Genetic Improvement of Shoreline Evolution Forecasting Models

Mahmoud Al Najar, Rafael Almar, Erwin W. J. Bergsma, Jean-Marc Delvit, Dennis G. Wilson

Coastal Zones

- High societal, ecological and economic importance
- Under increasing anthropogenic and climate pressures

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

- Goal: improved forecasts of wave-driven shoreline change

[1] Melet, A. et al. (2020). Earth observations for monitoring marine coastal hazards and their drivers. *Surveys in Geophysics*, *41*(6), 1489-1534.

Wave-driven shoreline change

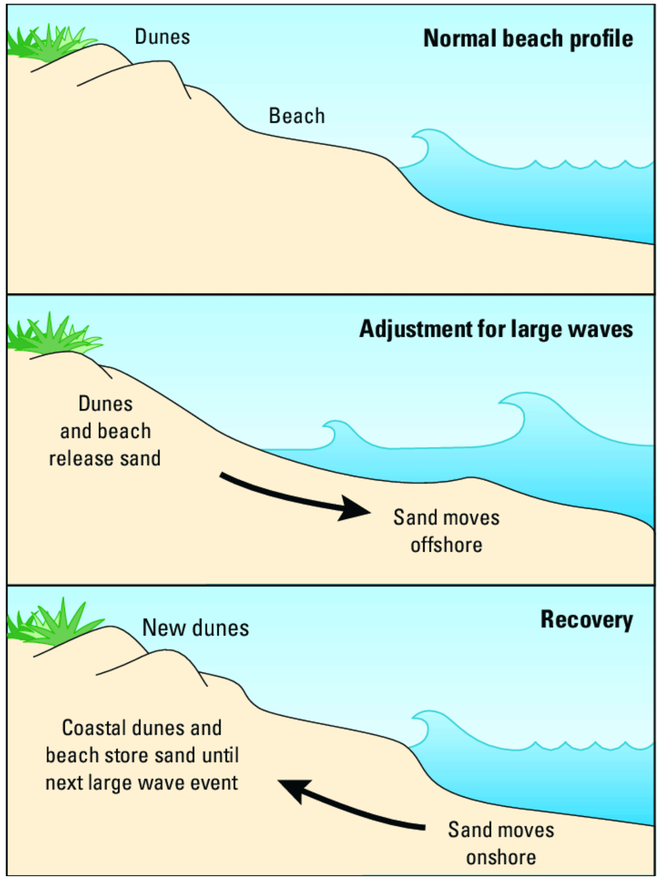
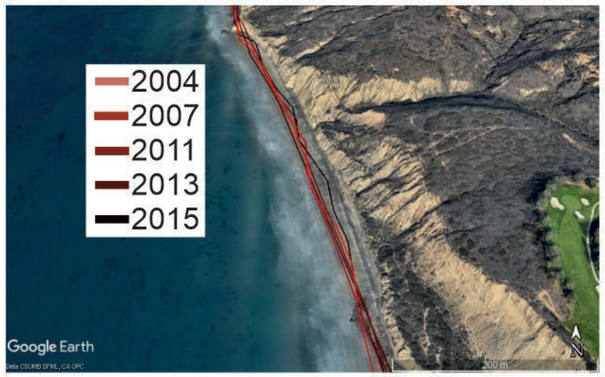
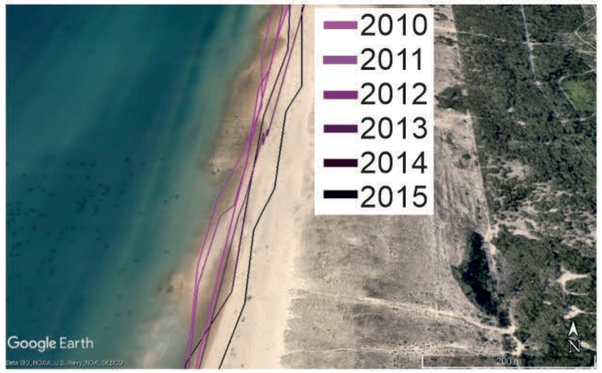


Figure: Seasonal beach-profile adjustments induced by seasonal swell variations and resulting cross-shore sediment transport. Source: [2]





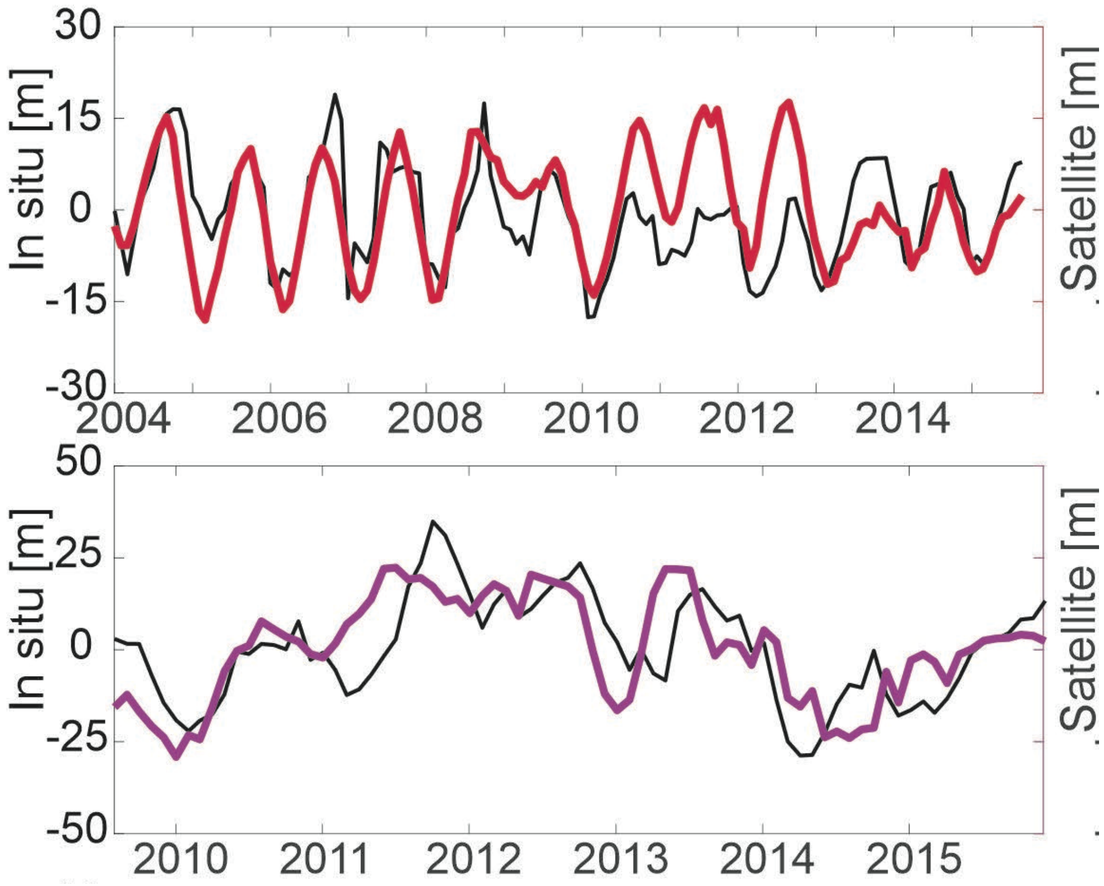


Figure: Illustration of shoreline variability. Source: [3]

[2] Fletcher, C. H. et al. (2012). National assessment of shoreline change: Historical shoreline change in the Hawaiian Islands.

