

# Genetic Improvement of Shoreline Equilibrium Models

19 May 2022

Mahmoud Al Najar

Supervised By: Rafael Almar (IRD), Dennis Wilson (ISAE), Jean-Marc Delvit (CNES), Erwin Bergsma (CNES)

# Genetic Improvement of Shoreline Equilibrium Models

## Context

- Need to anticipate changes in coastal topography/bathymetry in response to different natural processes
- Waves are a main driver in coastal zone evolution
- Goal: forecasting wave-driven shoreline change



Figure: "Schematic representation of the coastal zone, hazards, and metocean variables that are relevant for coastal marine hazards and their monitoring". Source: [1]

# Genetic Improvement of Shoreline Equilibrium Models

## Outline

- 1) Context and Dataset**
- 2) Cartesian Genetic Programming / Genetic Improvement**
- 3) ShoreFor in CGP**
- 3) Ablation study**
- 4) Current study & future directions**

# Dataset

# Dataset

- “Shoreshop” competition [8]
- Tairua, New Zealand
- ~15 years of data:
  - Daily video-derived shorelines
  - Hourly in-situ wave forcing (Hs, Tp, Dir)

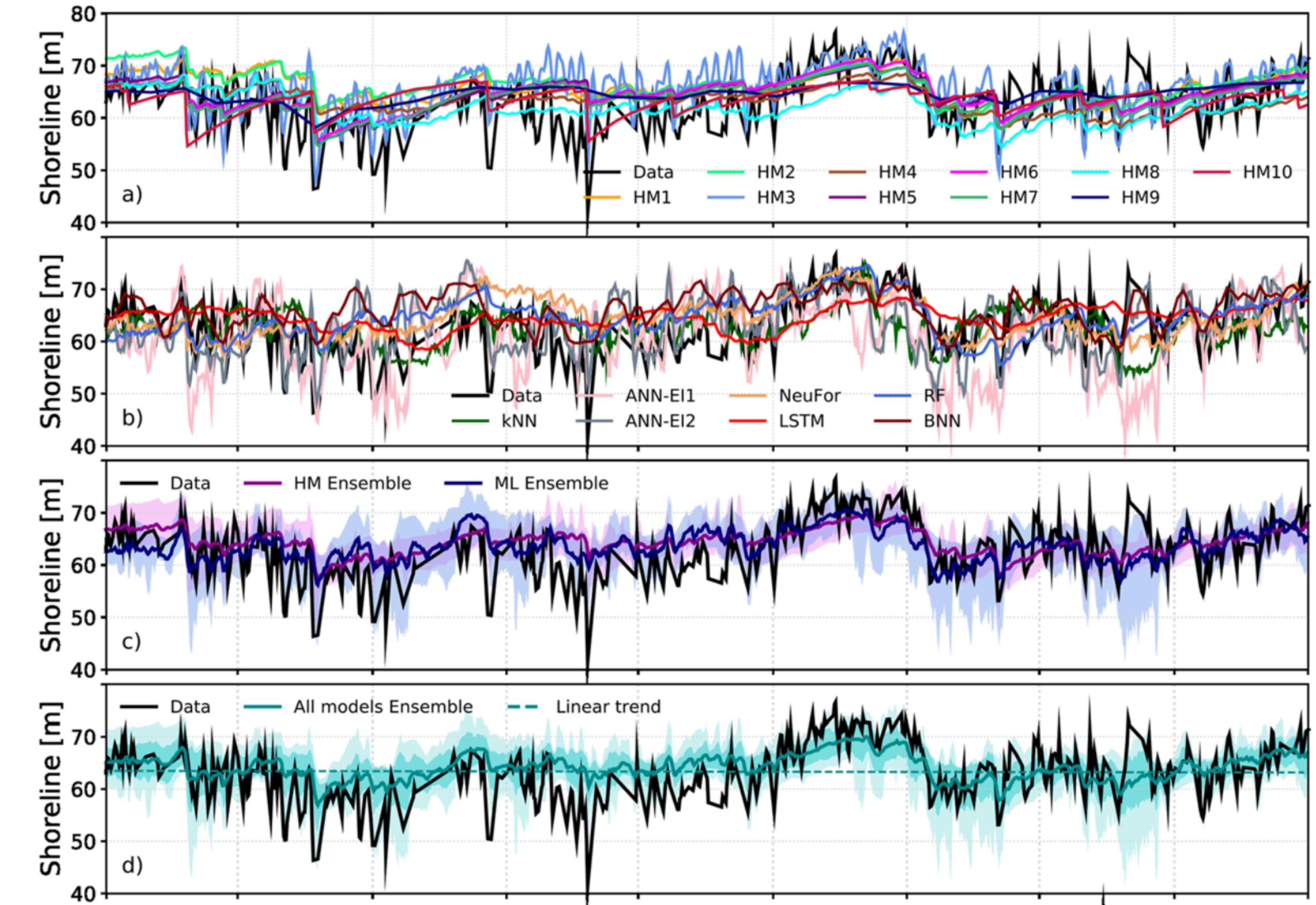


Figure: Model performance comparison [2]

# Methods

# Methods

## Cartesian Genetic Programming

- GP: population-based stochastic optimization

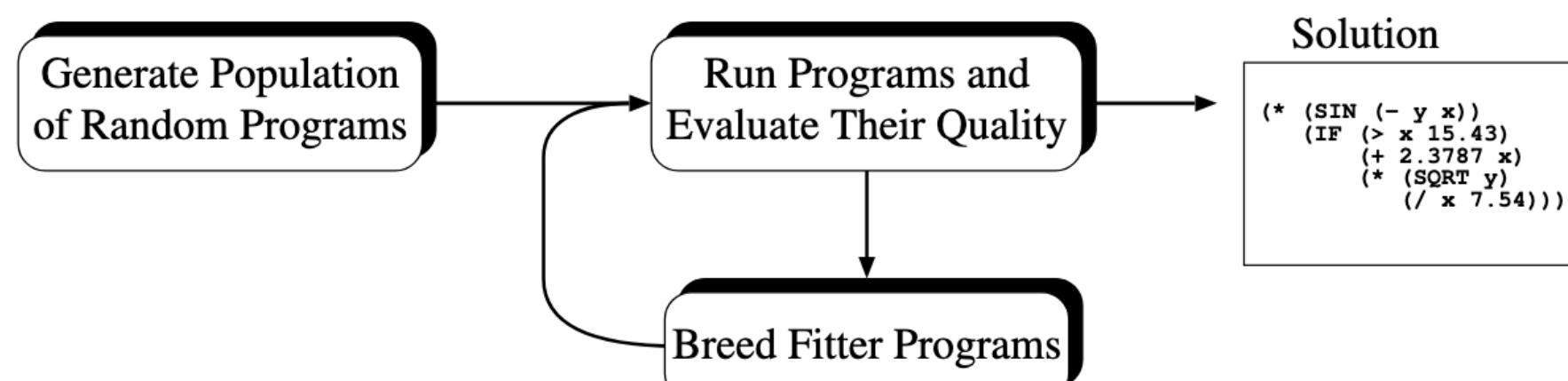


Figure: General structure of an evolutionary algorithm

- GP has different variants (Tree-based, Stack-based, Cartesian)
- “White-box” approach

