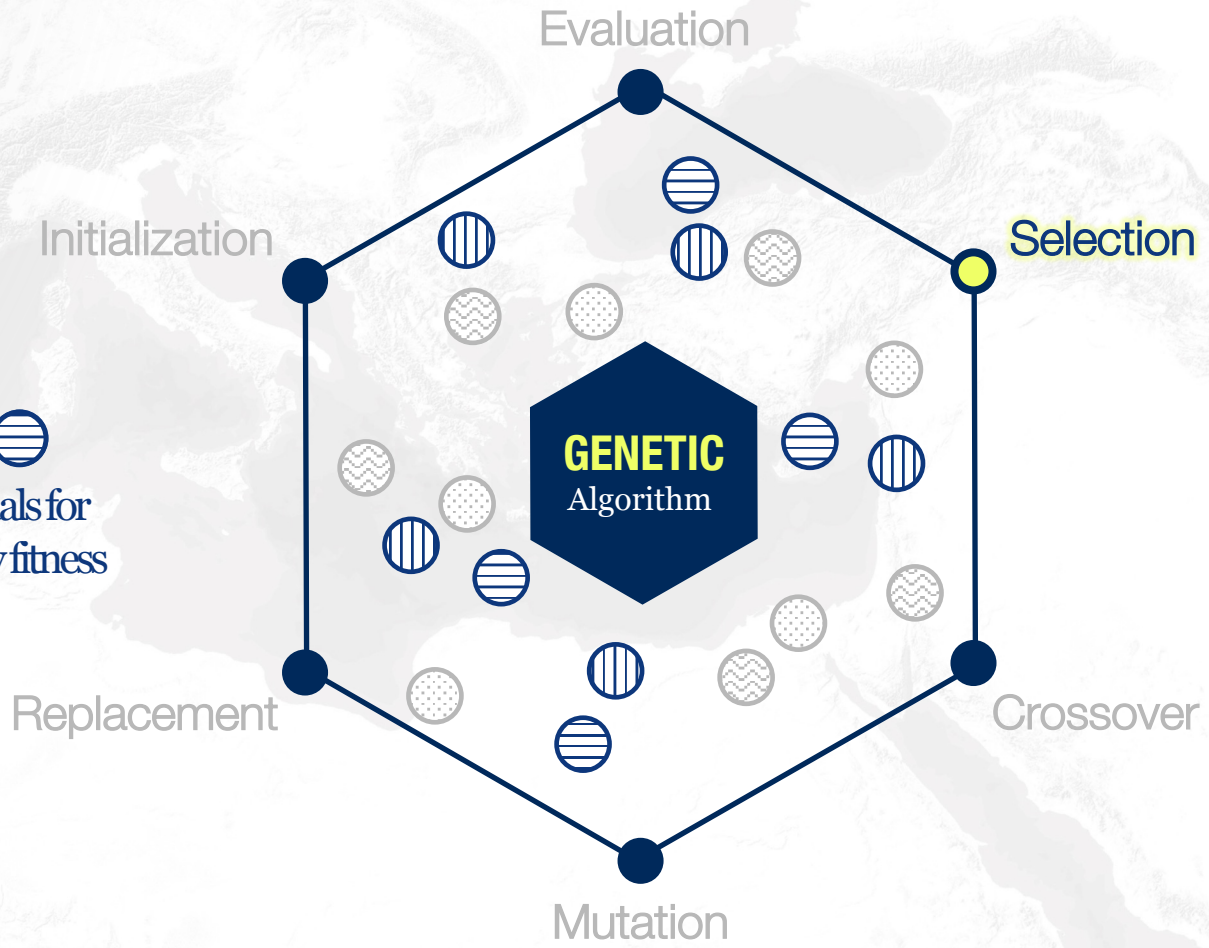
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Select individuals for reproduction by fitness score

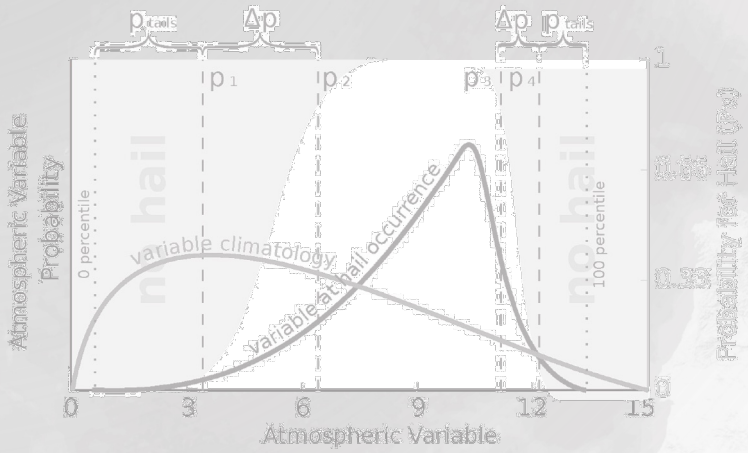


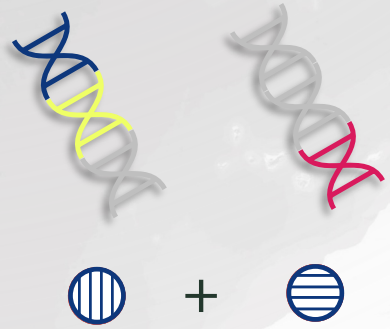
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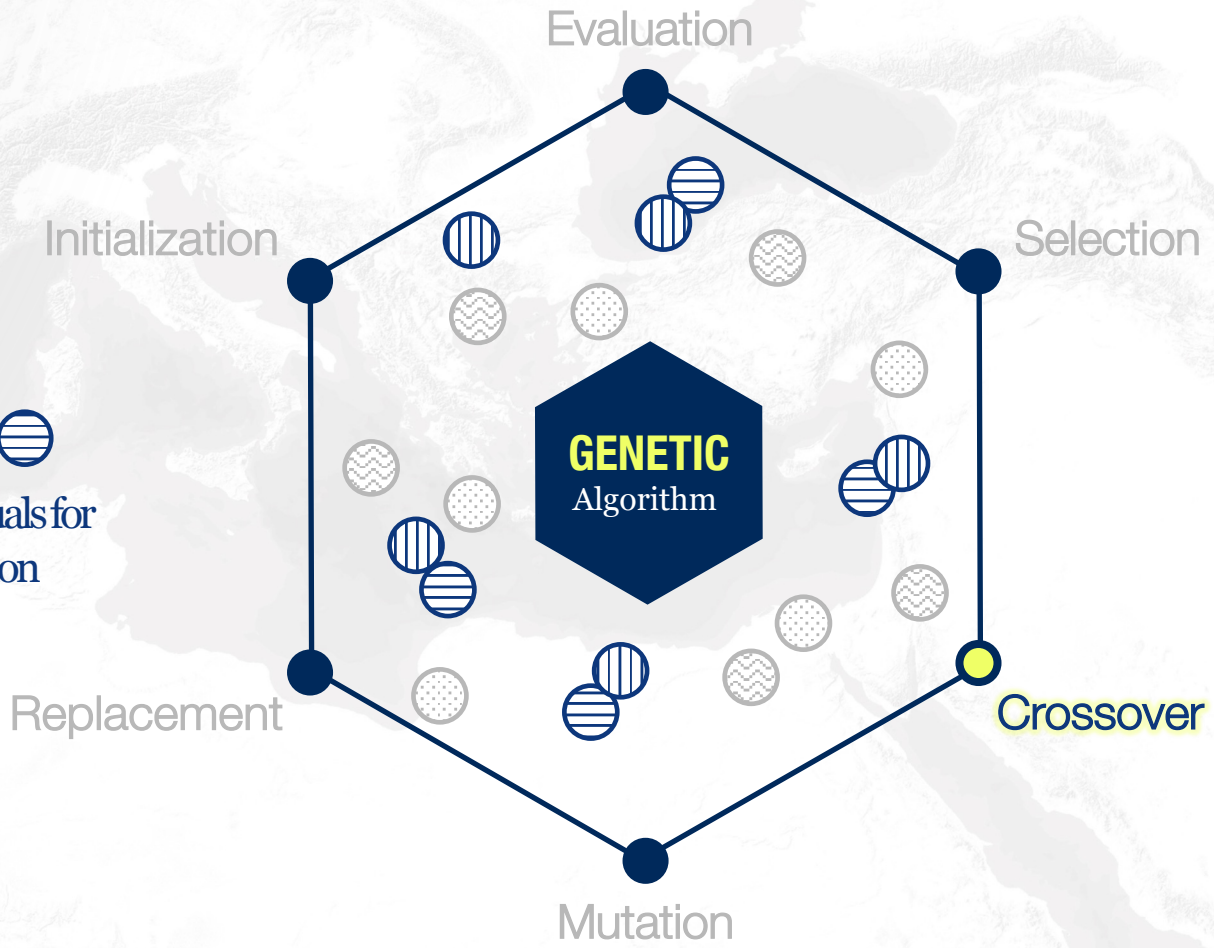
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Select individuals for reproduction

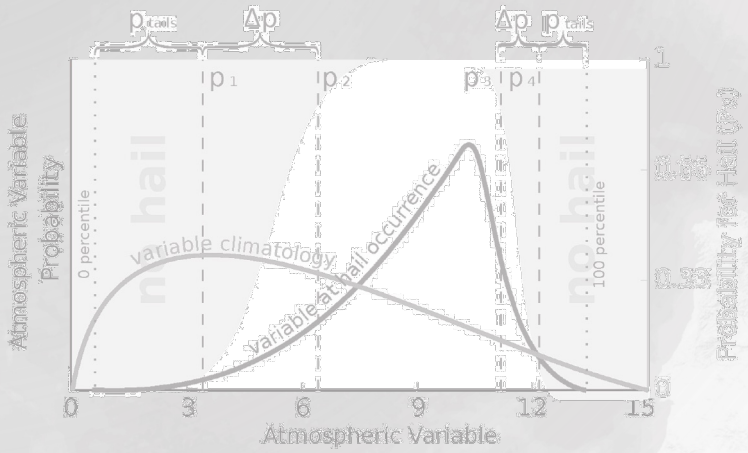


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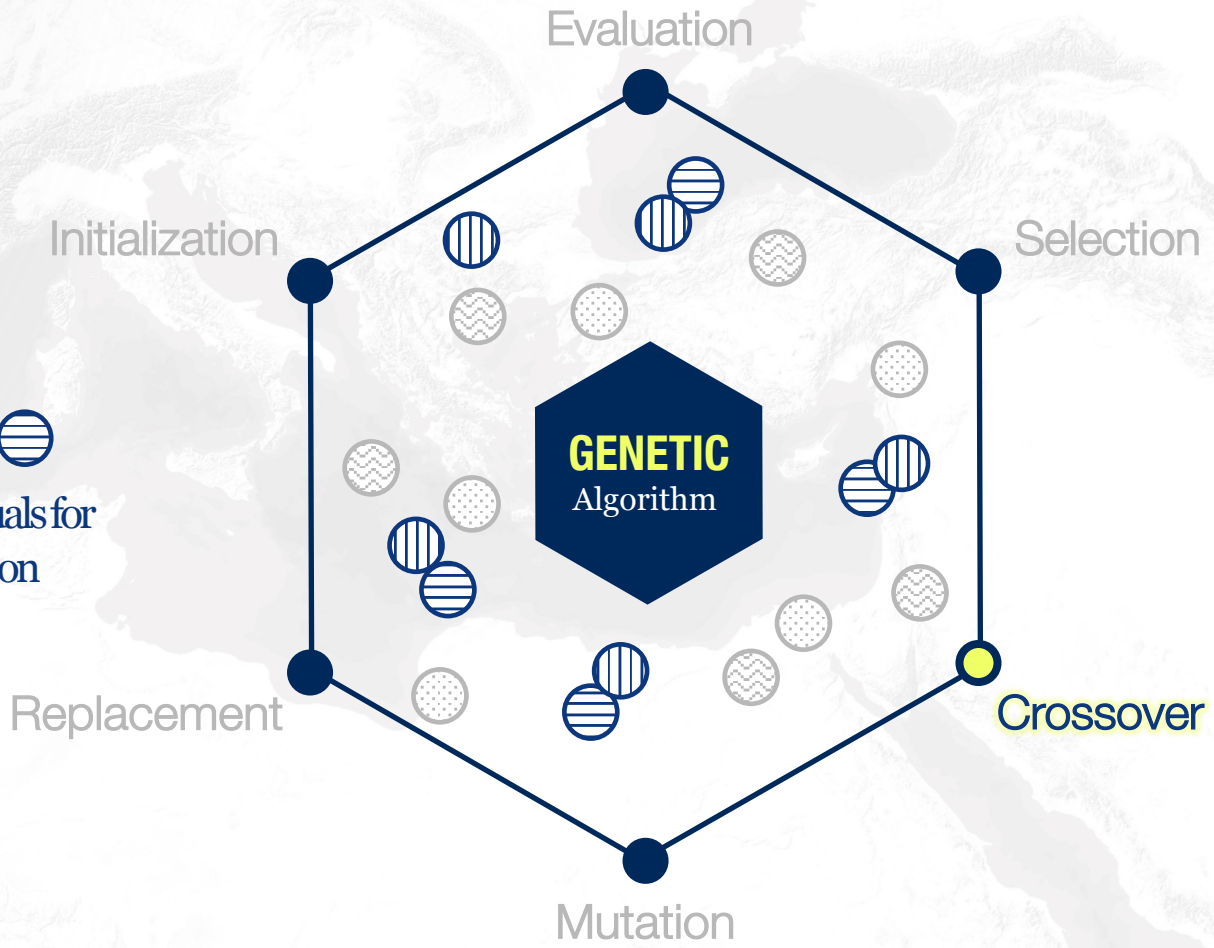