[3] Graffin, M. et al. (2022). El Niño controls the evolution of shorelines worldwide. (In review, preprint available online)

Genetic Improvement of Shoreline Equilibrium Models

Outline

1) Coastal zones & shoreline change

2) Study zone & dataset

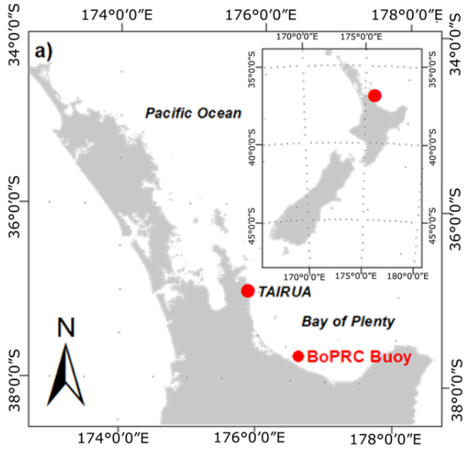
3) Existing methods

4) Proposed CGP/GI formulation

5) Experiments & results

6) Future directions & conclusions

Study Zone: Tairua, NZ



- Data was obtained from the "Shoreshop" competition [4]
- ~15 years of (open) data:
  - Daily video-derived shoreline positions
  - Hourly wave heights (Hs), periods (Tp) and directions (Dir)

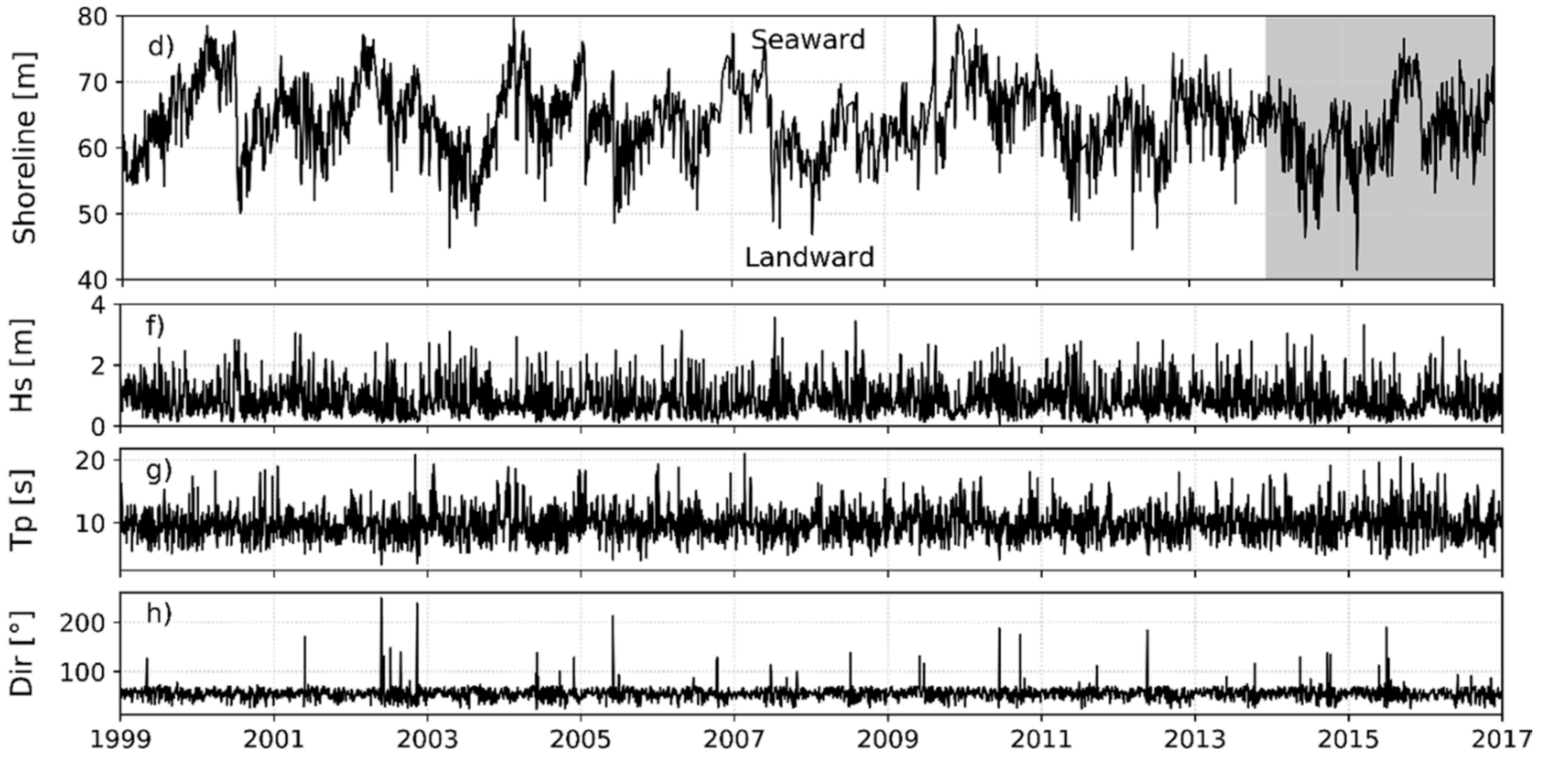


Figure: Tairua dataset. Source: [4]

[4] Montaño, J., Coco, G., Antolínez, J.A.A. et al. Blind testing of shoreline evolution models. Sci Rep 10, 2137 (2020). https://doi.org/10.1038/s41598-020-59018-y

Existing methods for shoreline forecasting

- Simulation-based methods
- Data-driven models
- Hybrid models
  - Embedded physical knowledge
  - Data-driven calibration