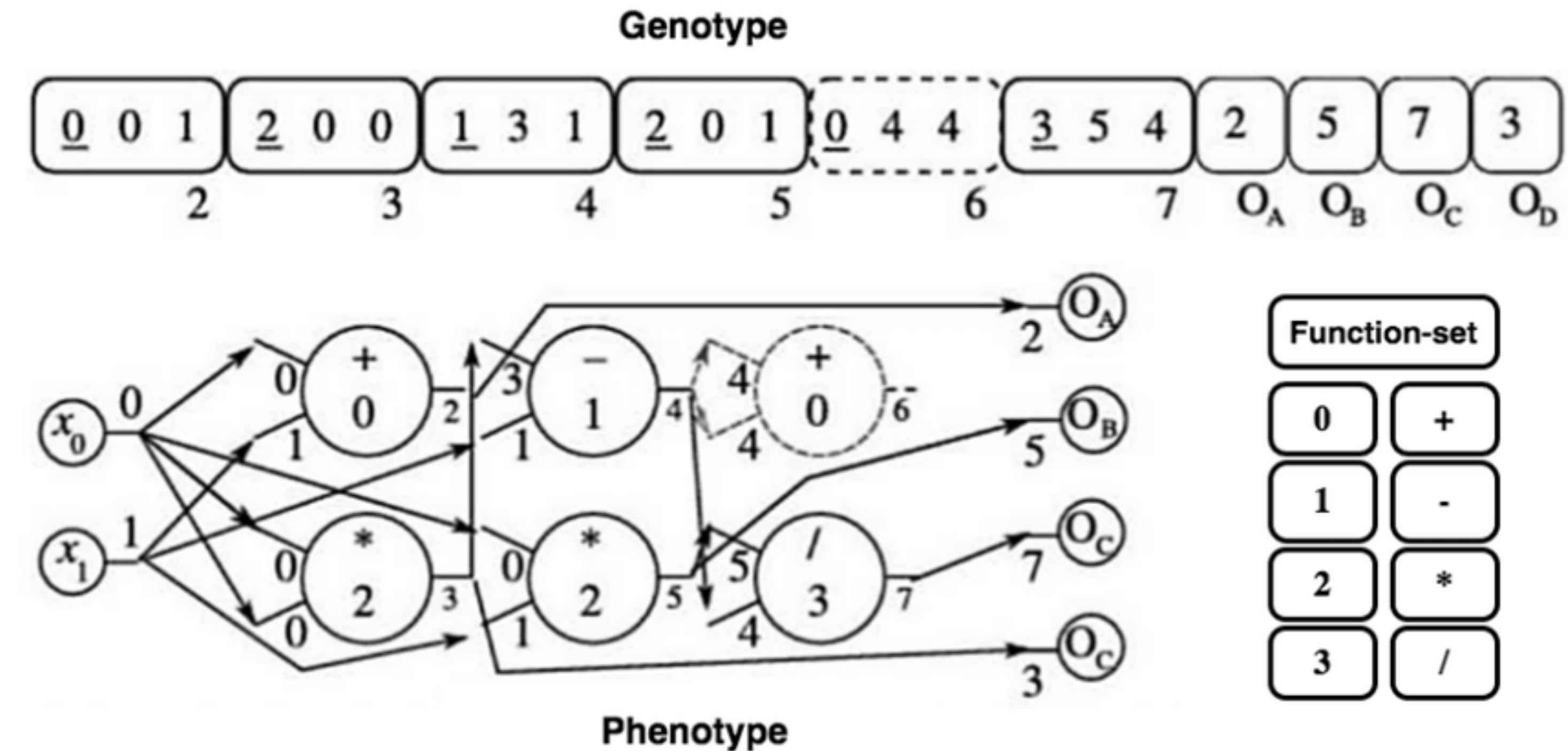


Figure: CGP Individual Encoding. Source: [3]

# Methods

## Genetic Improvement of ShoreFor

- GI: Optimization of existing software/models using GA's
- ShoreFor: shoreline equilibrium model [4,5]

$$\frac{dx}{dt} = c(F^+ + rF^-) + b$$

$$\Omega_{eq} = \frac{\sum_{i=1}^{2\phi} \Omega_i 10^{-i/\phi}}{\sum_{i=1}^{2\phi} 10^{-i/\phi}}$$

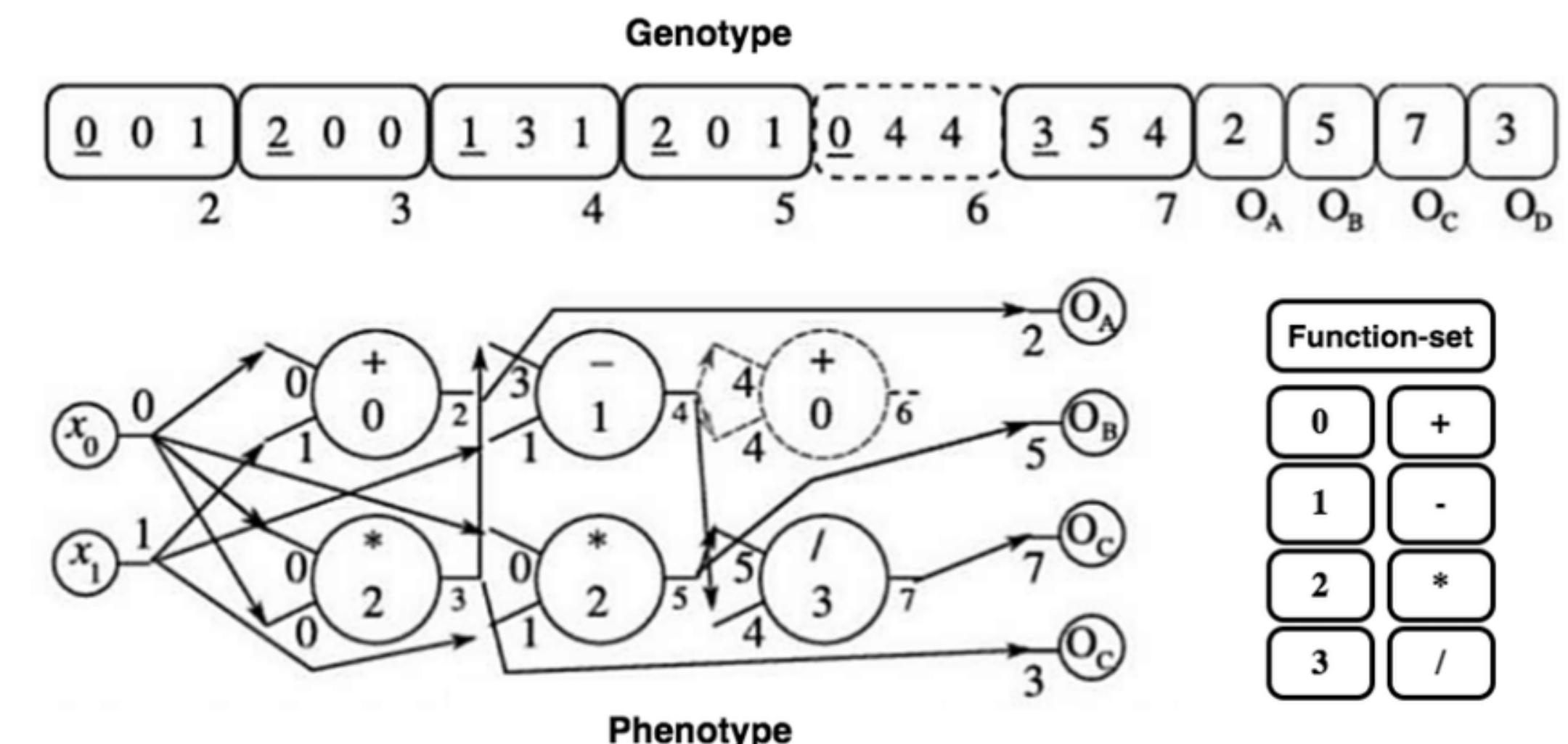


Figure: CGP Individual Encoding. Source: [3]