Select individuals for reproduction





New Individual

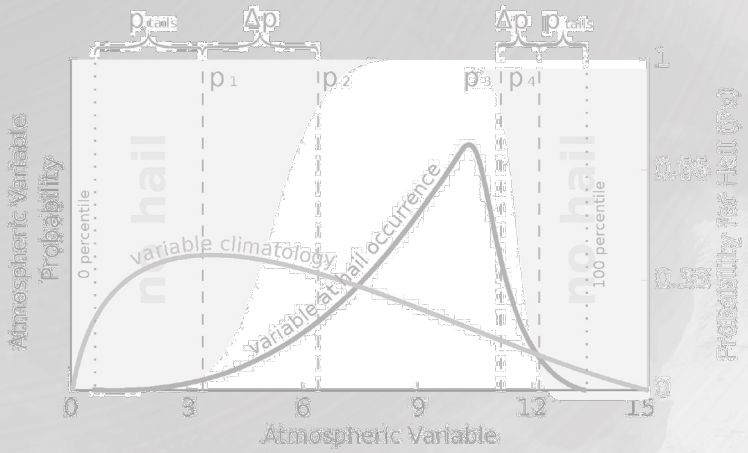


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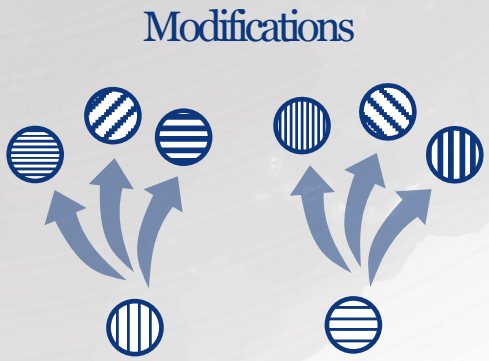
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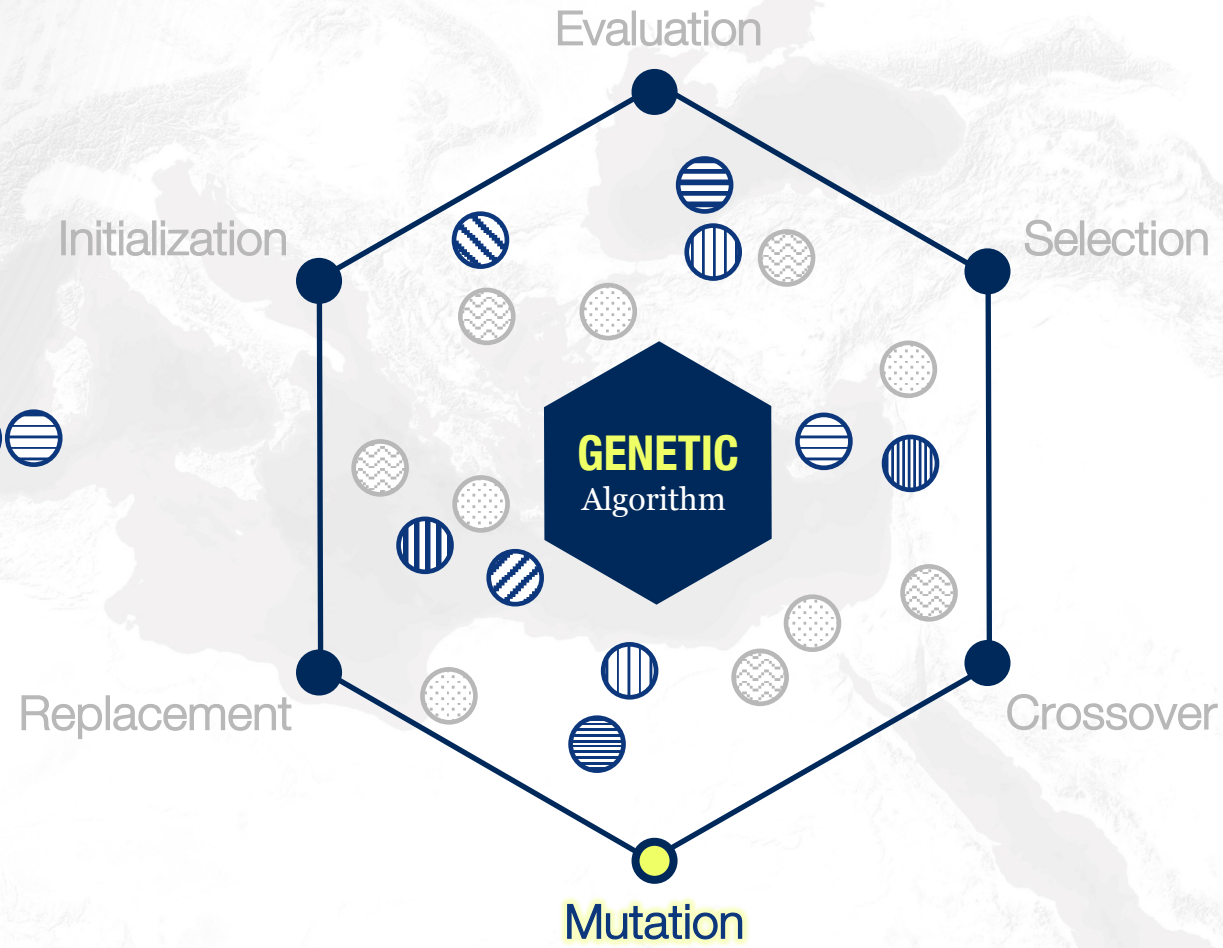






Modifications

New Individual

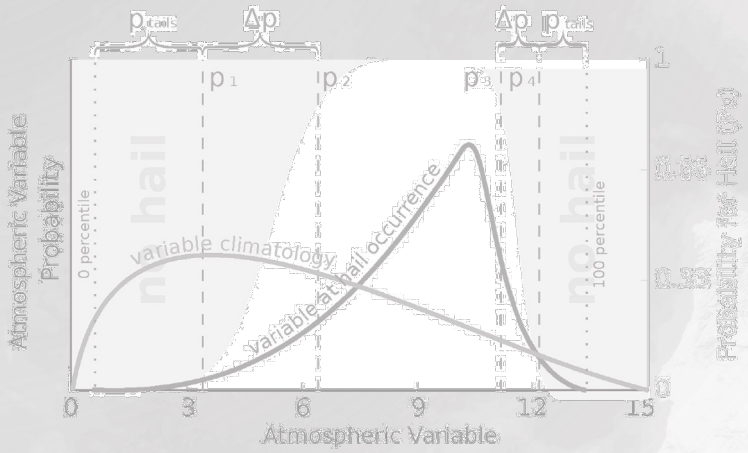


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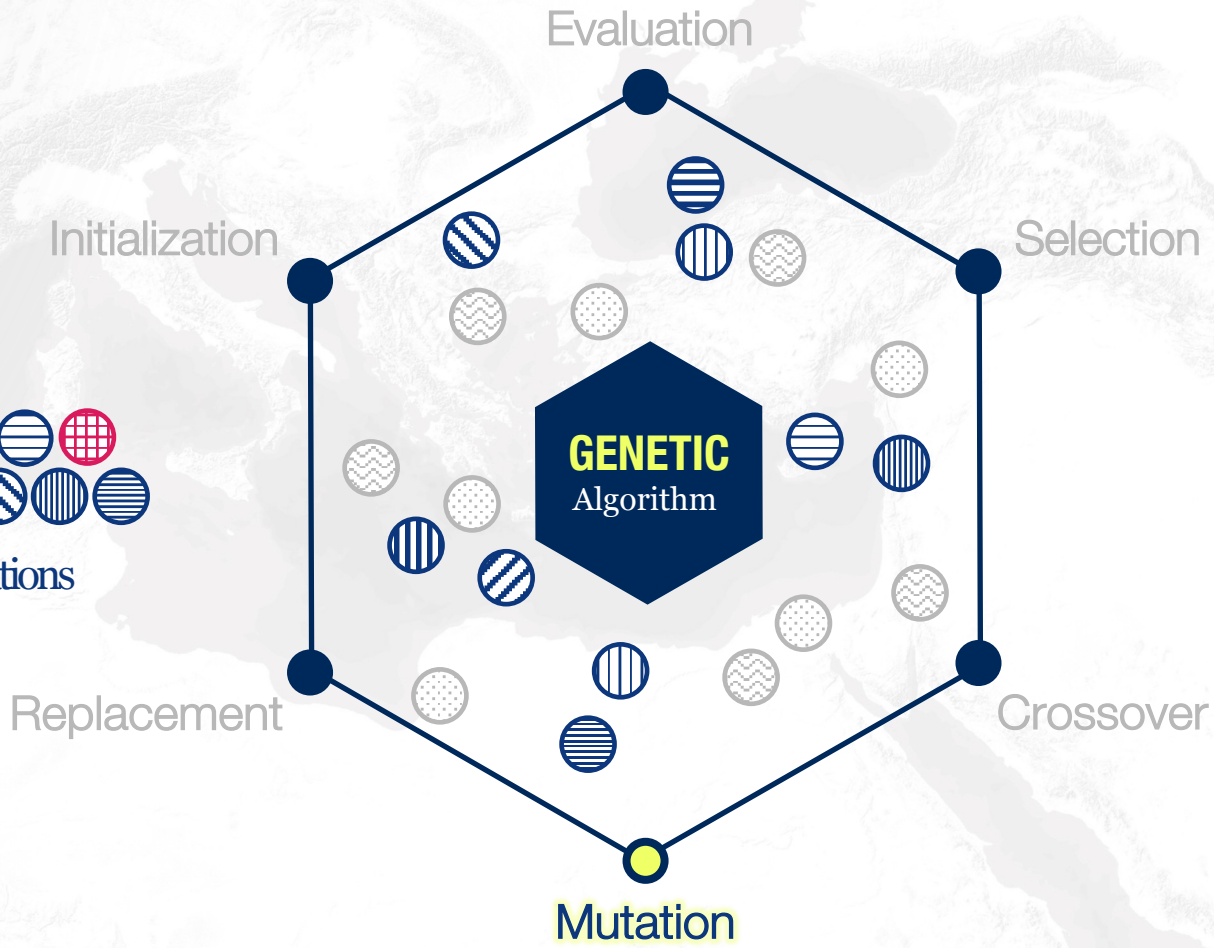
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Modifications