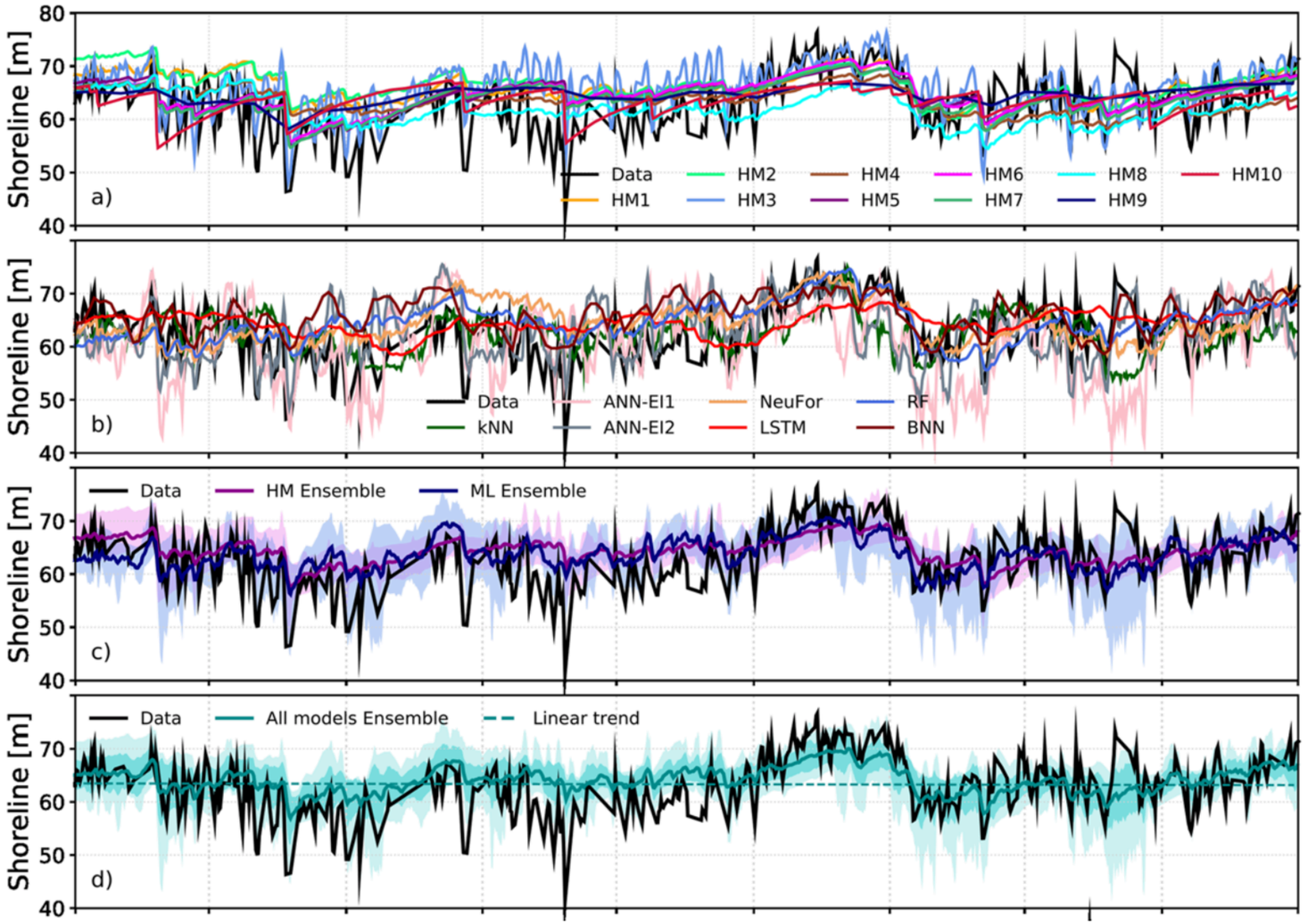


Figure: Performance comparison of hybrid and data-driven models included in the Shoreshop competition.
Source: [4]

[4] Montaño, J., Coco, G., Antolínez, J.A.A. et al. Blind testing of shoreline evolution models. Sci Rep 10, 2137 (2020). https://doi.org/10.1038/s41598-020-59018-y

ShoreFor

- ShoreFor: hybrid model [4,5] based on beach memory and equilibrium
- Variants proposed accounting for additional coastal processes and time scales

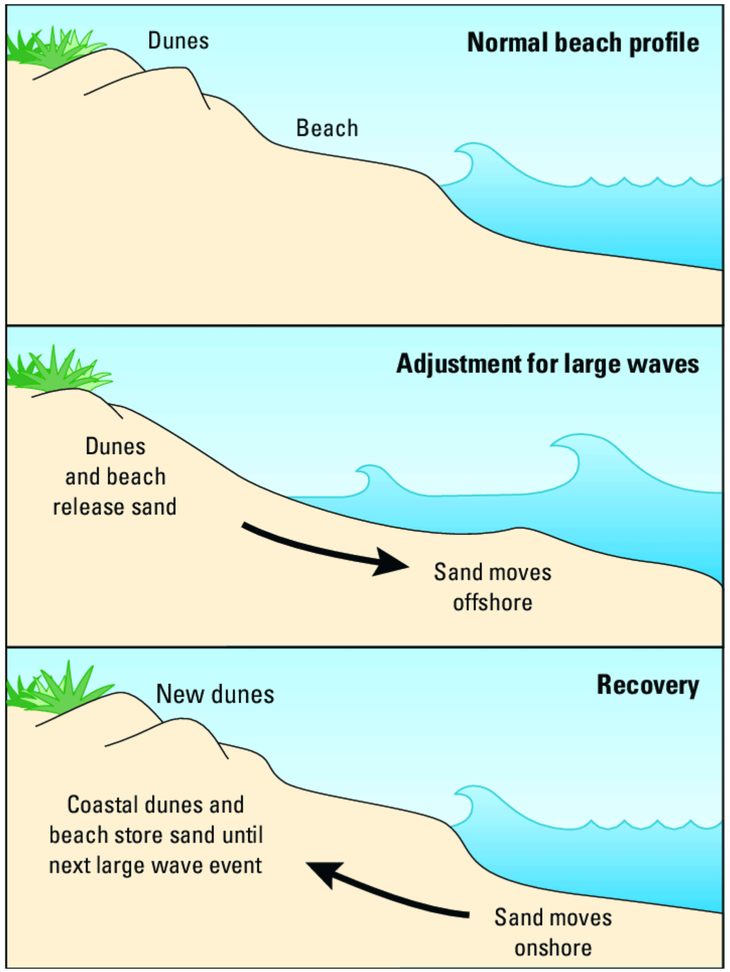


Figure: Seasonal beach-profile adjustments induced by seasonal swell variations and resulting cross-shore sediment transport. Source: [2]

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

Table: ShoreFor system of equations

[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)

Cartesian Genetic Programming

- Relatively low-data regime
- “White-box” approach

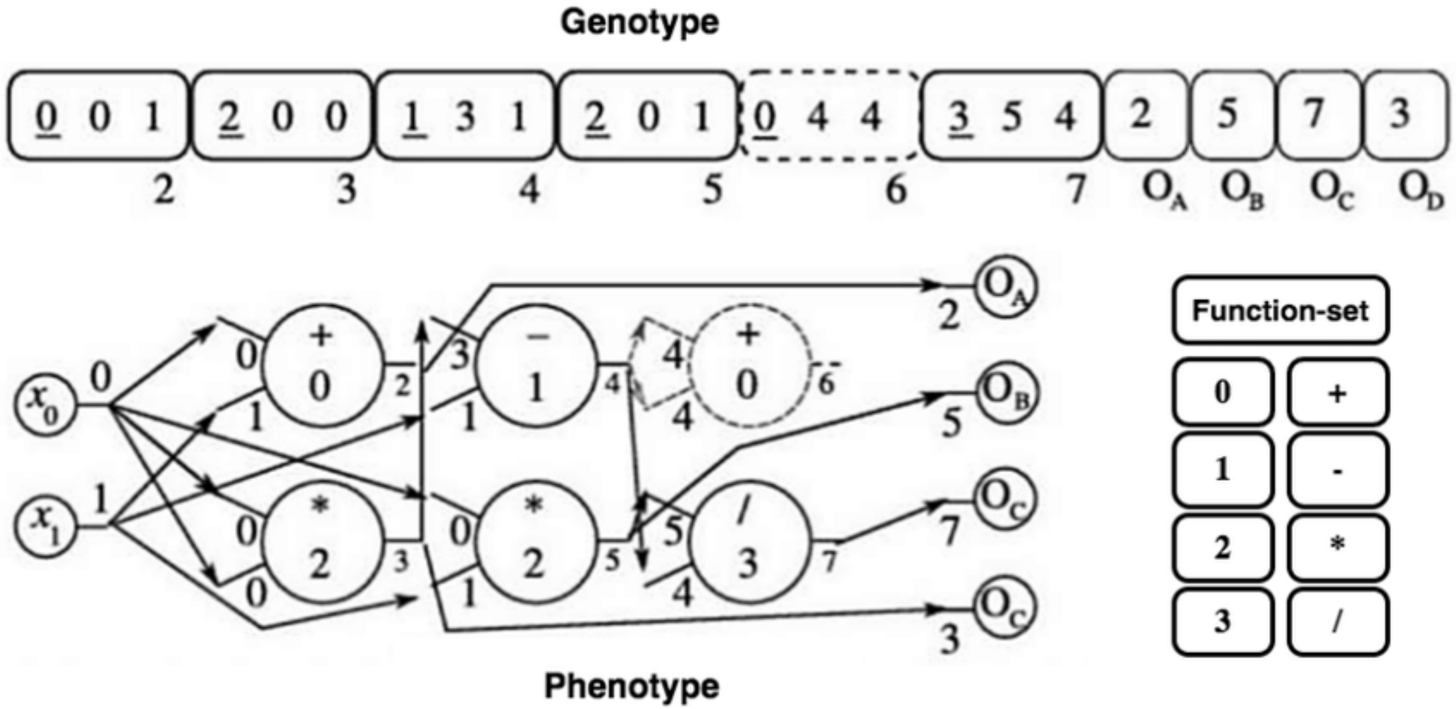


Figure: CGP Individual Encoding. Source: [6]