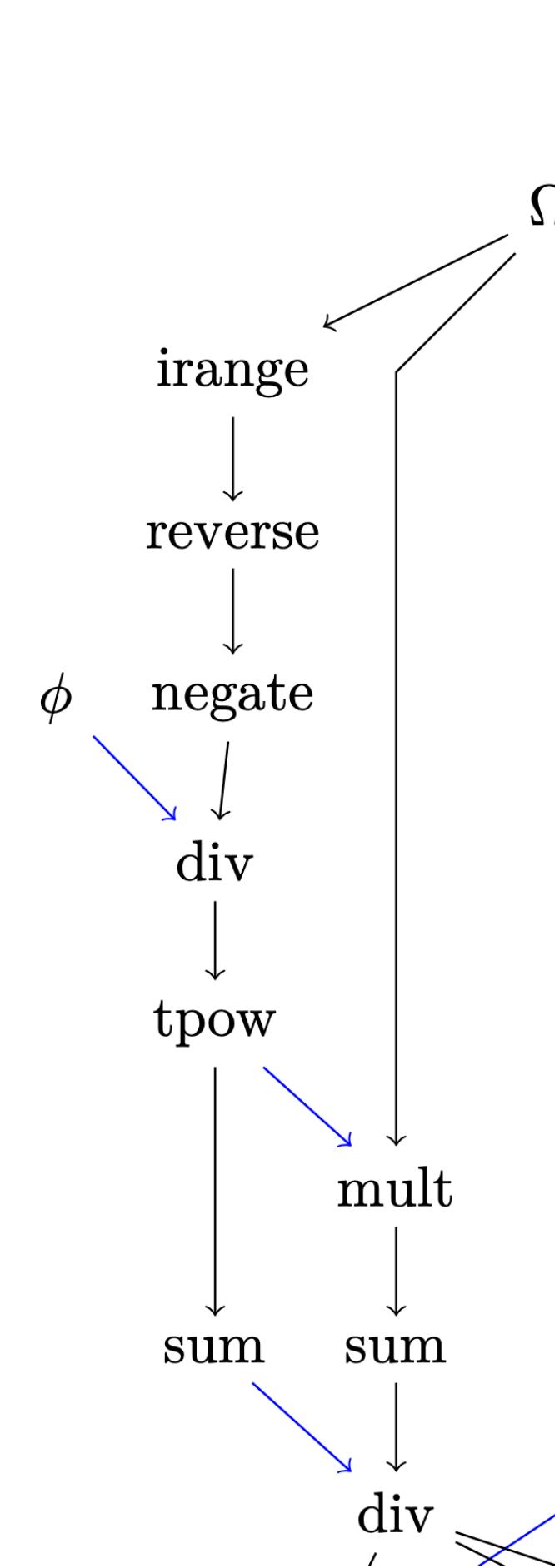
[4] Davidson, M. A., Splinter, K. D. & Turner, I. L. A simple equilibrium model for predicting shoreline change. Coast. Eng. 73, 191–202 (2013).

[5] Splinter, K. D. et al. A generalized equilibrium model for predicting daily to interannual shoreline response. J. Geophys. Res. F Earth Surf. 119, 1–23 (2014)

# Methods

## ShoreFor as a (sequential) CGP individual

$$\Omega_{eq} = \frac{\sum_{i=1}^{2\phi} \Omega_i 10^{-i/\phi}}{\sum_{i=1}^{2\phi} 10^{-i/\phi}}$$



ShoreFor	
$\frac{dx}{dt}$	$= c(F^+ + rF^-) + b$
$\Omega_{eq}$	$= \frac{\sum_{i=1}^{2\phi} \Omega_i 10^{-i/\phi}}{\sum_{i=1}^{2\phi} 10^{-i/\phi}}$
$F$	$= P^{0.5} \frac{\Delta\Omega}{\sigma_{\Delta\Omega}}$
$r$	$= \left  \frac{\sum_{i=0}^N \langle F_i^+ \rangle}{\sum_{i=0}^N \langle F_i^- \rangle} \right $
$\Omega$	$= \frac{H_{s,b}}{wT_p}$

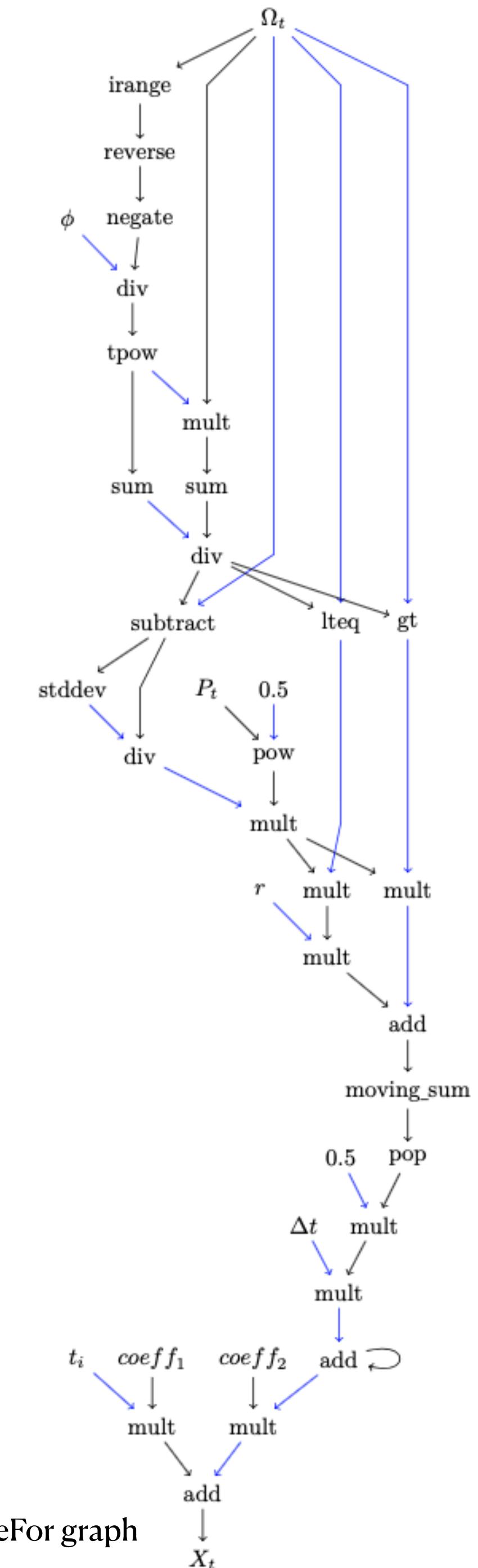
Figure: example sub-graph showing the encoding of the  $\Omega_{eq}$  equation