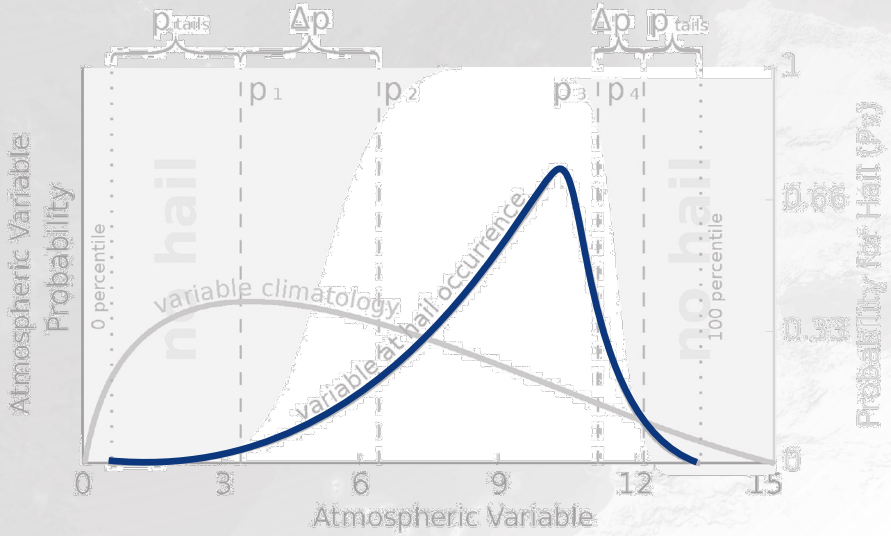


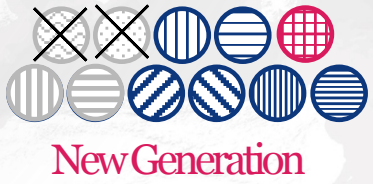
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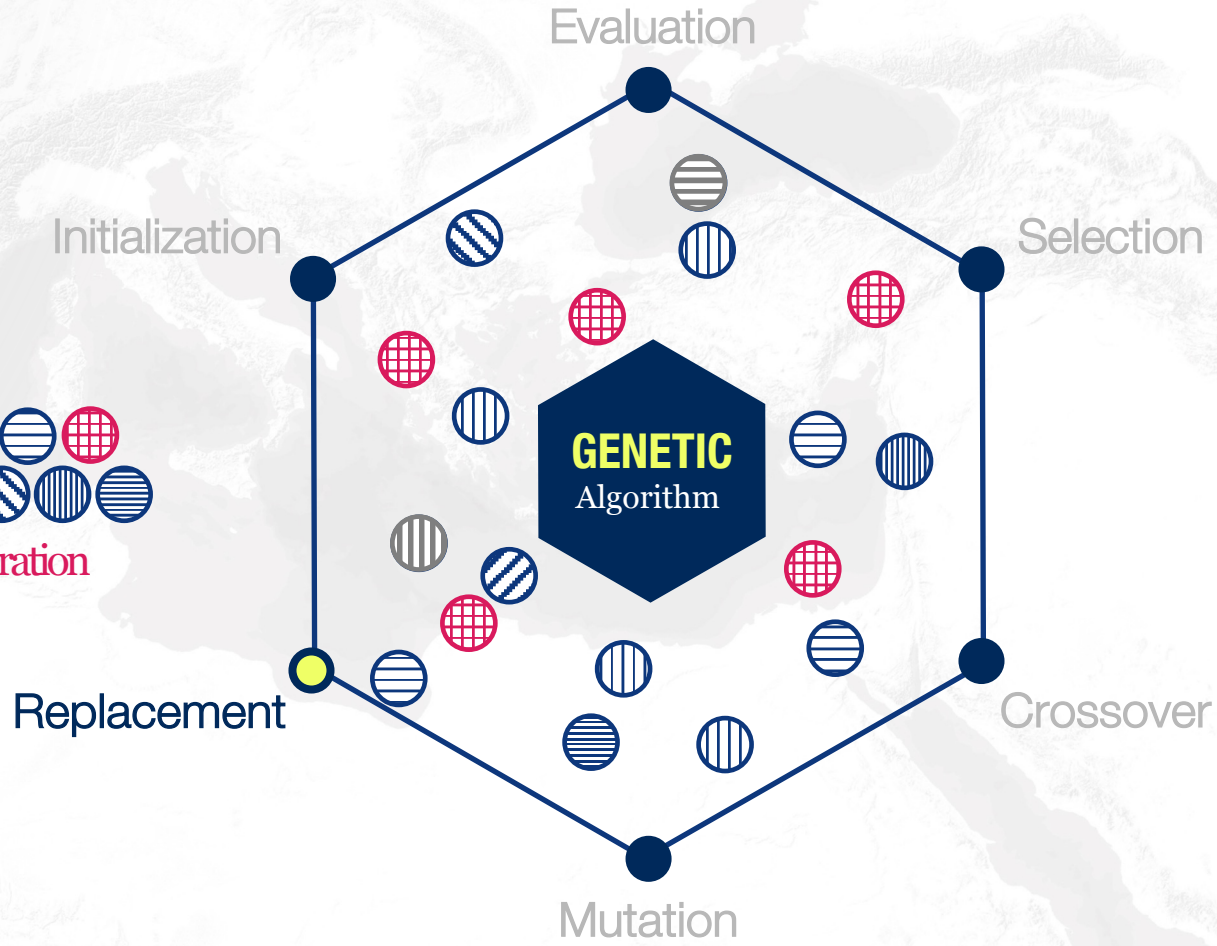
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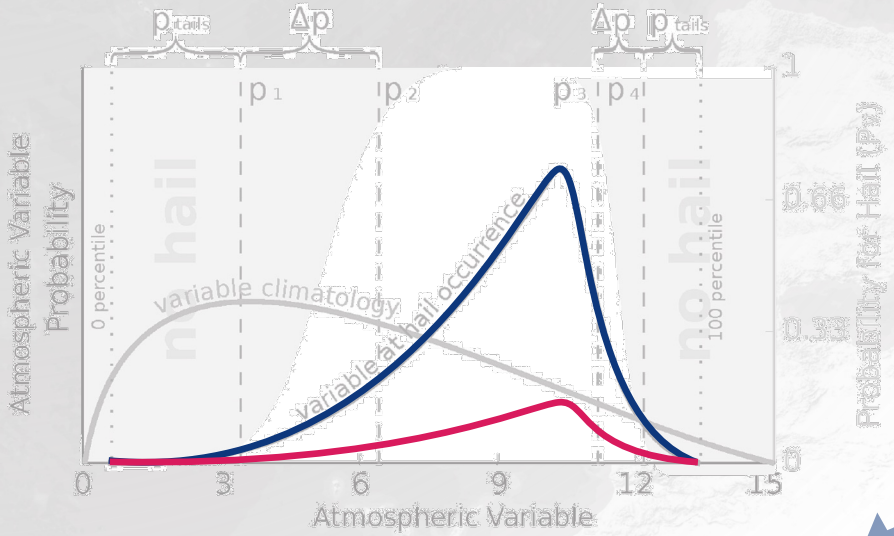


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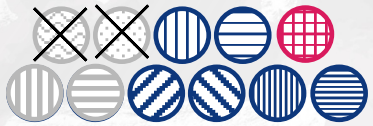
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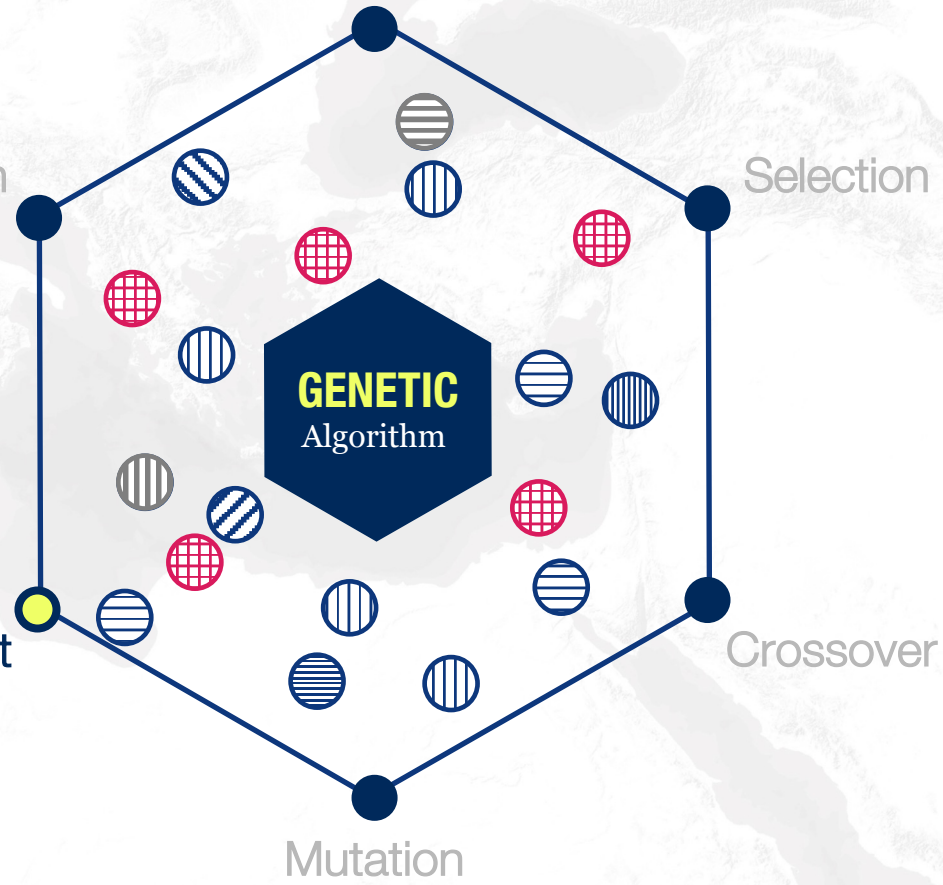
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New Distribution



New Generation

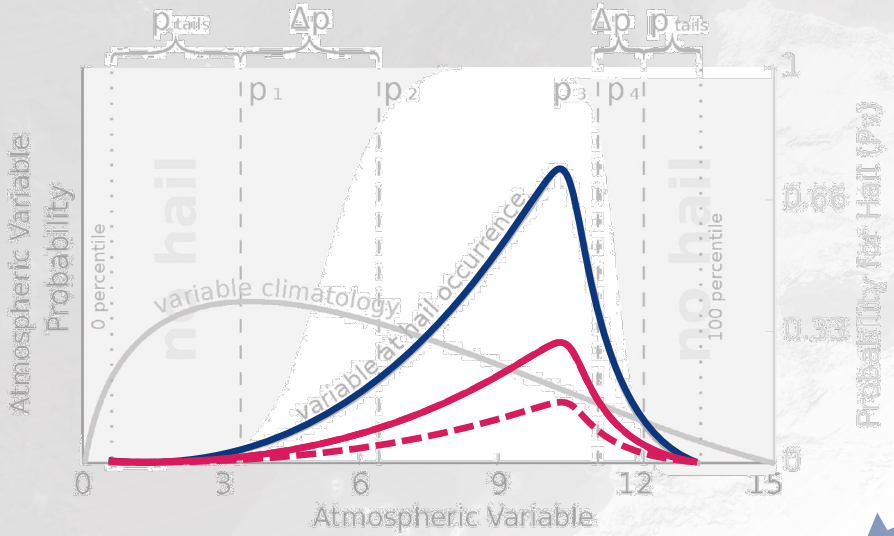


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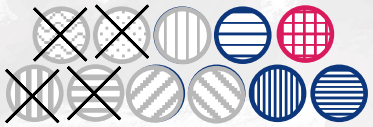
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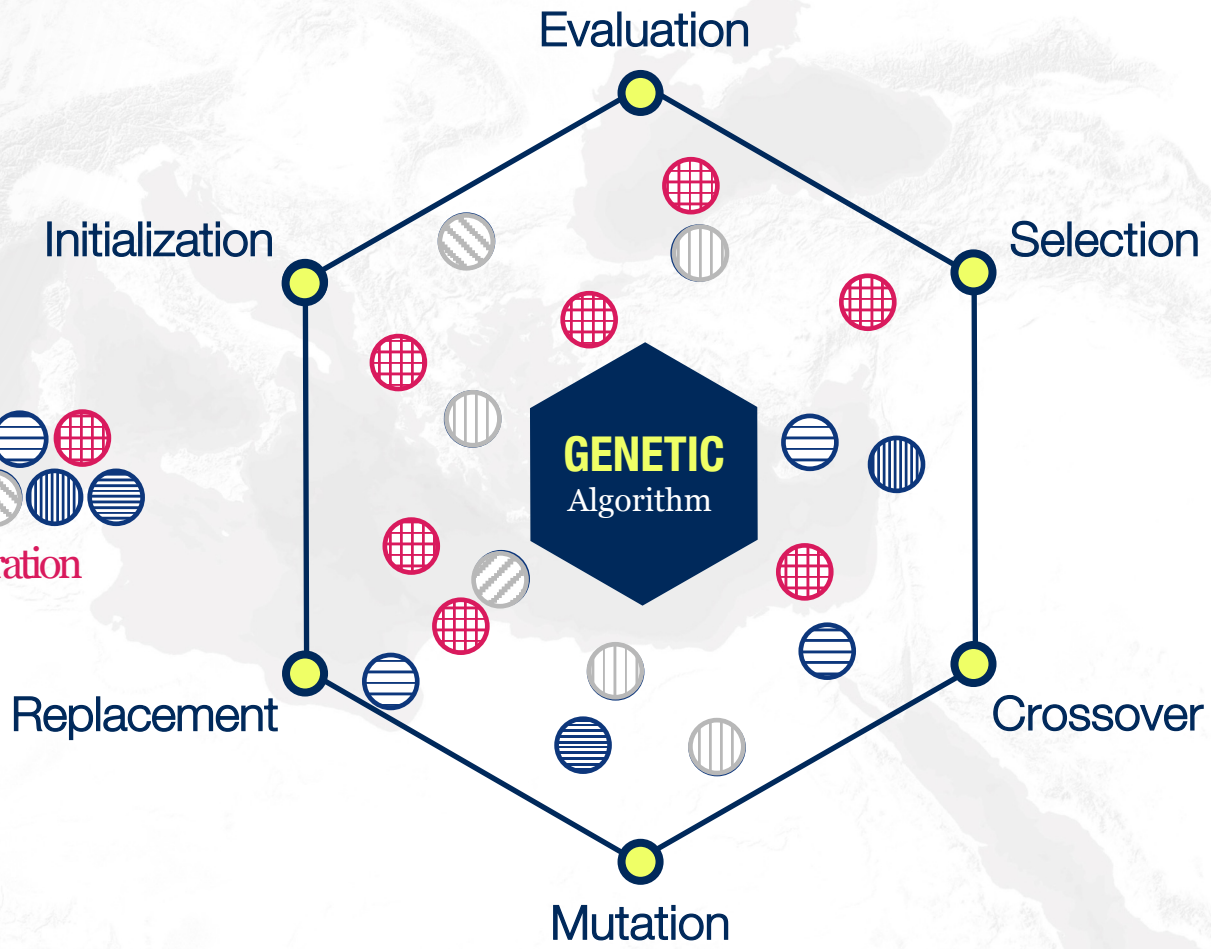
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New Distribution