[6] Miragaia, R.; Fernández, F.; Reis, G.; Inácio, T. Evolving a Multi-Classifier System for Multi-Pitch Estimation of Piano Music and Beyond: An Application of Cartesian Genetic Programming. *Appl. Sci.* **2021**, *11*, 2902. https://doi.org/10.3390/app11072902

ShoreFor as a (sequential) CGP individual

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

Table: ShoreFor system of equations

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

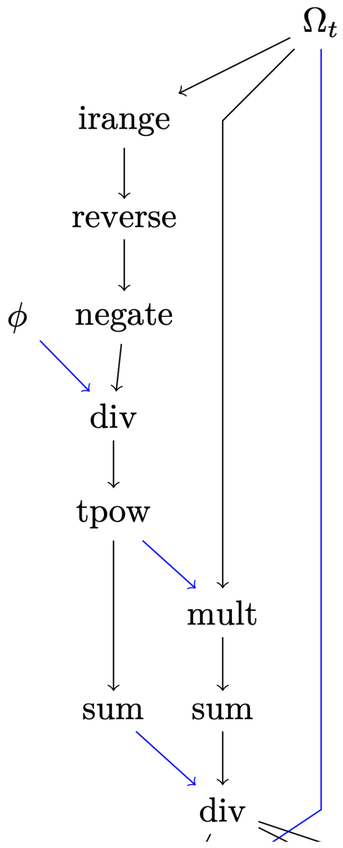
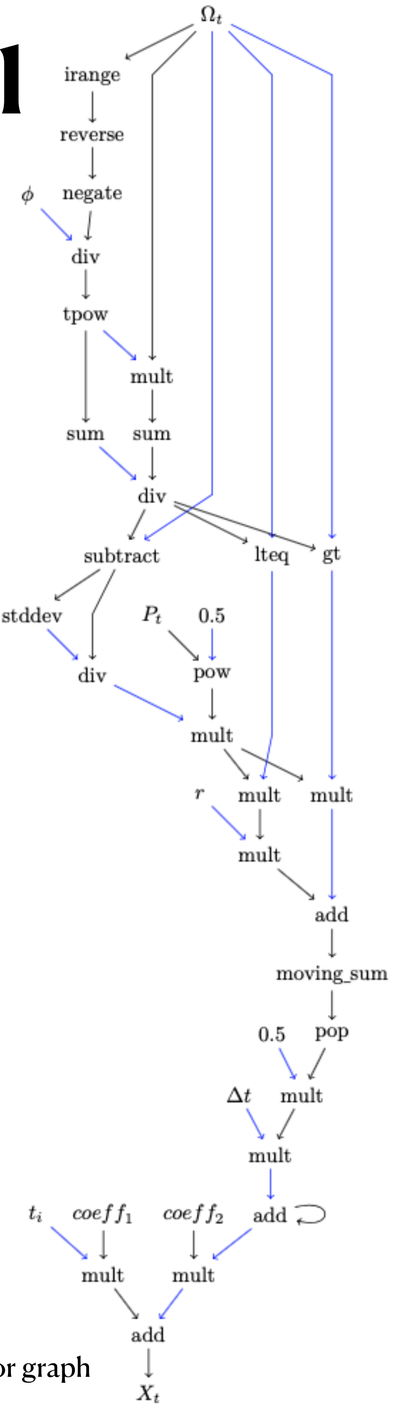


Figure: example sub-graph showing the encoding of the Ω_{eq} equation

Inputs
Ω
P
ϕ
0.5
dt_waves
current_time
coeff_time
c
r

Input window size = 2ϕ



Table, Figure: sequential ShoreFor graph

Experimental setup

Mielke fitness

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

Function set

Type	*Description*
List processing	list manipulation functions (e.g. tail, pop, reverse)
Scalar	Scalar operations (e.g. add, div, mult)
Vector	Vector operations (e.g. sum, mean, max)

Default configuration using μ+λ GA

Parameter	*Value*
Evaluation series length	11 years
Number of columns	300
Constraints	all
Population size	30/5
Mutation rate	0.1
Output mutation rate	0.3
Recurrent connection rate	0.1