Table: ShoreFor system of equations

Inputs
$\Omega$
$P$
$\phi$
0.5
dt_waves
current_time
coeff_time
c
r

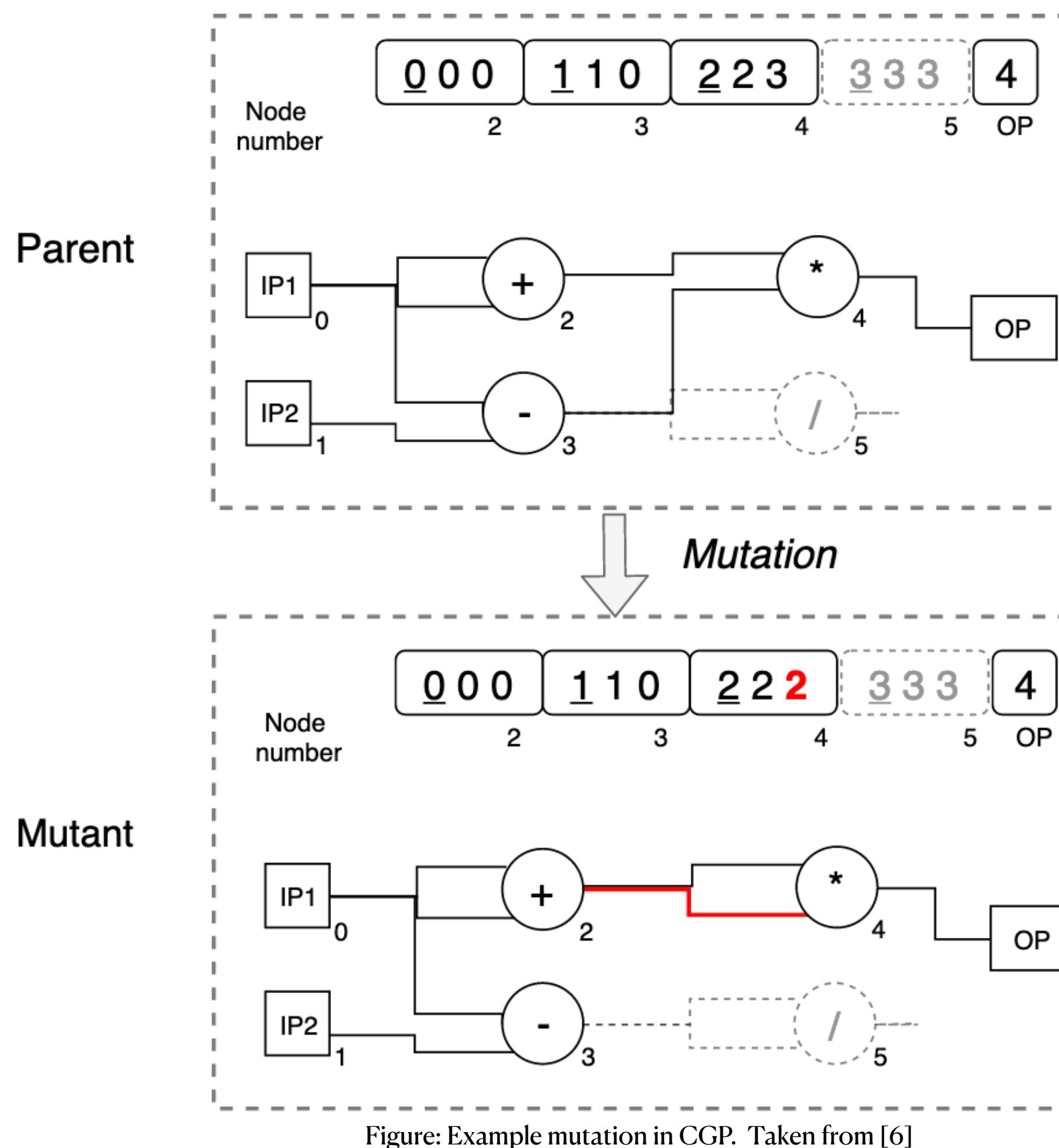
Input window size =  $2\phi$

Table, Figure: sequential ShoreFor graph



# Methods

## Mutations & Constraints



Level	Constraint
Evaluation	$std(\hat{y}) > \alpha_1$
Mutation	model length $> \alpha_2$
Mutation	$model(rand_1) \neq model(rand_2)$
Mutation	no input-output connections

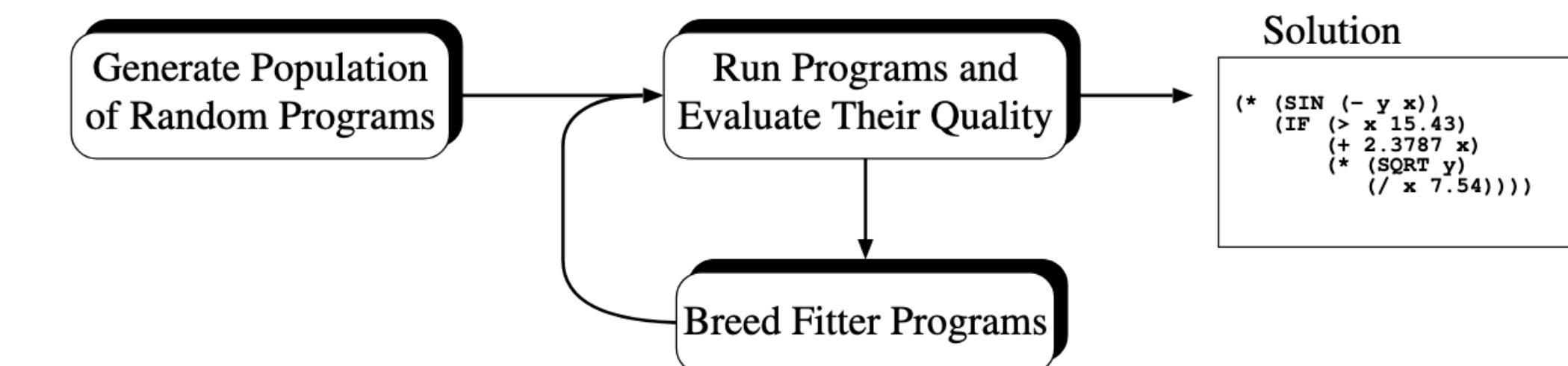


Figure: General structure of an evolutionary algorithm

# Ablation Study

# Ablation Study

## Aggregate results

Fitness: Mielke skill

$$\lambda = 1 - \frac{N^{-1} \sum_{i=1}^N (o_i - m_i)^2}{\sigma_o^2 + \sigma_m^2 + (\hat{o} - \hat{m})^2}$$

Parameter	Value
Evaluation series length	11 years
Number of columns	300
Constraints	all
Population size	30
Mutation rate	0.1
Output mutation rate	0.3
Recurrent connection rate	0.1