New Generation

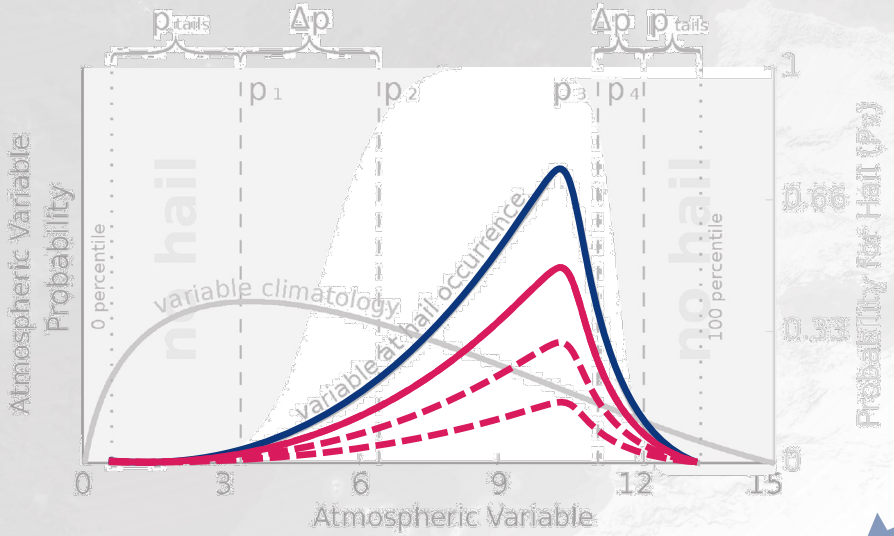


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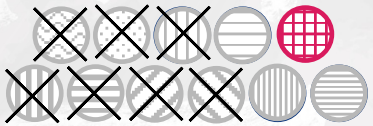
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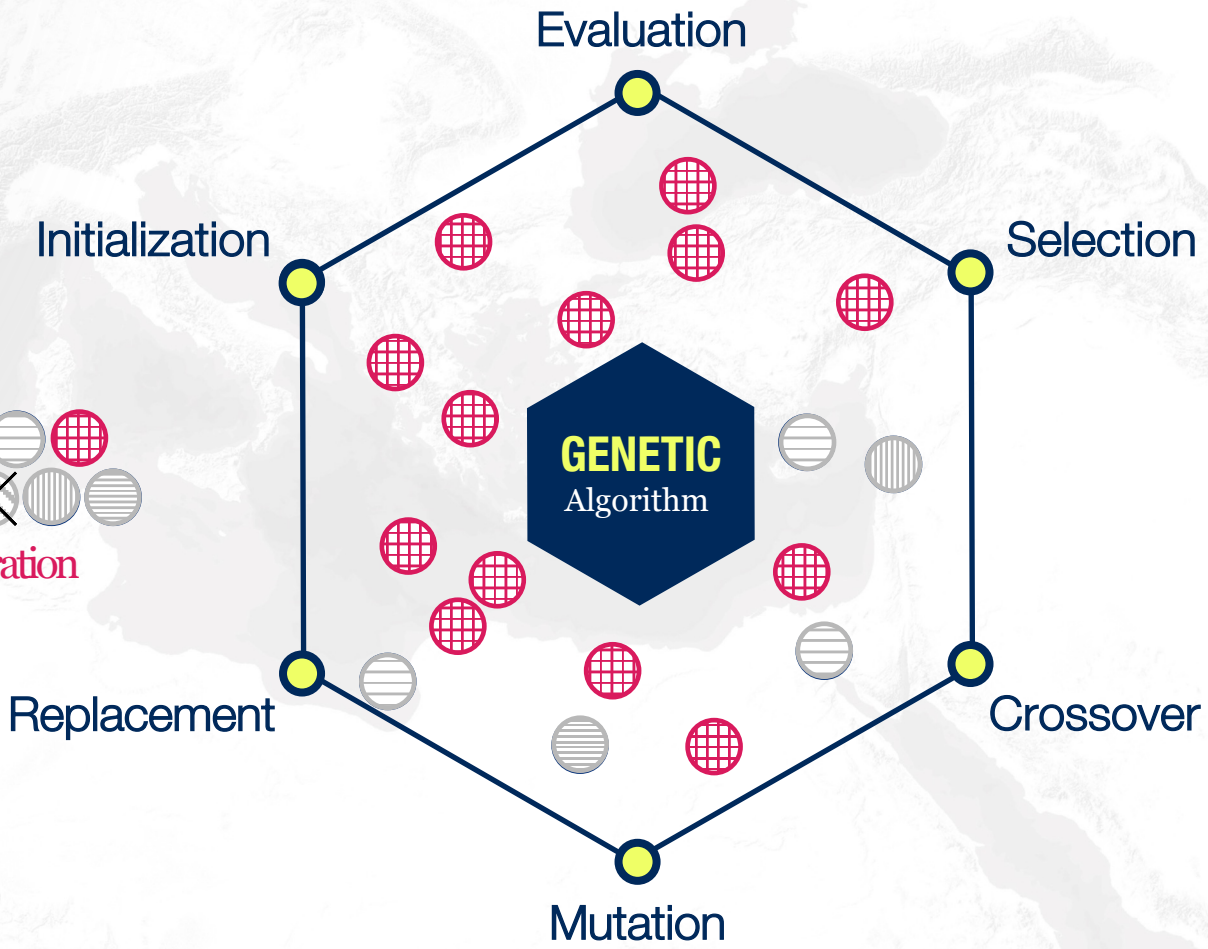
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New Distribution



New Generation

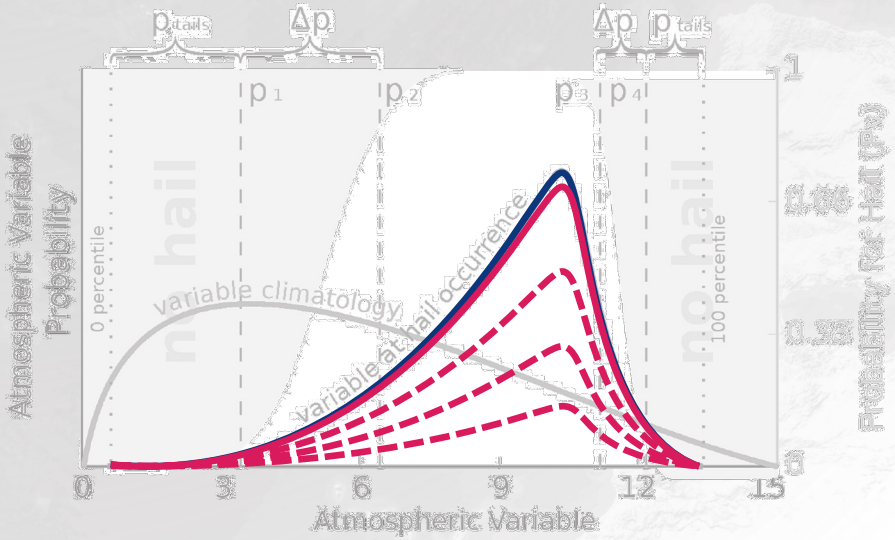


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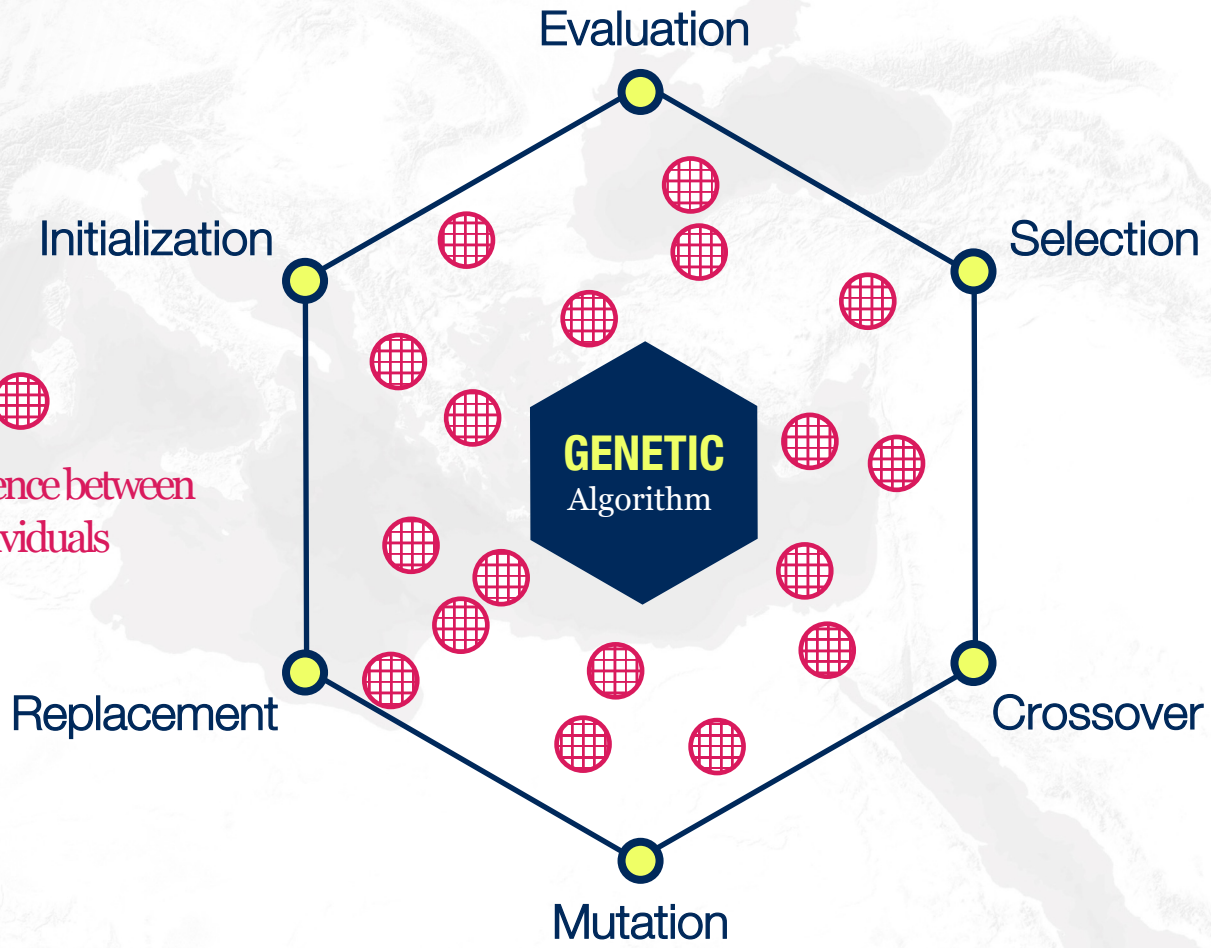
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No difference between individuals