Experiments

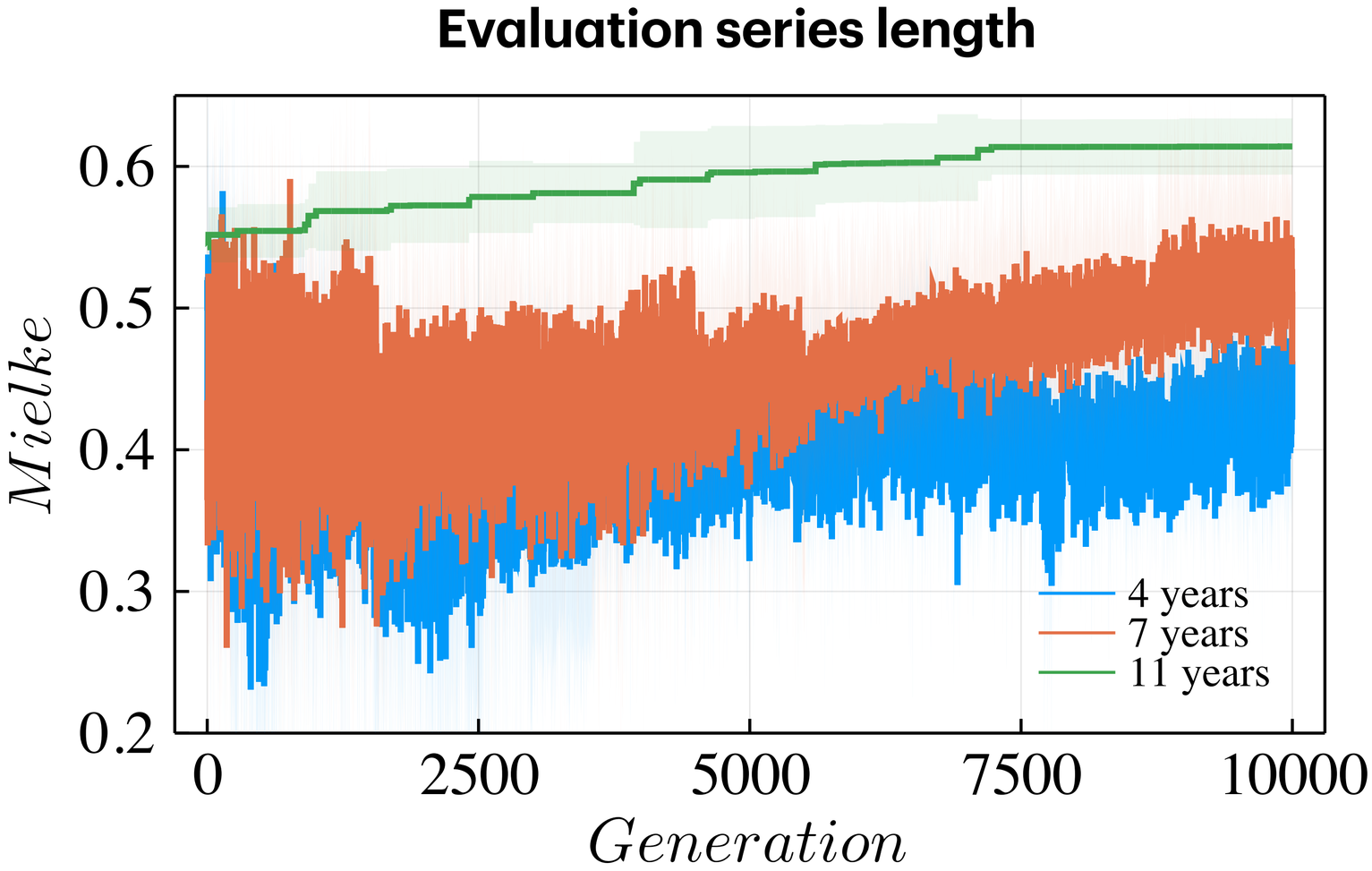


Figure: evaluation series length effect on model performance

Experiments

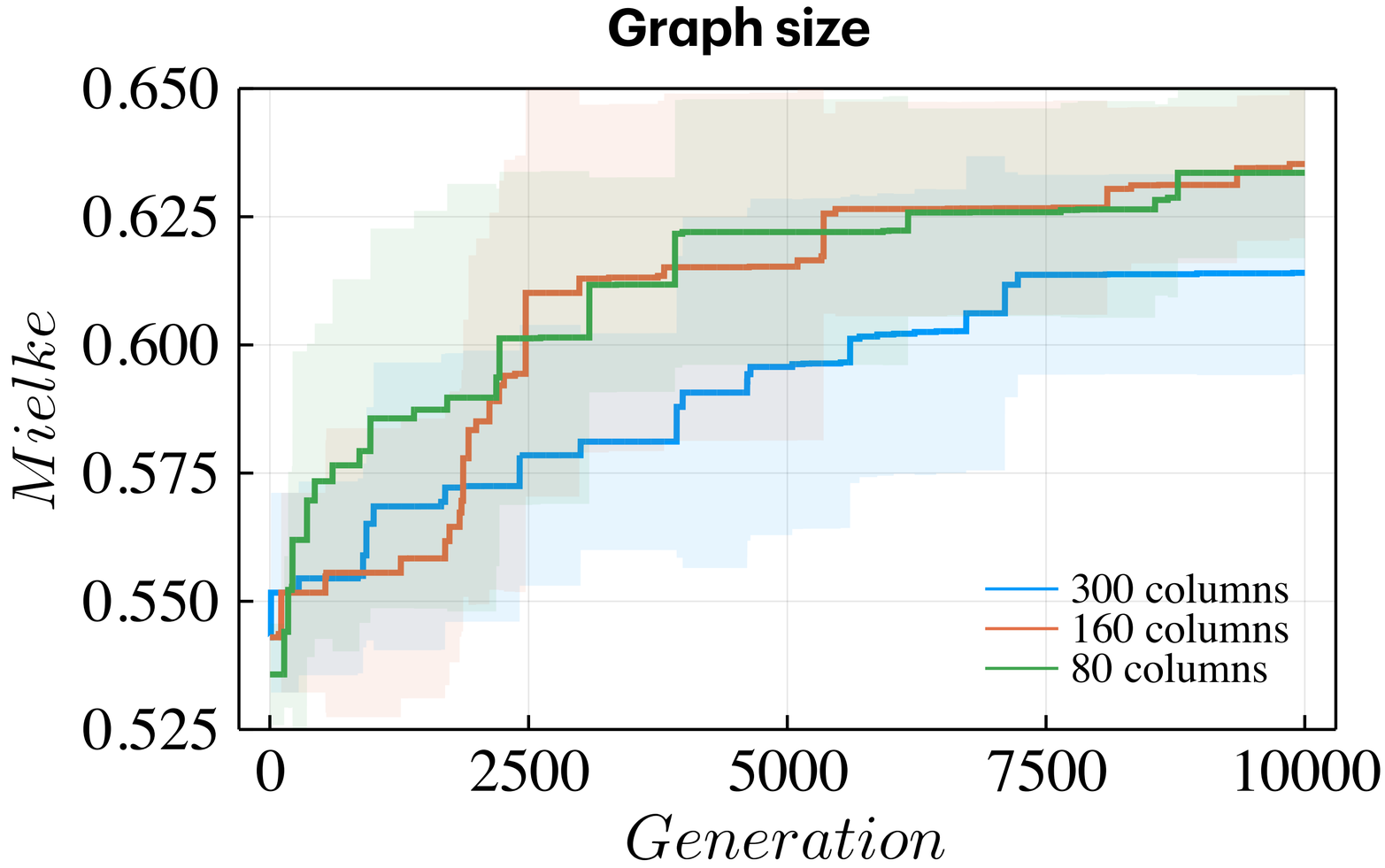