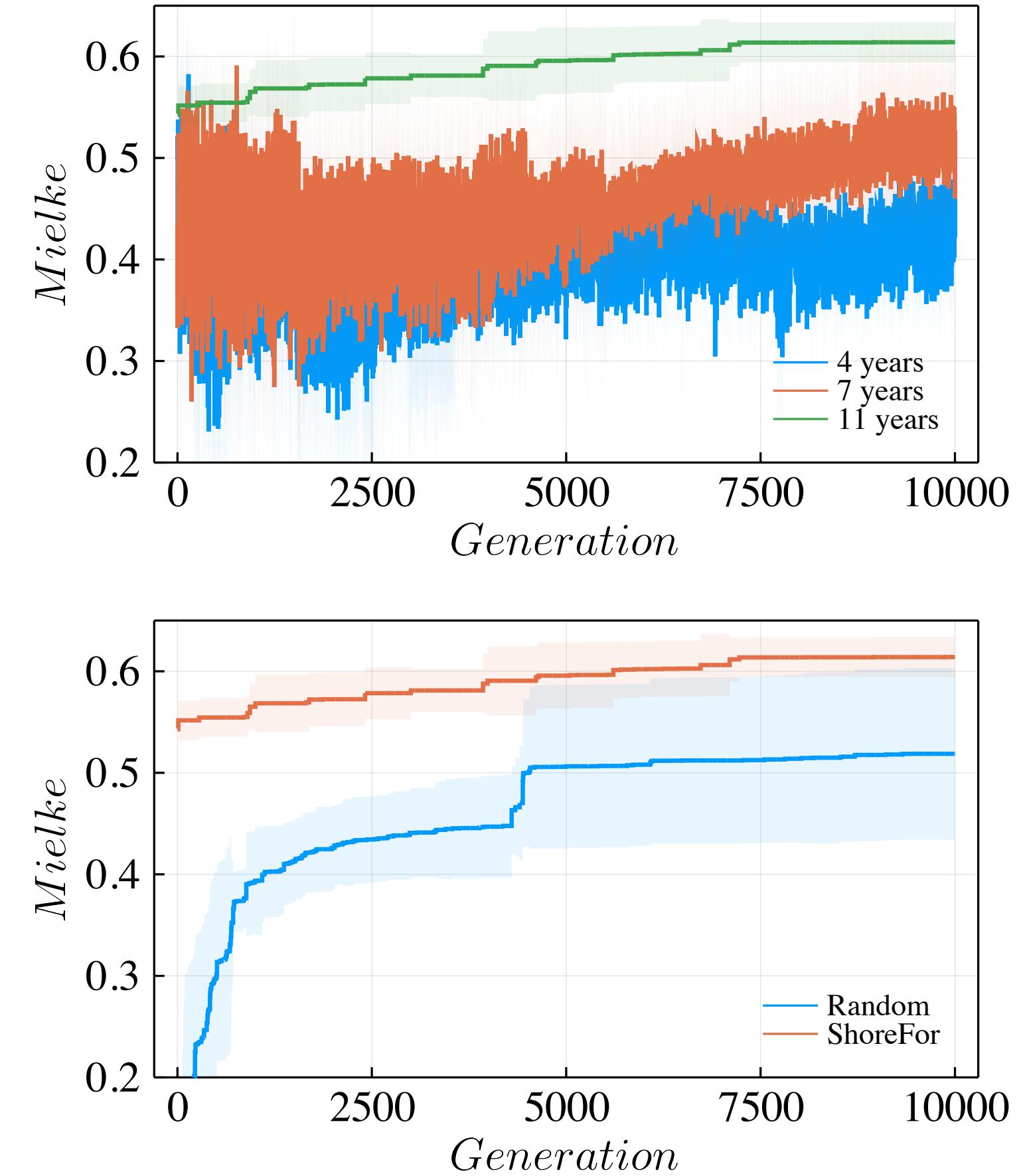
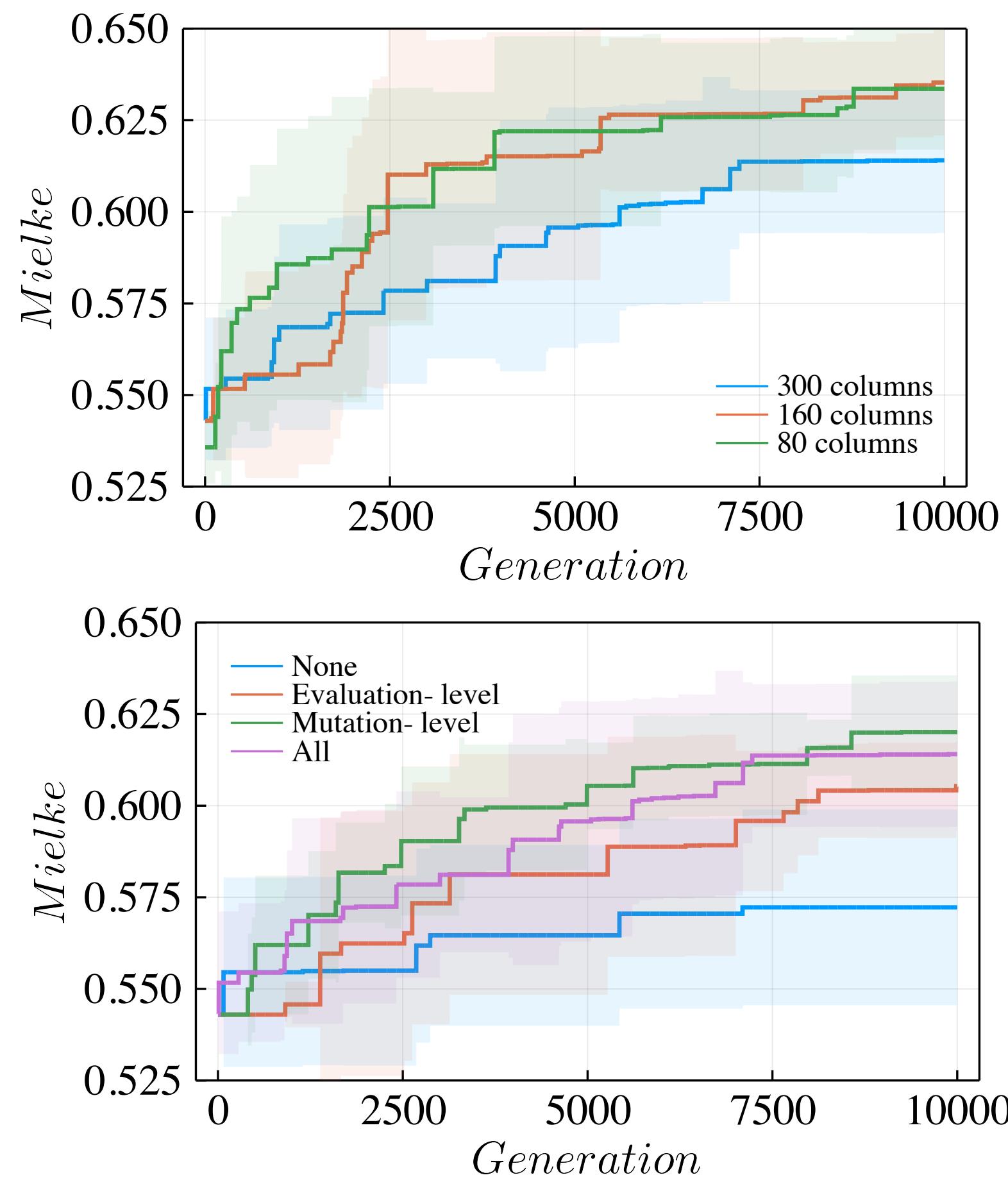
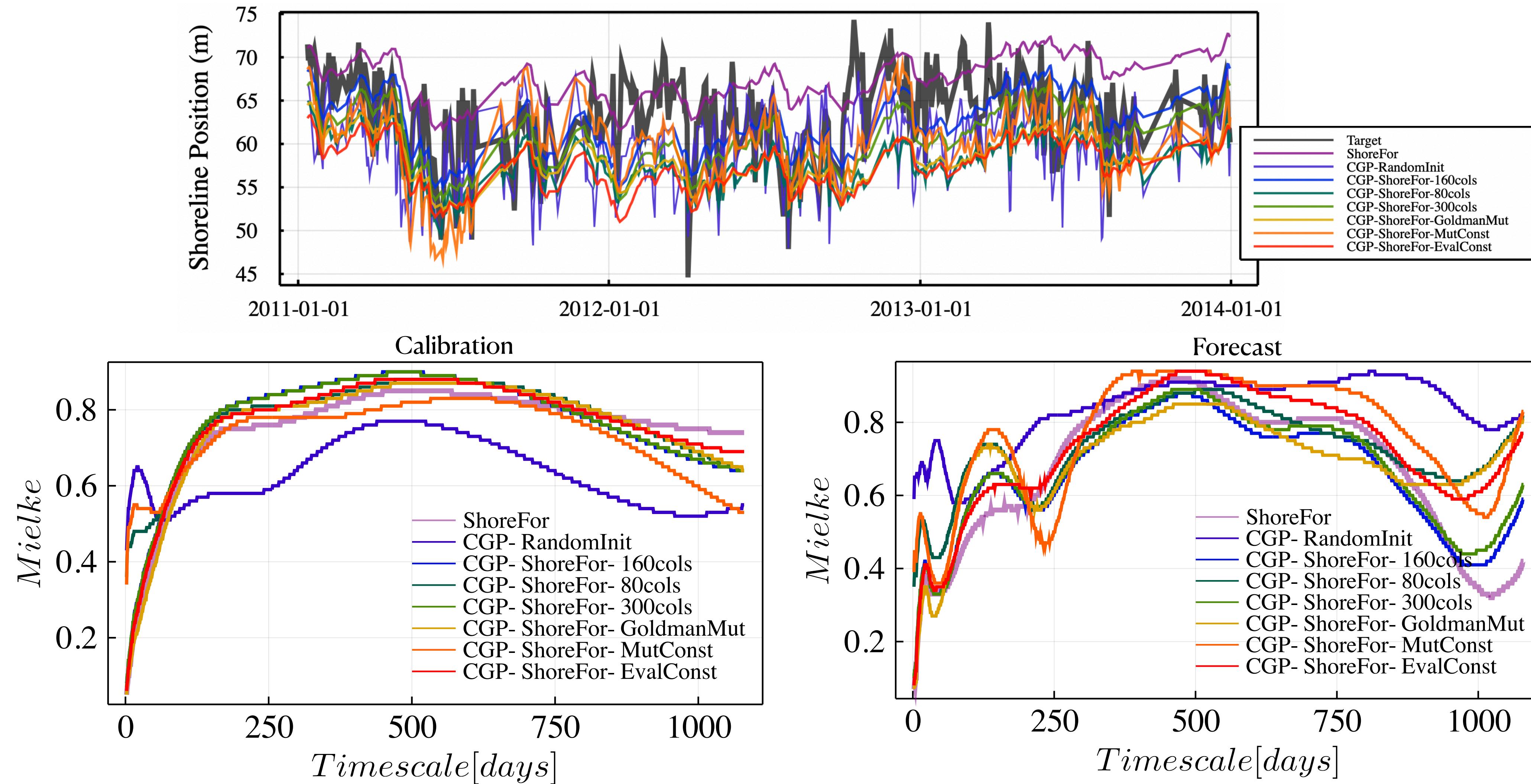