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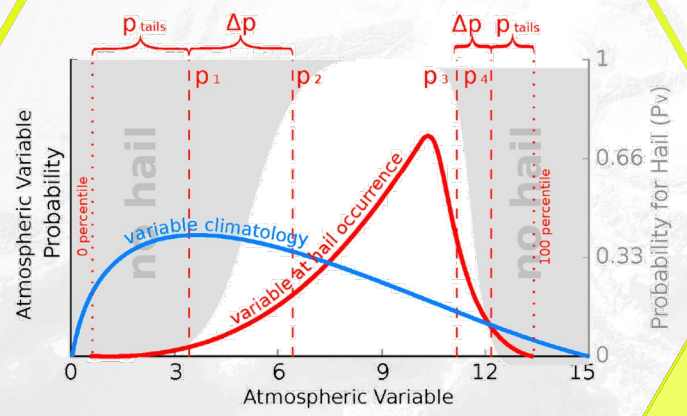
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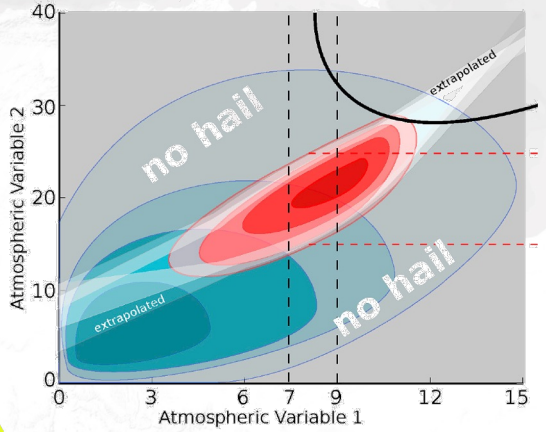
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HAIL records

LARGE SCALE Conditions





GENETIC Algorithm

HAIL Probability

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HAIL
records

LARGE SCALE
Conditions

TRAIN GASWE™

Receives training sets from PreGASWE

Extreme event probability function by variable

Variable's contribution on extreme event probability

GENETIC
Algorithm

HAIL
Probability

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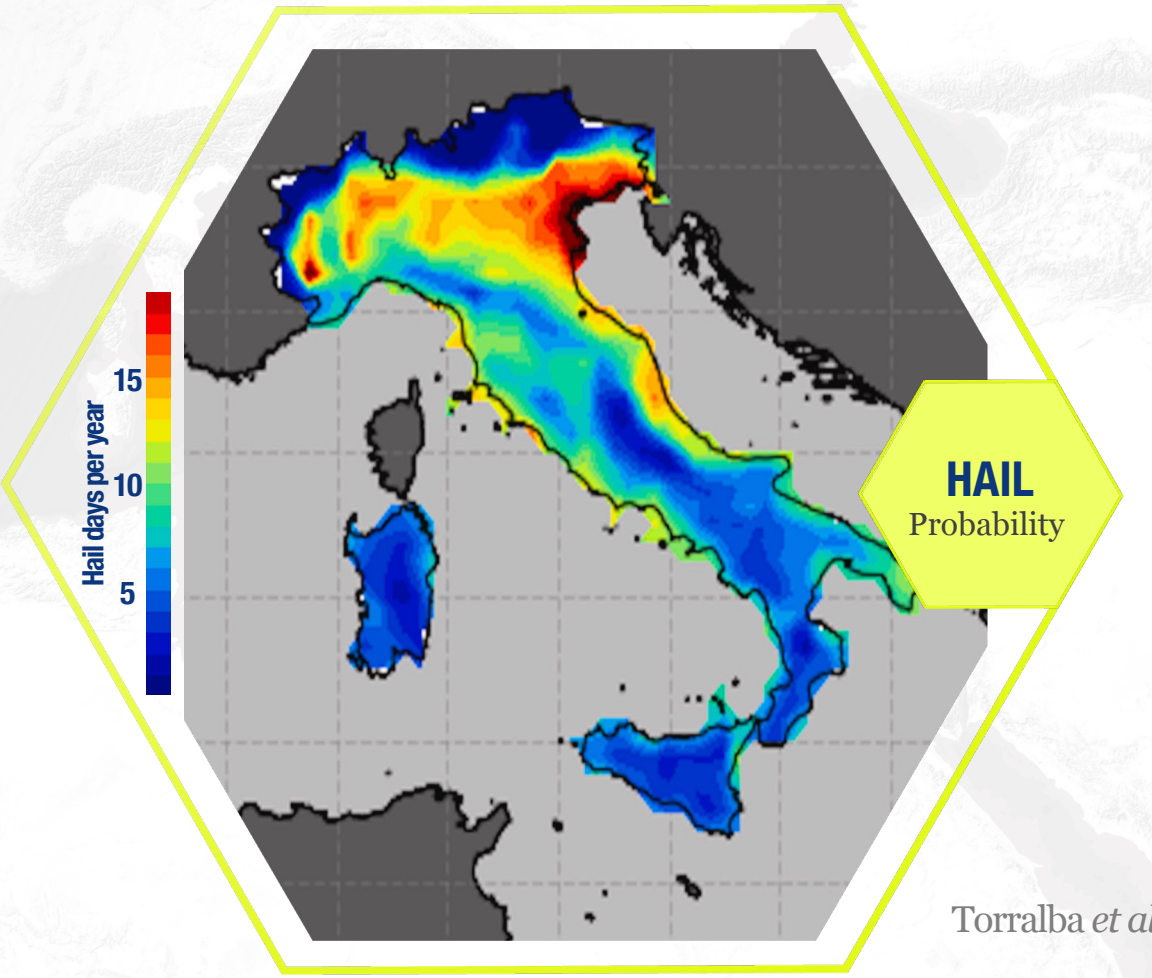
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HAIL records

LARGE SCALE Conditions

GENETIC Algorithm



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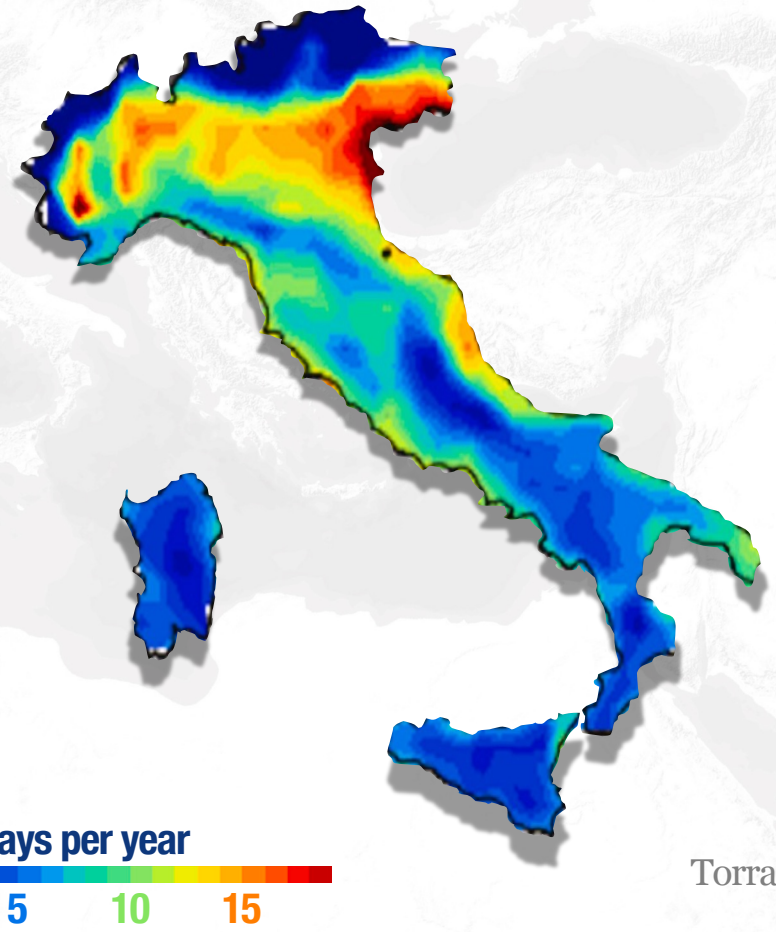
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Table 3
Selected variables and corresponding parameters for the general hail model (p_t = 0.0049). CAPE-FLH is the bivariate predictor resulting from the joint probability of CAPE and FLH. Note these variables are listed in alphabetical order as the GA does not provide ranked predictors.

	p_{tail}	Δp	c
BLH	1.9	25	0.31
CAPE	0.99	13	0.3
CAPE-FLH	3.02	19	0.26
CBH	5.89	7	0.32
TOTALI	3.5	5	0.31
VIDMF	1.12	29	0.32
WSH6	1.25	8	0.27

162 predictors → **7** Best predictors



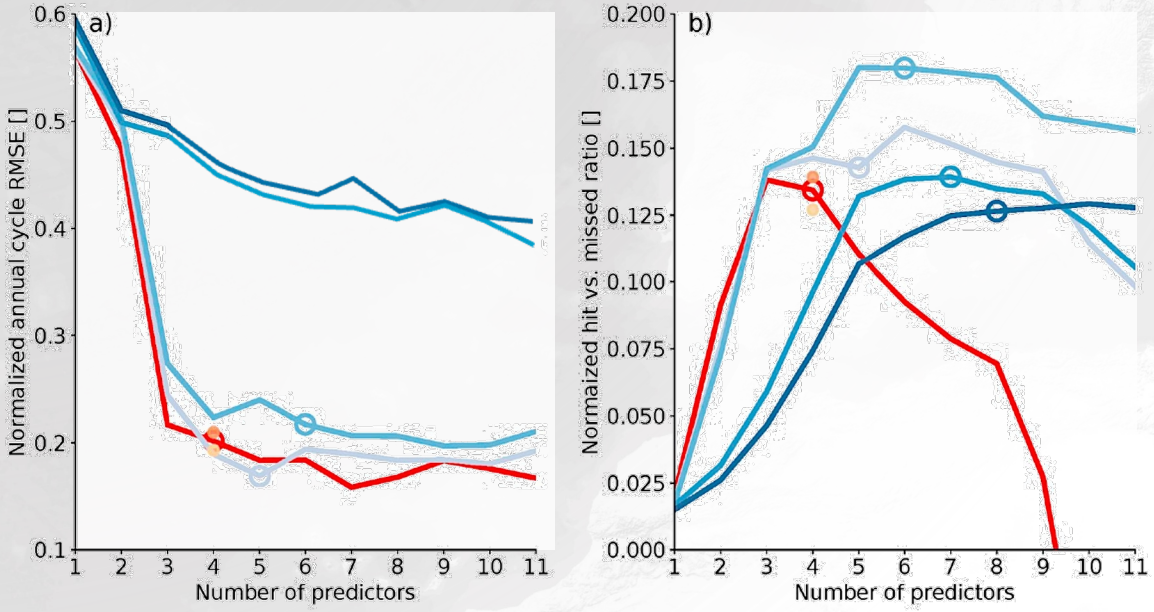
adapted from Torralba *et al.* (2023)

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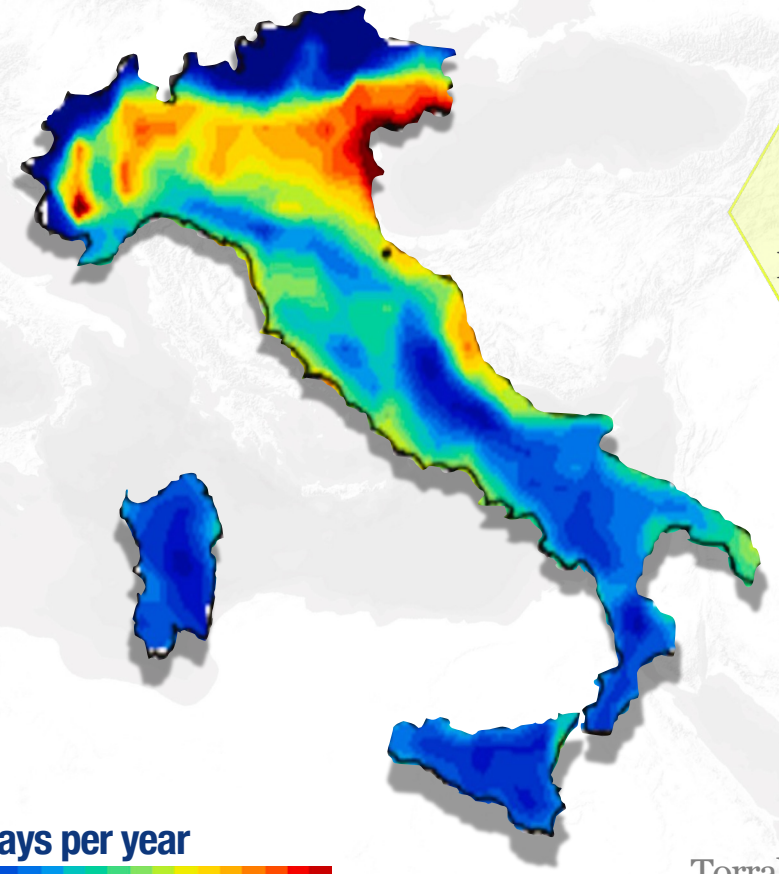
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adapted from
Prein & Holland (2018)