Figure: Sensitivity of CGP to different graph sizes

Experiments

Constraints

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

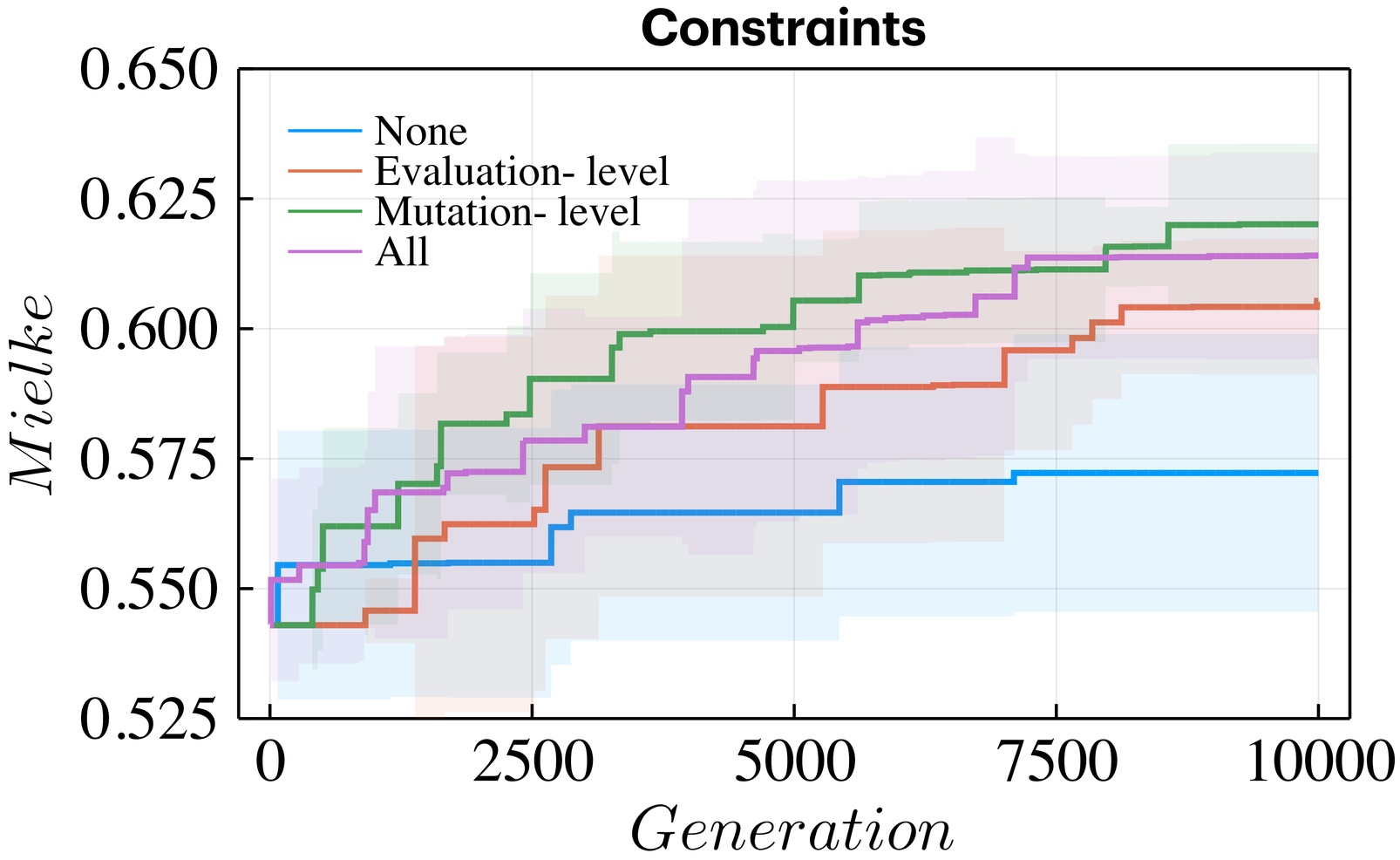


Figure: Effect of different constraint regimes on evolution