Figure: Ablation study results comparing the sensitivity of CGP to the graph size (top left), evaluation series length (top right), constraint regime applied (bottom left) and initialization scheme (bottom right). Taken from [7]

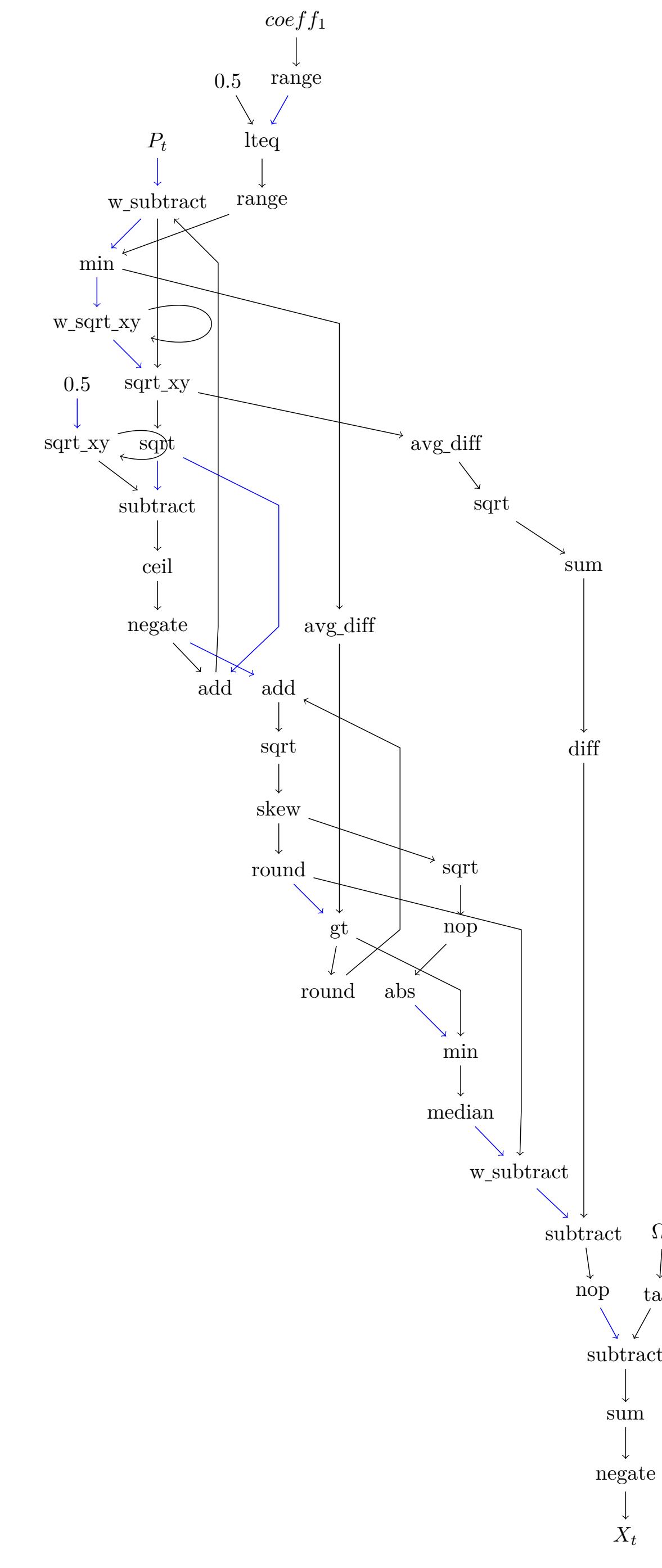
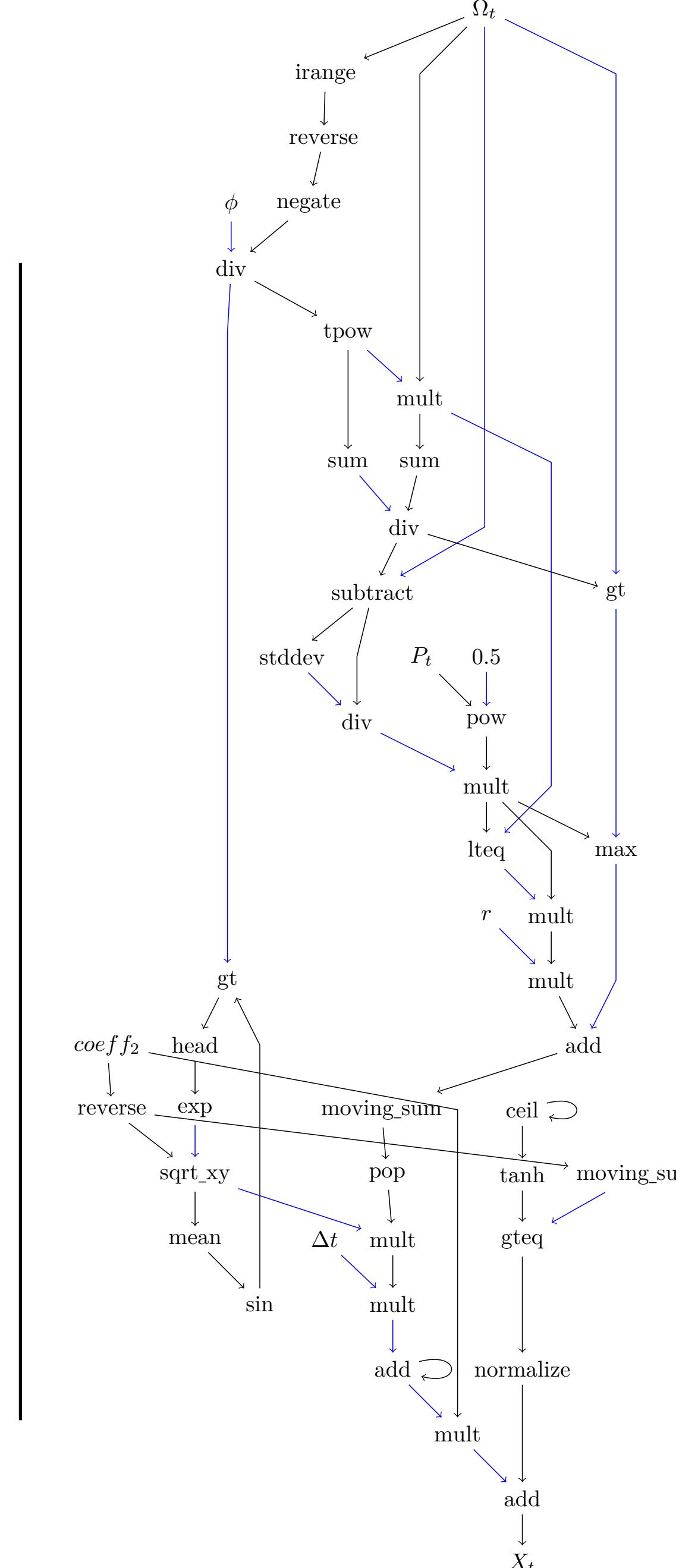
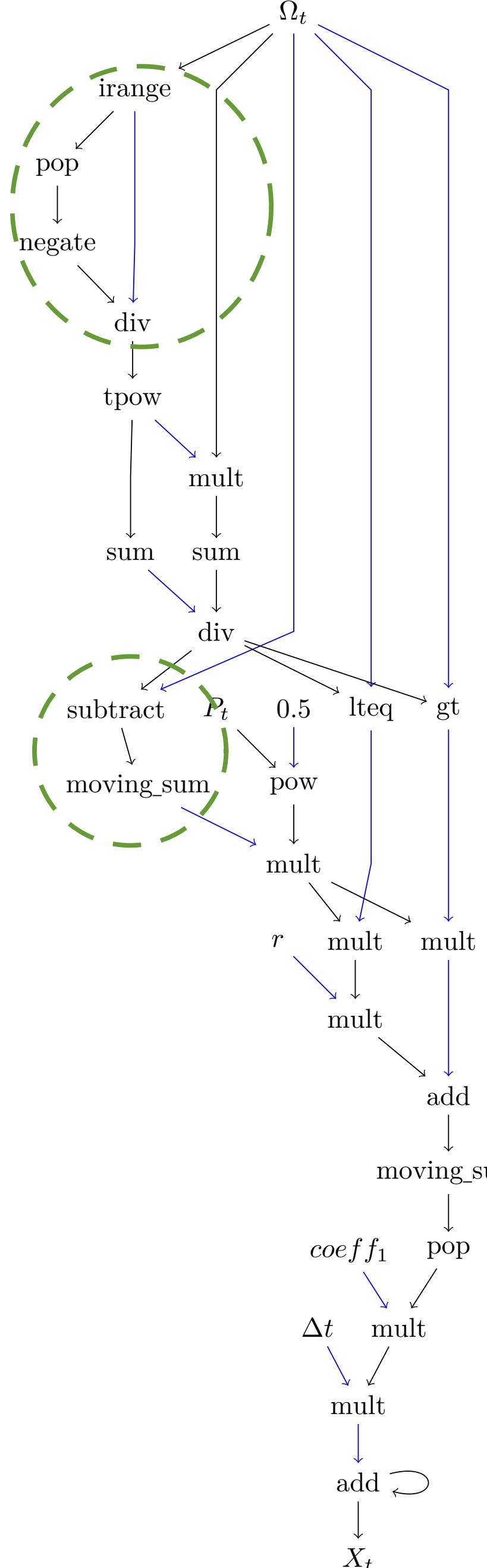
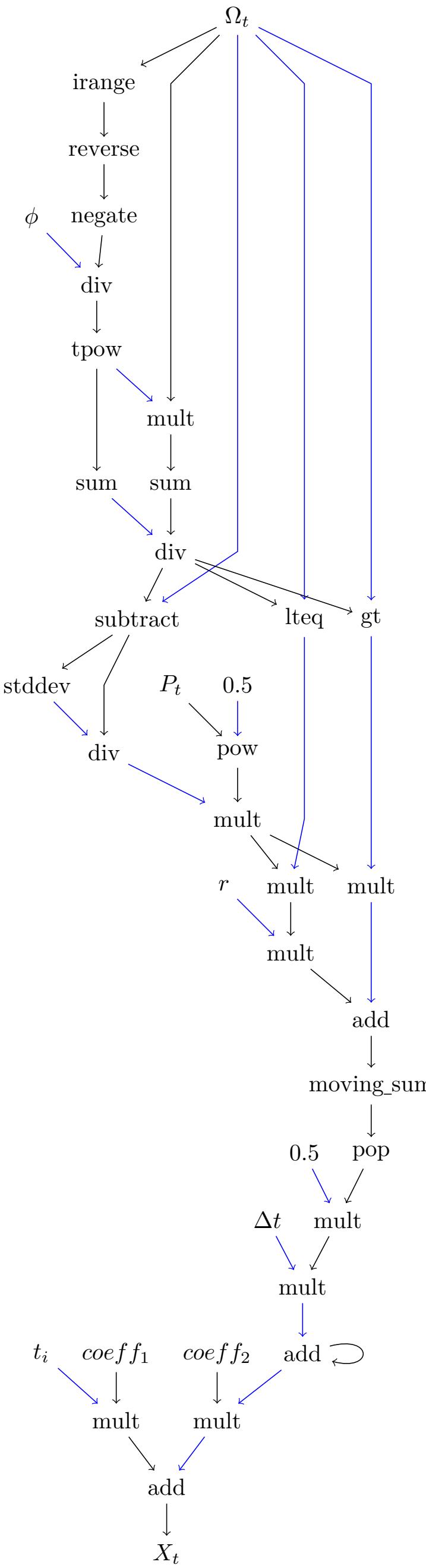
# Ablation Study