7
Best predictors

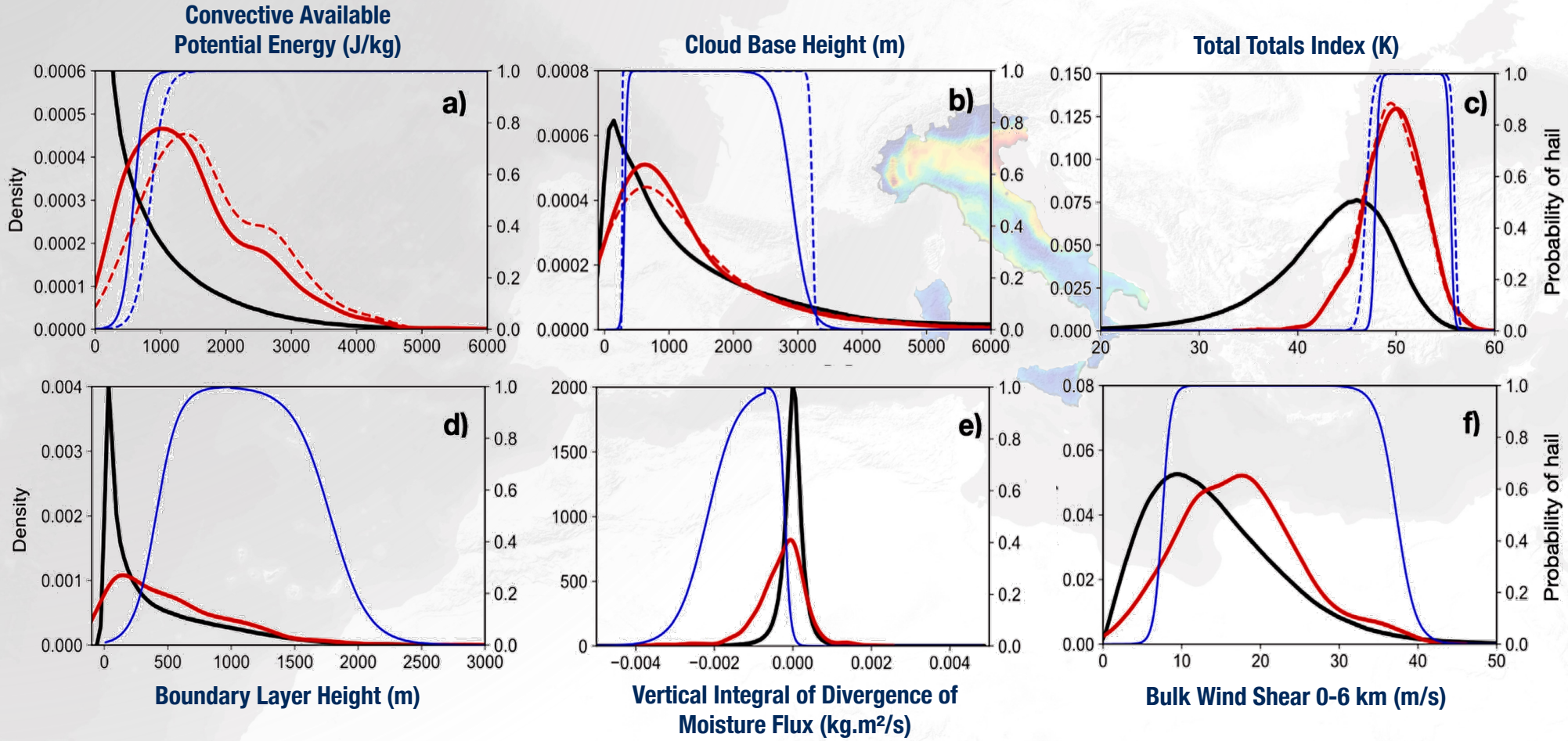
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7
Best predictors*

*CAPE-FLH omitted

Climatology
Hail days
Probability

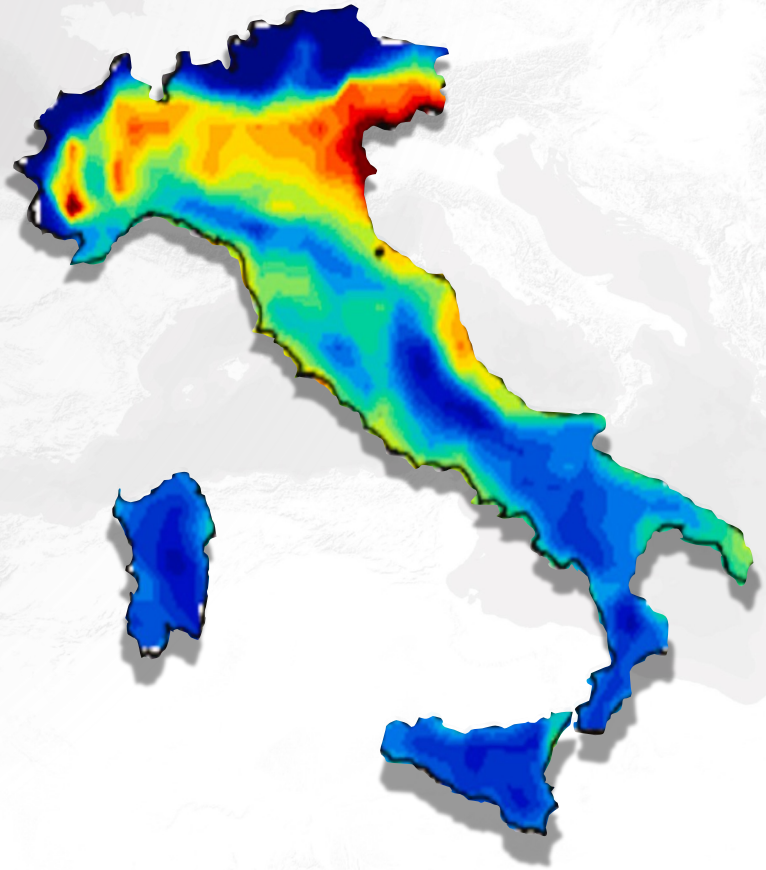
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Hail days per year

0 5 10 15

adapted from
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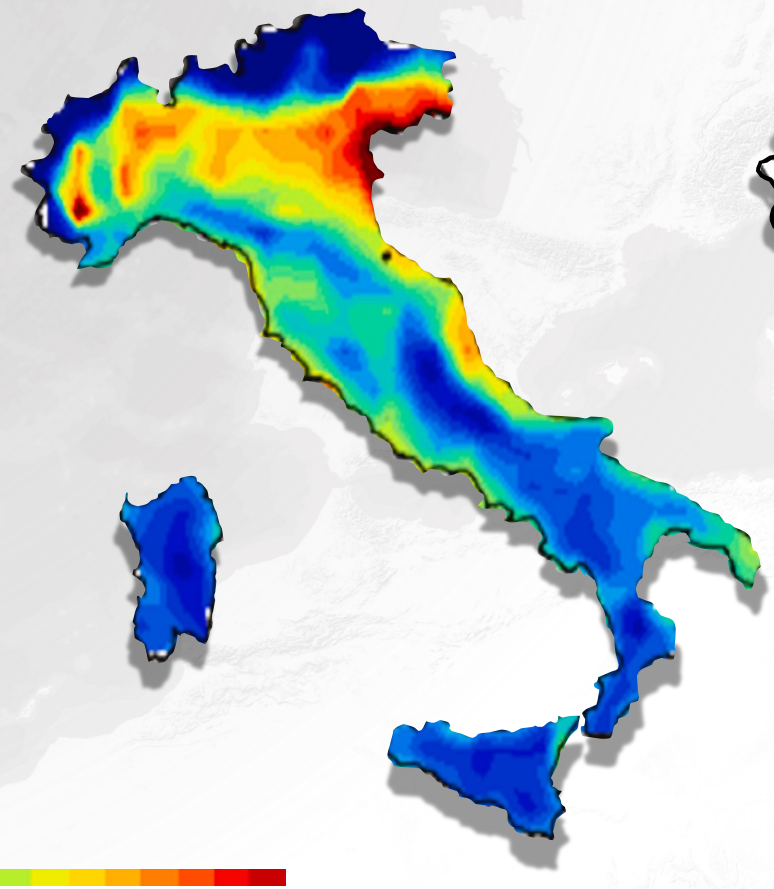
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HAIL PROBABILITY 1979-2020

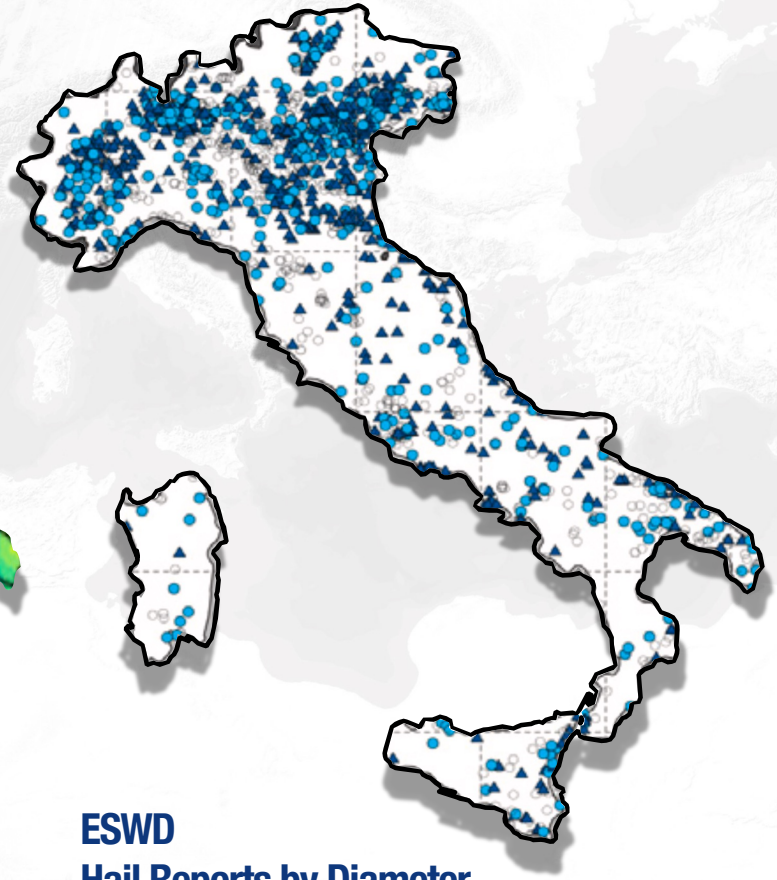
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Hail days per year