Experiments

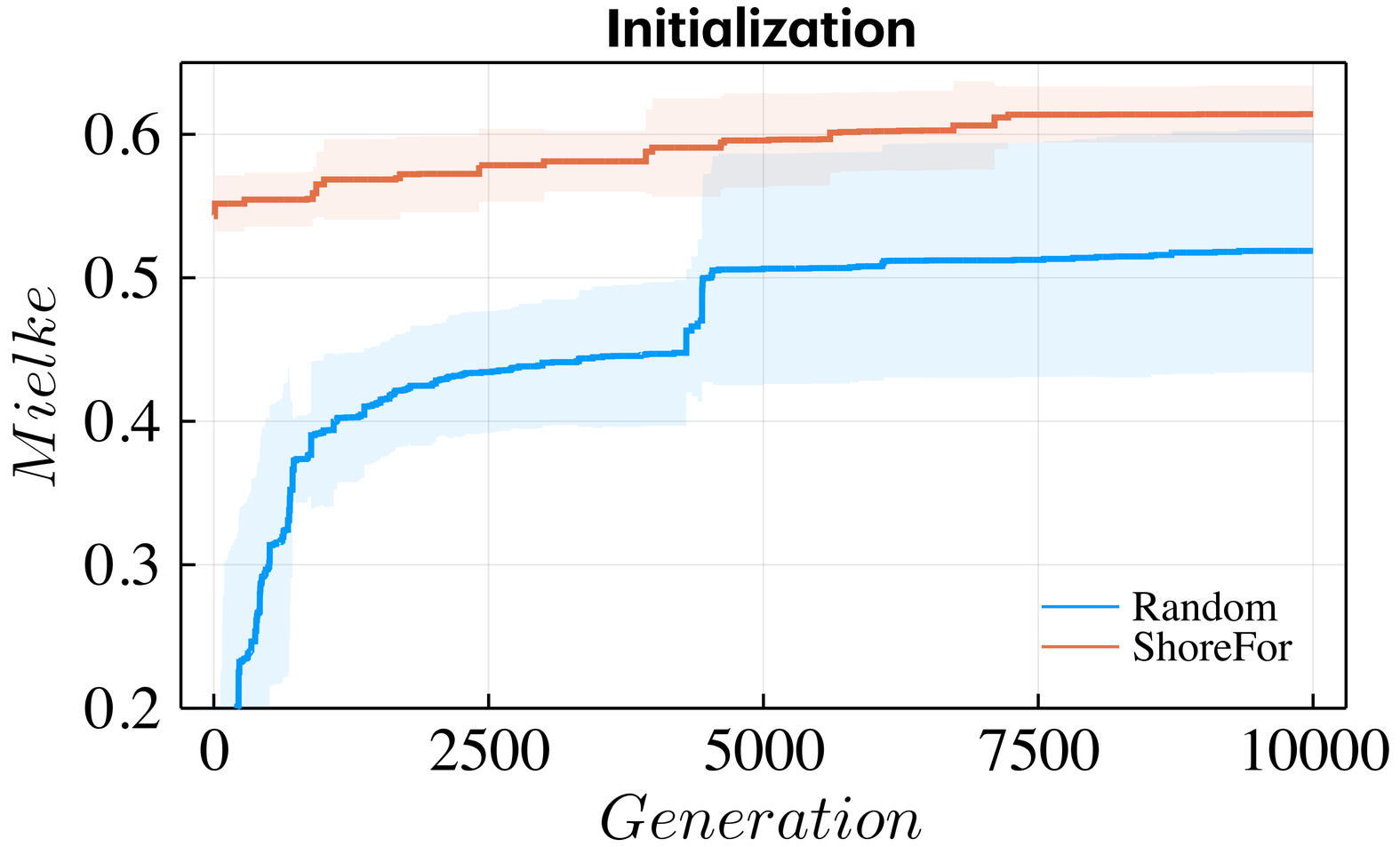
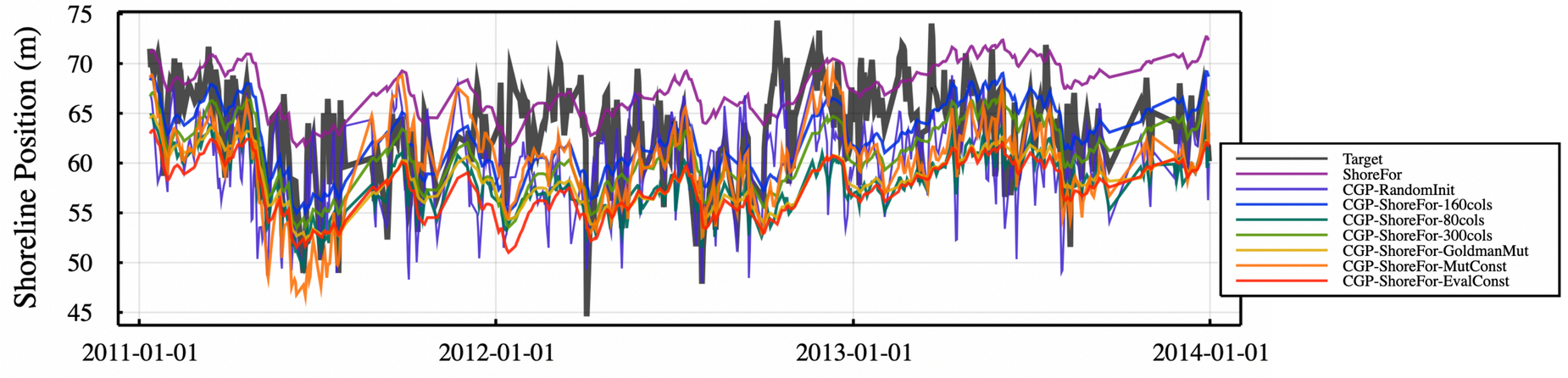
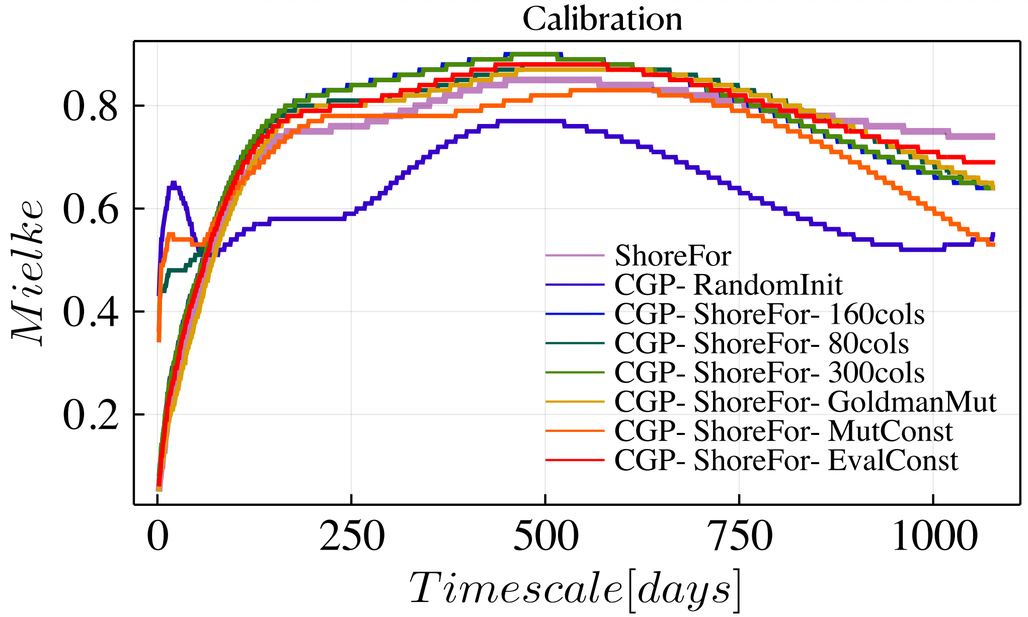
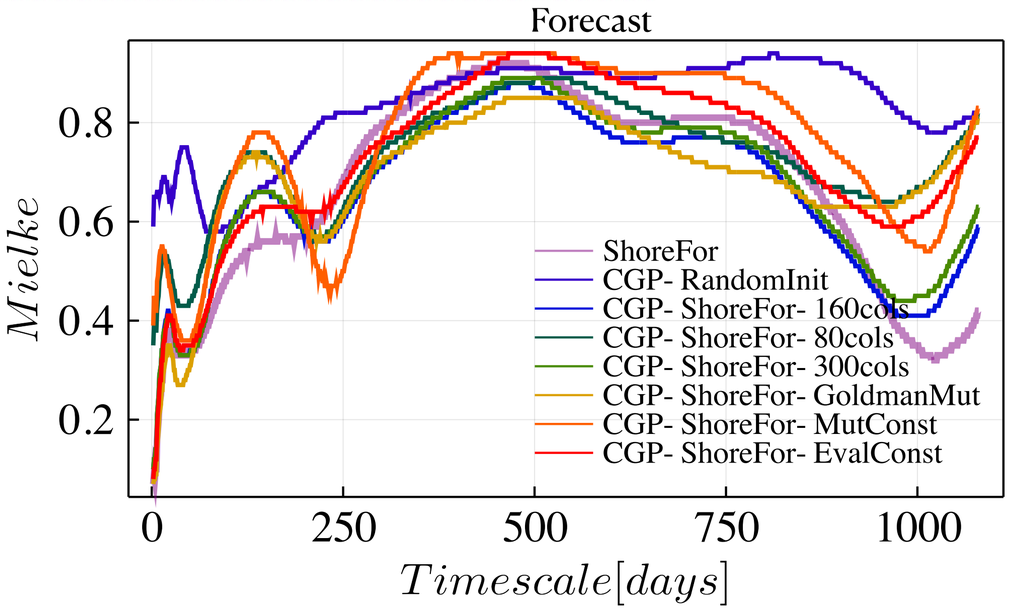