## Best individuals



# Ablation Study - Evolved variants of ShoreFor

CGP Inputs
$\Omega$
P
$\phi$
0.5
dt_waves
current_time
coeff1
coeff2
r



# Ablation Study

## Conclusions

- Full calibration series (~11 years in Tairua)
- Mutation-level constraints
- Smaller graph sizes
- Predicting  $dx/dt$  instead of  $X$ :
  - More direct interpretability of the evolved graphs
  - Model-free parameter calibration during fitness evaluation

# **Current Study**

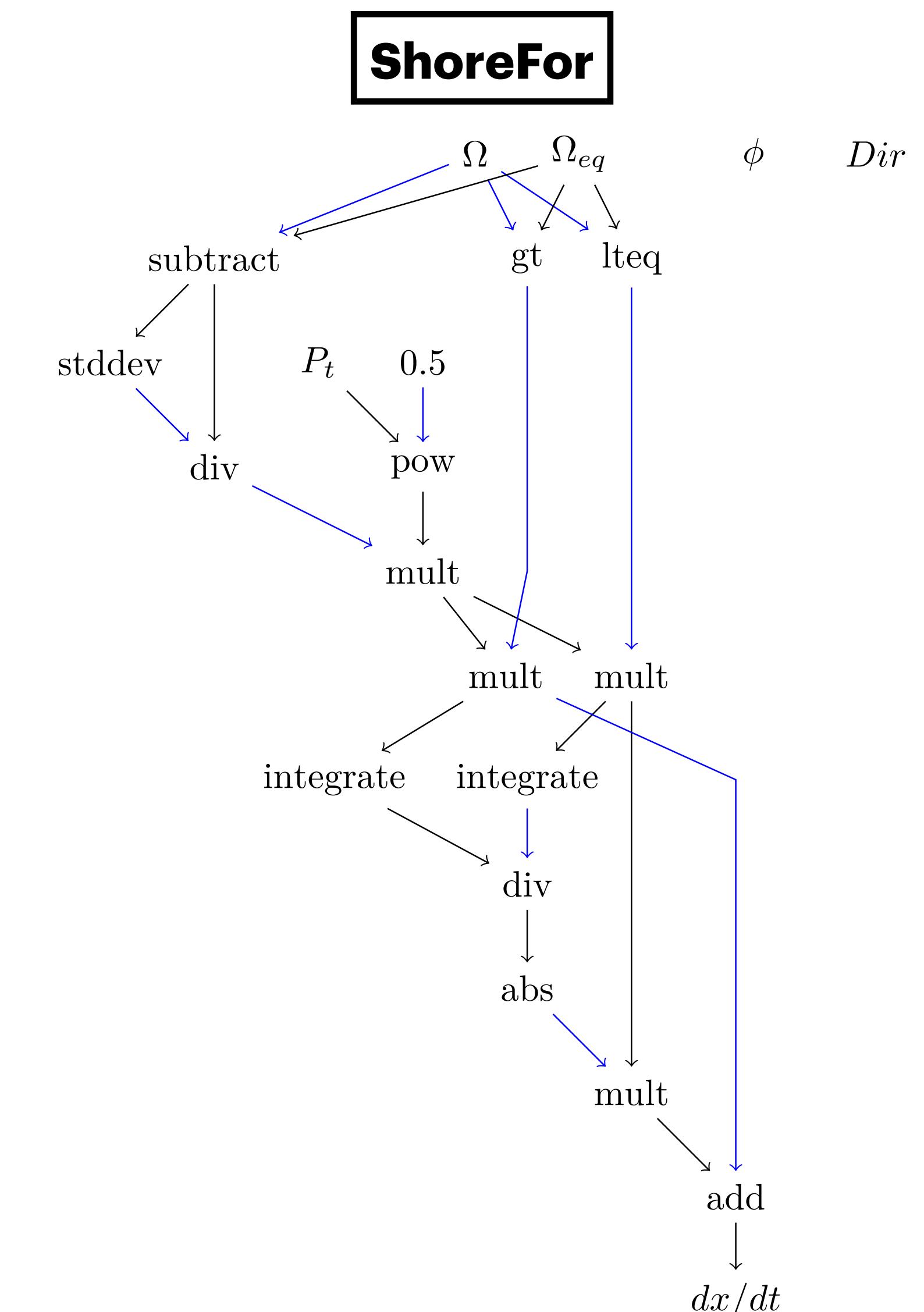
# Current Study

## Modelling complete and sequential CGP-ShoreFor-dxdt

Implementation of complete variant:

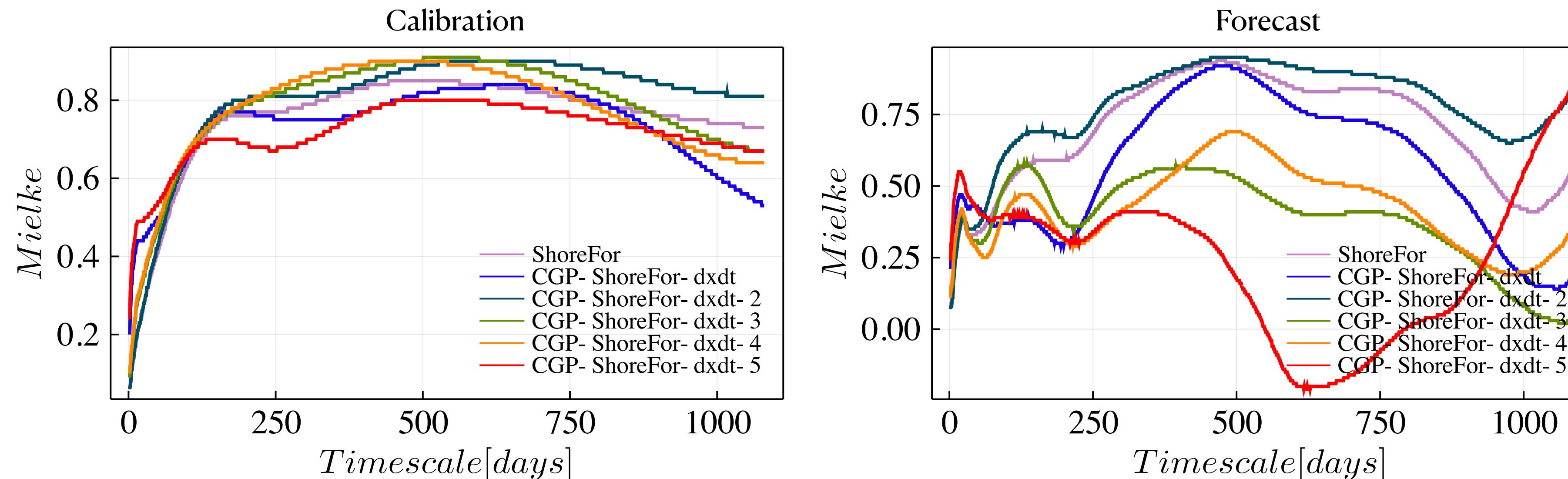
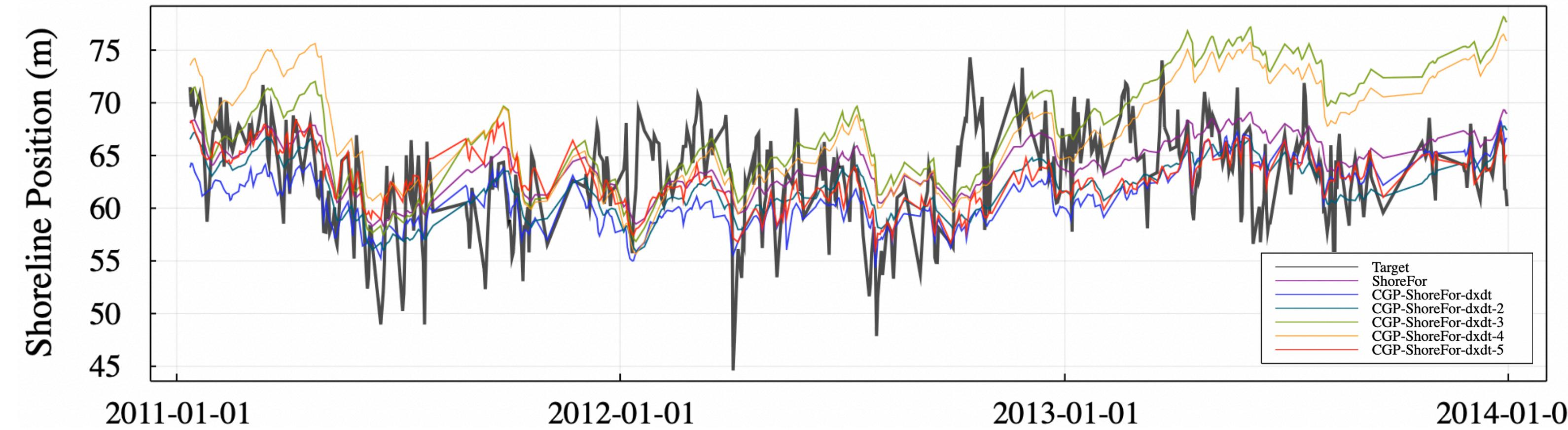
- Prediction of full target series in one model step
- ‘r’ can be calculated within the model
- Equilibrium omega passed as input (sequential calculation not modelled)

CGP Inputs
$\Omega$
$\Omega_{eq}$
$P$
$\phi$
0.5
$Dir$



# Current Study

## Complete CGP-ShoreFor-dxdt results



# Current Study

## Complete CGP-ShoreFor-dxdt results

Model	Calibration			Forecast		
	Correlation	RMSE	Mielke Skill	Correlation	RMSE	Mielke Skill
ShoreFor	0.68	4.11	0.62	0.42	4.4	0.35
CGP-ShoreFor-dxdt	$0.74 \pm 0.01$	$3.77 \pm 0.31$	$0.7 \pm 0.03$	$0.42 \pm 0.05$	$4.32 \pm 1.37$	$0.37 \pm 0.06$
CGP-RandomInit	$0.75 \pm 0.04$	$3.72 \pm 0.33$	$0.7 \pm 0.06$	$0.39 \pm 0.11$	$4.86 \pm 0.51$	$0.35 \pm 0.1$

# Genetic Improvement of Shoreline Equilibrium Models

## Future directions

- Sequential  $dx/dt$  variant
- Separate phenotypes ( $\Omega_{eq}, dx/dt$ )
- Mutation operators and selection methods
- Improved evaluation:
  - Multi-objective fitness (graphs, time-scales)
  - Wider variety of sites

# Genetic Improvement of Shoreline Equilibrium Models

Thank you

Mahmoud AL NAJAR

Supervised By:

Rafael ALMAR (IRD), Dennis WILSON (ISAE), Jean-Marc DELVIT (CNES), Erwin BERGSMA (CNES)