0 5 10 15



ESWD

Hail Reports by Diameter

○ Not Identified ◉ <= 2.5 cm ▲ > 2.5 cm

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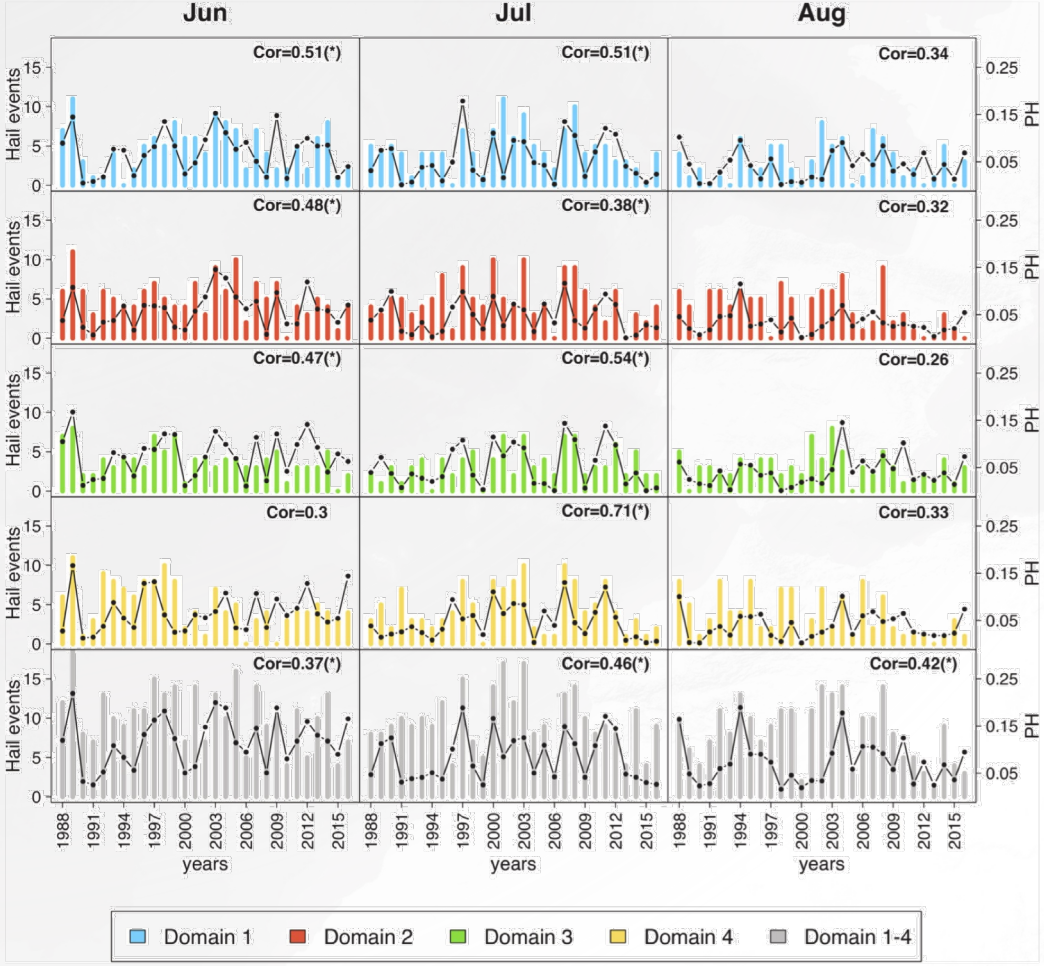
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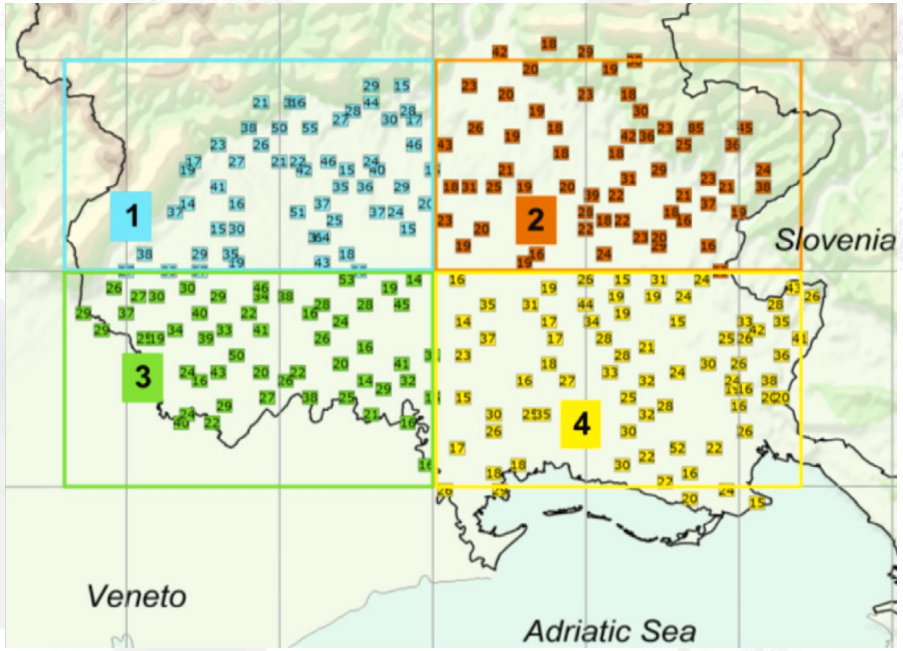
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Validation using 4 domains gathering 240 ARPA Friuli Venezia Giulia stations over the 1988-2016 period (June, July, and August)

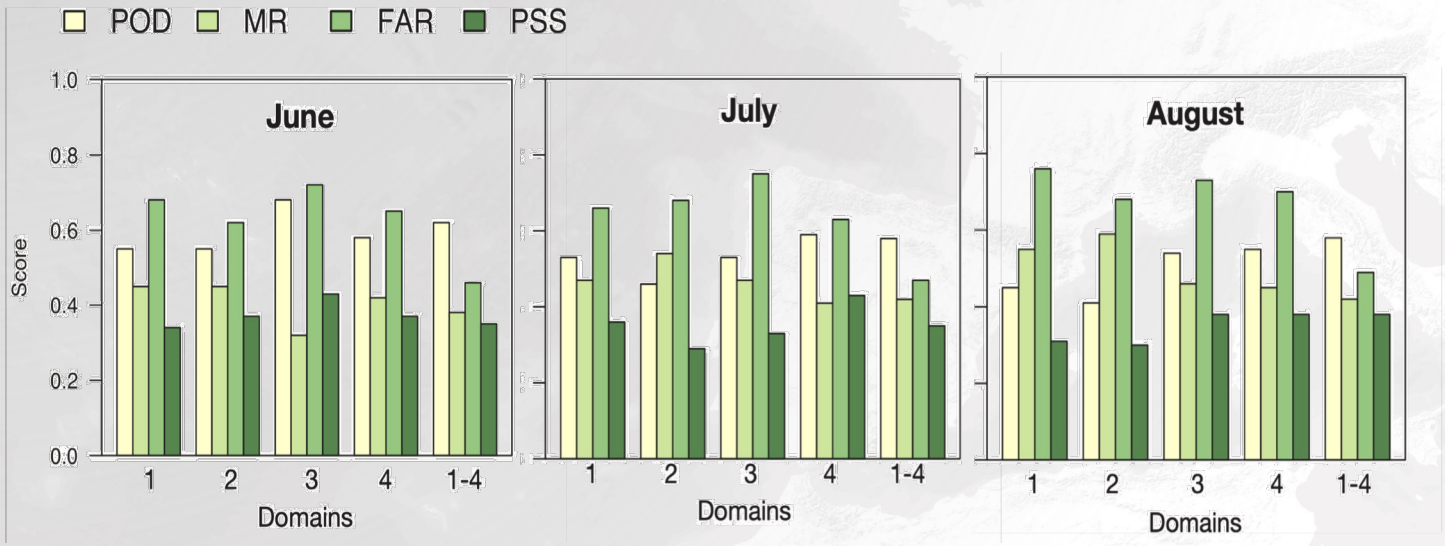
adapted from Torralba *et al.* (2023)

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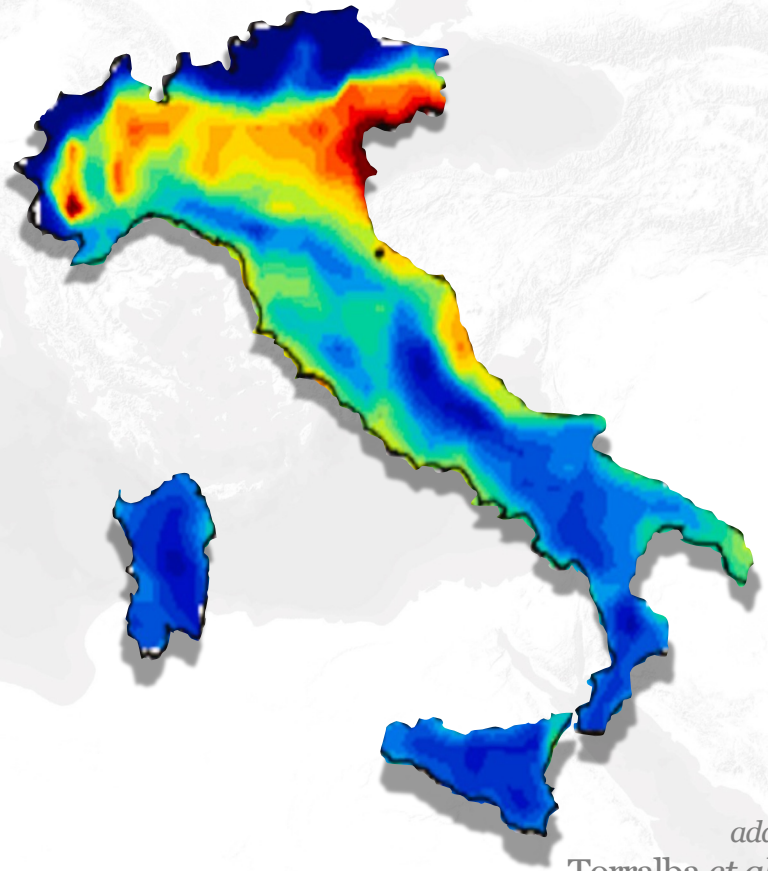
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over Italy using GA based on large-scale ERA5 predictors

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POD Probability of Detection, **MR** Missing Rate, **FAR** False Alarm Rate, **PSS** Peirce Skill Score



Hail days per year

0 5 10 15

adapted from Torralba *et al.* (2023)

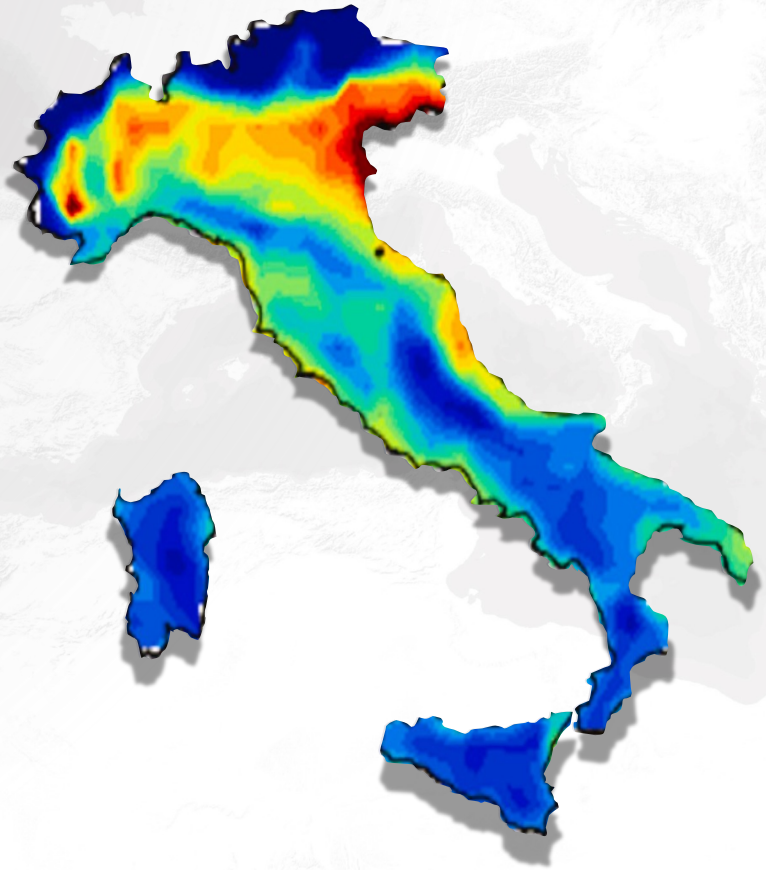
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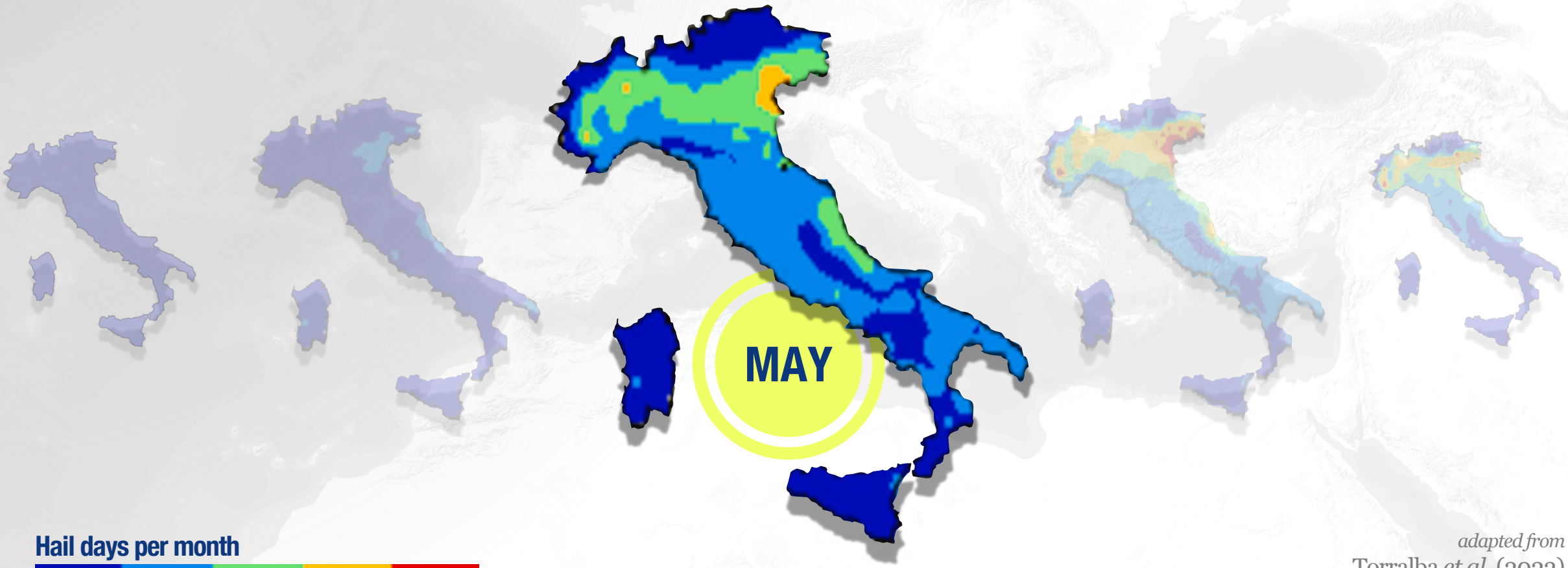
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Hail days per month