Figure: GI vs. pure CGP

Best individuals



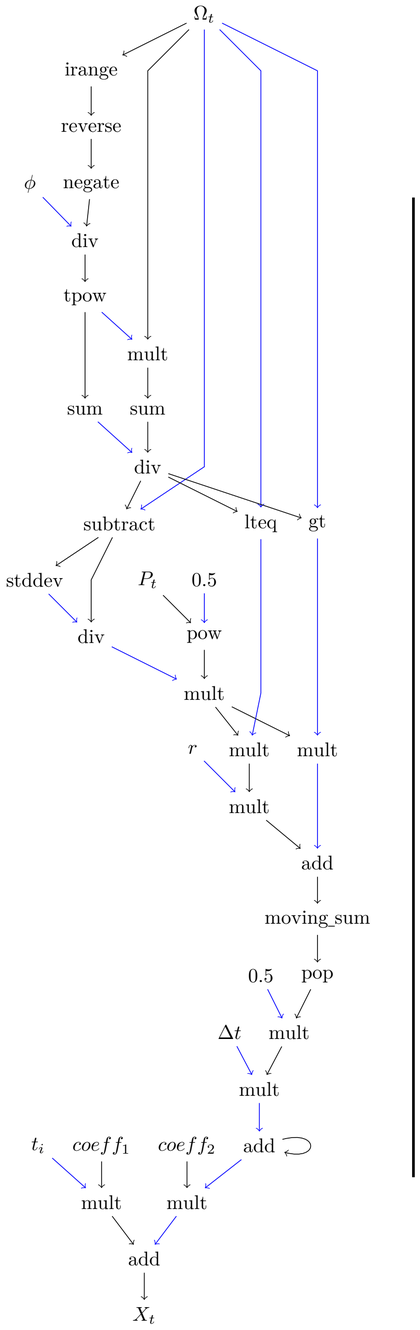


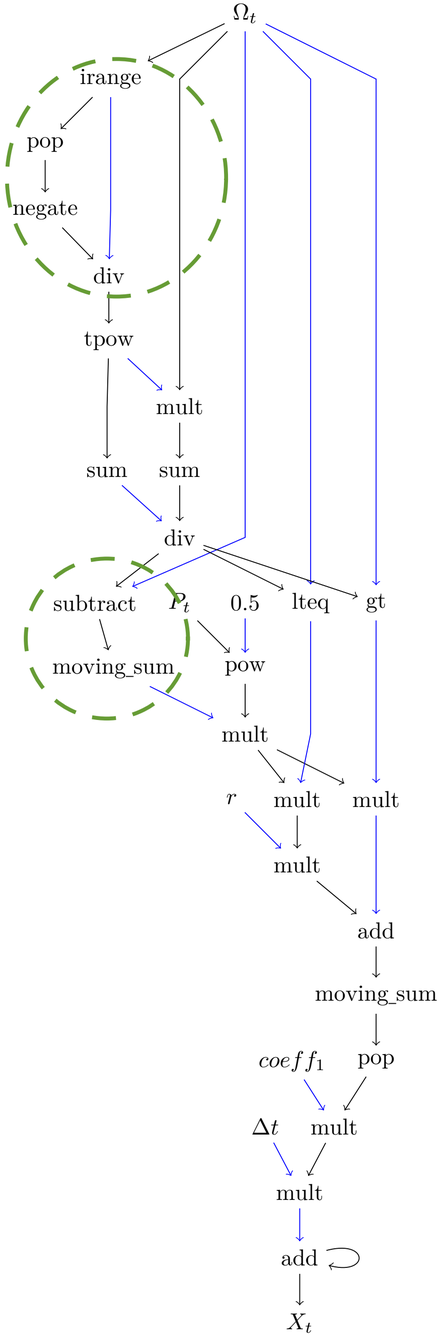


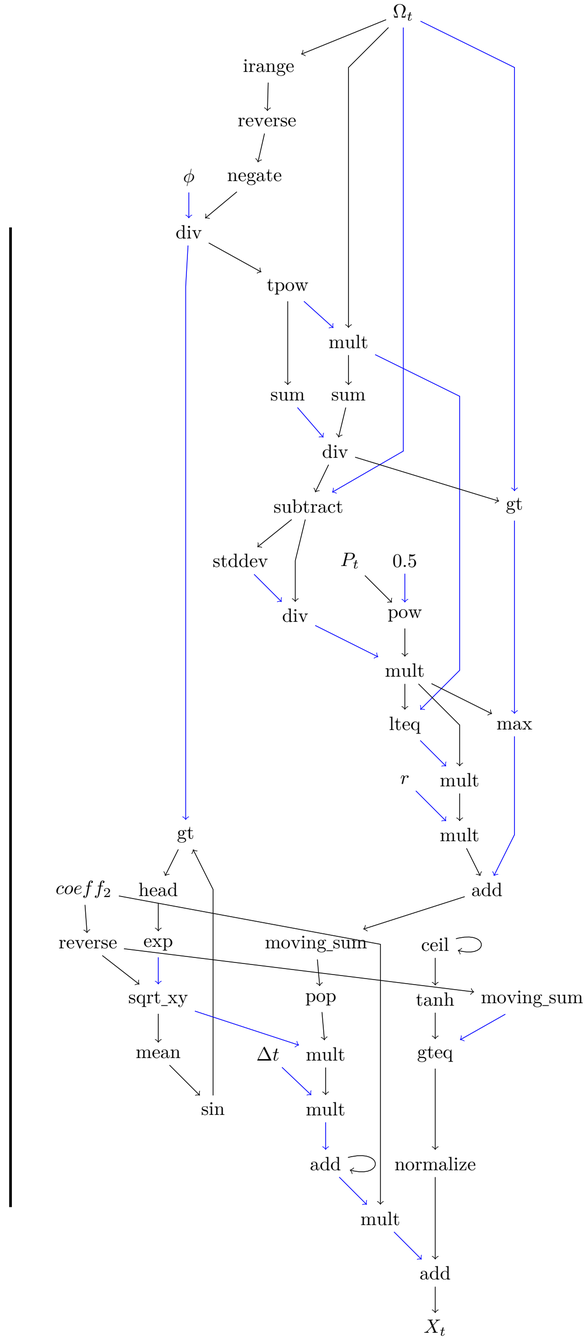
Evolved variants of ShoreFor

CGP Inputs
Ω
P
ϕ
0.5
dt_waves
current_time
coeff1
coeff2
r

ShoreFor



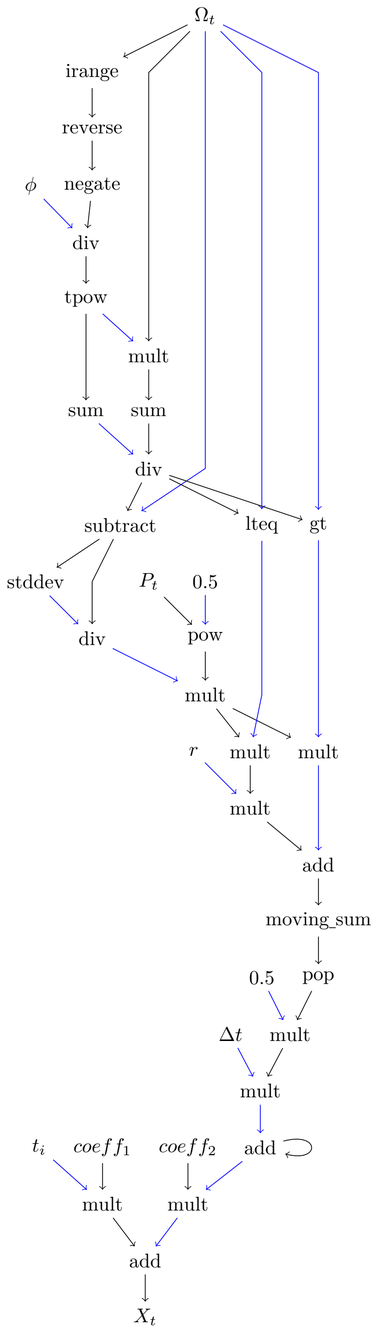


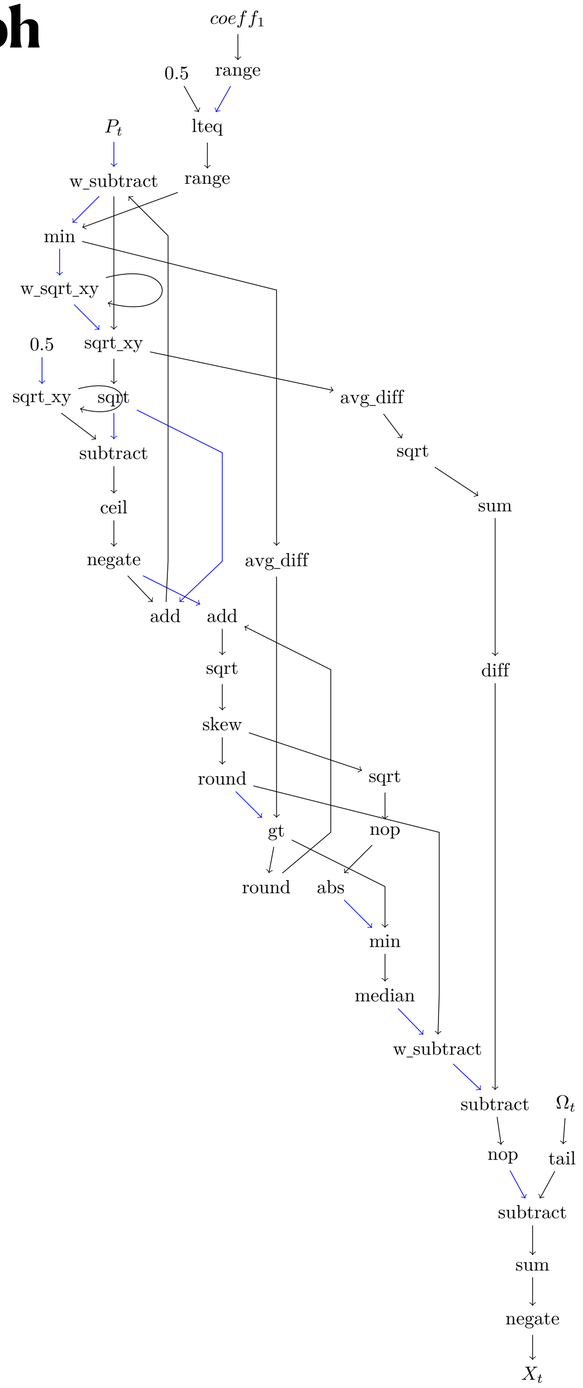


ShoreFor

Evolved random-init graph

CGP Inputs
Ω
P
ϕ
0.5
dt_waves
current_time
coeff1
coeff2
r





Conclusions & future directions

Conclusions:

- First step towards the use of CGP in shoreline studies
- GI-based models demonstrated statistically higher skills
- Promising first results, establishing basis for future work

Future perspectives:

- Sequential (RCGP) vs full-series formulations (CGP)
- Additional sites/datasets for multi-objective optimization

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Thank you

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