0 1 2 3 4

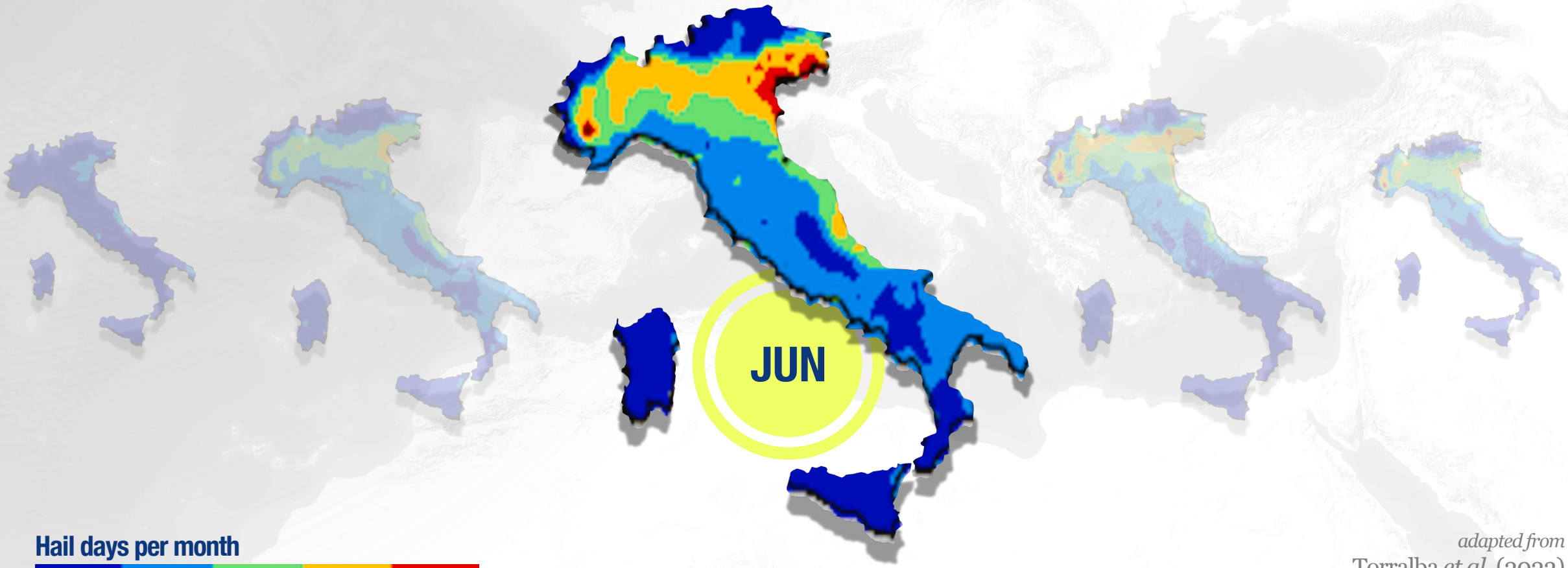
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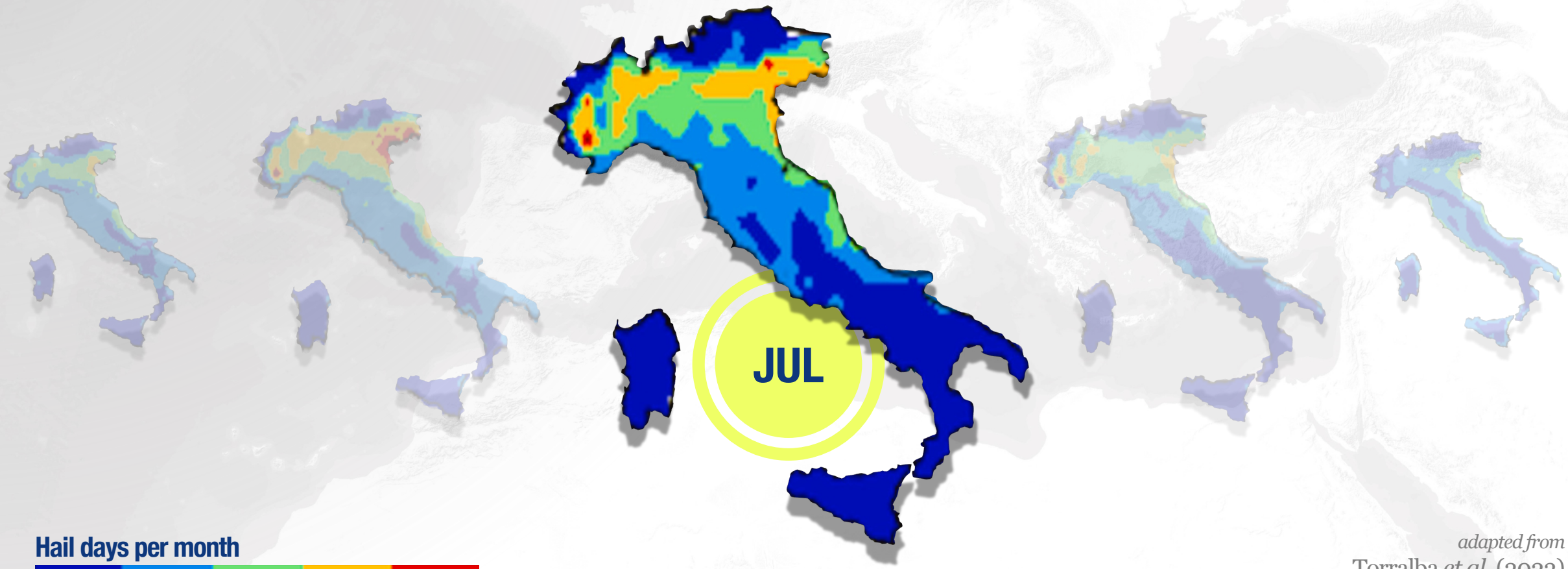
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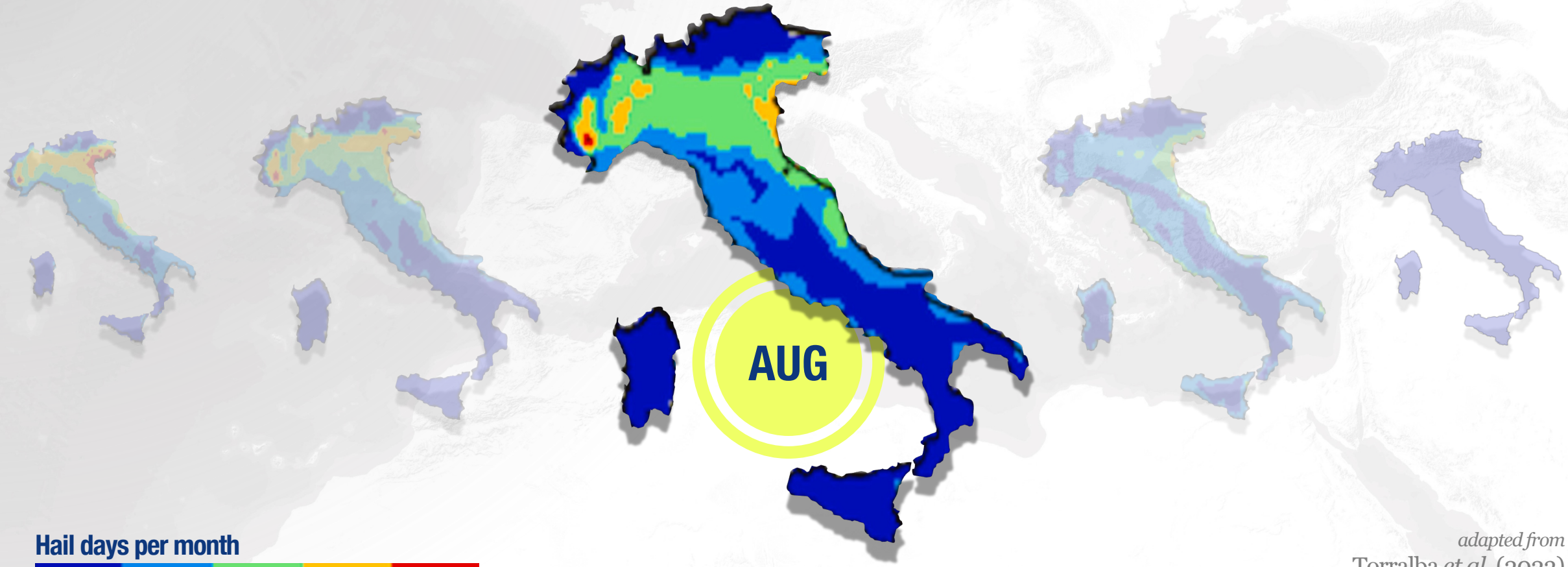
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SUMMARISED CONCLUSIONS

and take-home messages

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This study introduces and validates an innovative general hail model to assess total hail hazard across Italy from 1979 to 2020. Unlike most existing literature that focuses exclusively on severe hail, the hail probability model was trained on all available observations without any constraints on hailstone size. This provides a much more comprehensive overview of the total hail hazard across the Italian Peninsula.

The primary methodological advantage of this approach is the incorporation of a Genetic Algorithm. This method entirely eliminates human subjectivity from the predictor selection process and enables the algorithm to systematically evaluate 162 parameters to identify the most effective combination of seven convective indices and ERA5 variables.

The hail probability model effectively captured a significant spatial dynamic across Italy. Hail hazard is most prominent in northern Italy during early summer, reaching its peak in June and July. Conversely, in southern Italy, the hazard shifts to late summer and autumn, attributable to the Mediterranean Sea's thermal capacity, which maintains atmospheric instability later in the year.

Regarding the successful aspects of the model, it offers a significant enhancement in spatial resolution, achieving a sub-regional grid of 0.25 degrees—approximately 30 kilometres. Moreover, independent validation using ground-based hail pad data in the Friuli Venezia Giulia region confirmed that the model's detection capabilities are highly satisfactory during the peak summer months when such events are most prevalent.

Given these challenges, the model exhibits a high false-alarm rate, indicating a tendency to overestimate hail occurrences. This is a common obstacle for probabilistic severe weather models. Furthermore, it underestimates risk in mountainous regions such as the Alps because the smoothed orography in the ERA5 reanalysis distorts boundary-layer variables such as CAPE and the Total Totals index. Future research will focus on using higher-resolution datasets, such as ERA5-Land, to mitigate these limitations.

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SUMMARISED CONCLUSIONS

and take-home messages

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Innovative Modelling Approach

SUMMARISED CONCLUSIONS

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SUMMARISED CONCLUSIONS

and take-home messages

> *identify the most effective combination of seven convective indices and ERA5 variables.*

Genetic Algorithm Optimisation

SUMMARISED CONCLUSIONS

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SUMMARISED CONCLUSIONS

and take-home messages

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Seasonal Variability Mapping

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SUMMARISED CONCLUSIONS

and take-home messages

> *independent validation using ground-based hail pad data in the Friuli Venezia Giulia region confirmed that the model's detection capabilities*

Sub-regional scale validation

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SUMMARISED CONCLUSIONS

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The primary [illegible] incorporation of a Gaussian [illegible] subjectivity from the [illegible] systematically evaluate six parameters to identify the most effective combination of severe convection indices and ERA5 variables.

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[illegible] the model exhibits a high false-alarm rate, [illegible]. This is a common [illegible]. Furthermore, it underestimates risk in mountainous regions [illegible] the Alps because the smoothed orography in the ERA5 reanalysis distorts boundary-layer variables such as CAPE and the Total Totals index. Future research will focus on using higher-resolution datasets, such as ERA5-Land, to mitigate these limitations.

> *"the model exhibits a high false-alarm rate, indicating a tendency to overestimate hail occurrences."*

Next challenges

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SUMMARISED CONCLUSIONS

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STRENGTHENING THE RESEARCH CAPACITIES
FOR EXTREME WEATHER EVENTS IN ROMANIA

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SEVERE WEATHER THROUGH HAIL PROBABILITY

Extreme precipitation contextualised as severe weather events and described by AI probabilistic models

leonardo.aragao@cmcc.it

Leonardo Aragão[1], Leone Cavicchia[2] & Silvio Gualdi[1]

CMCC Foundation - Euro-Mediterranean Center on Climate Change
[1]Earth SYstem modeling and Data Assimilation (ESYDA)
[2]CLImate VAriability and Predictions (CLIVAP)

Thank you!

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