Identifying disentangled climate prototypes of forest mortality with generative deep learning

Mohit Anand, Lilly-belle Sweet, Gustau Camps-Valls, Jakob Zscheischler

30th November 2022

Introduction

- Forest are global carbon sink
- Climate change leads to higher forest mortality
- Forest mortality is complex
  - Multiple drivers
  - Long temporal scale
  - State dependency

Introduction

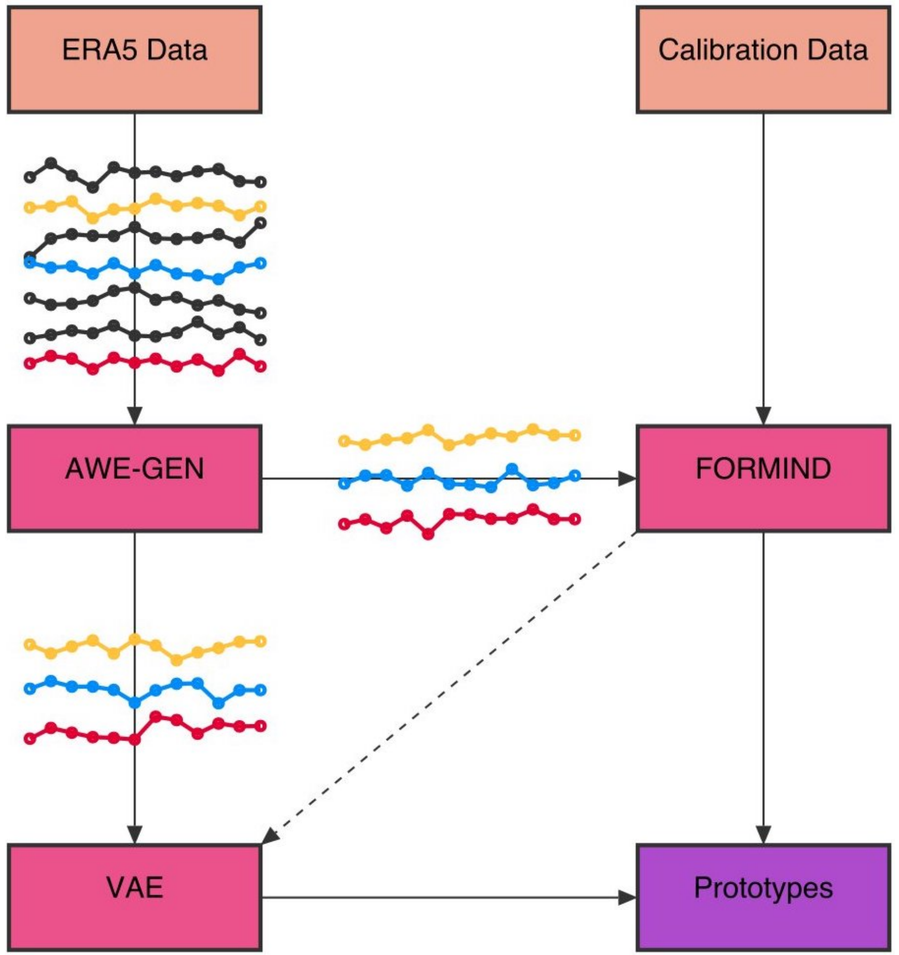
Why?

- Understanding the climatic drivers of forest mortality
  - How forest mortality will change with changing climate?
  - Important for forest management and policy makers

Methodology

Flow

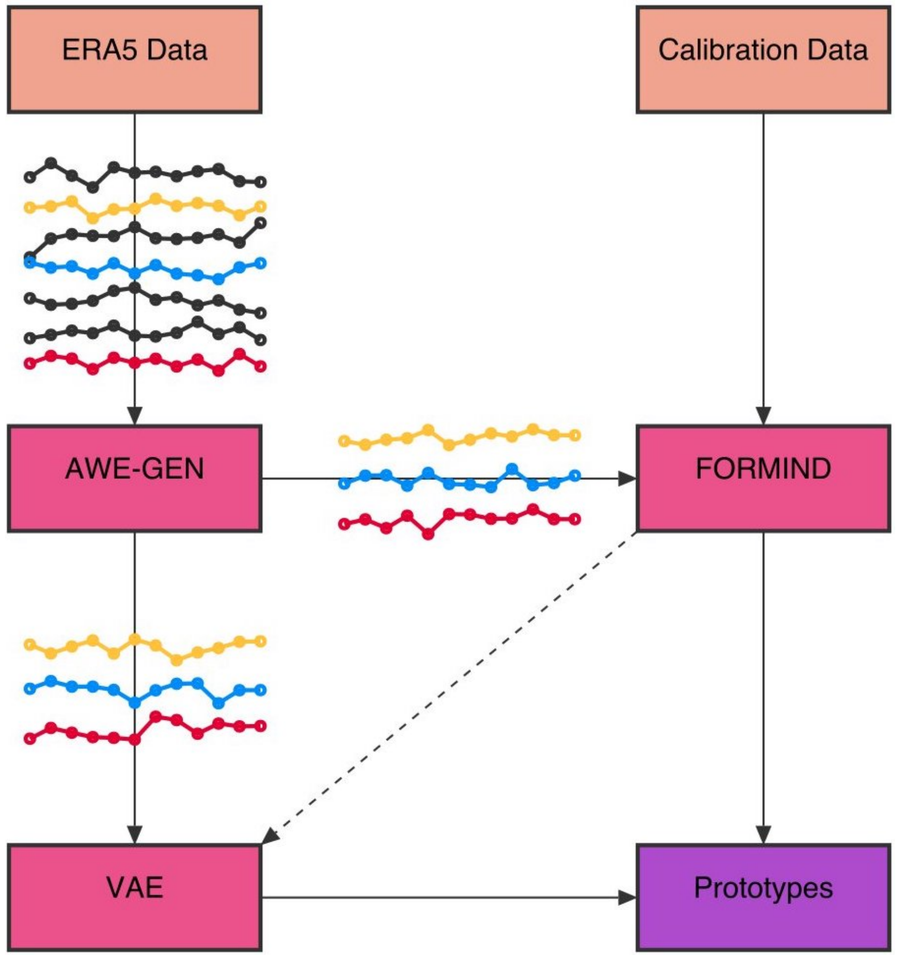
- ERA5 reanalysis dataset
- Variables
  - Precipitation
  - Cloud cover
  - Shortwave-radiation
  - Relative humidity
  - Wind speed
  - Atmospheric pressure
- 1979-2019



Methodology

Flow

- AWE-GEN
  - Stochastic weather generator
  - Radiation, Precipitation and Temperature
- FORMIND
  - Process and individual based forest model
- Variational Autoencoders (VAE)
  - Generative deep learning model



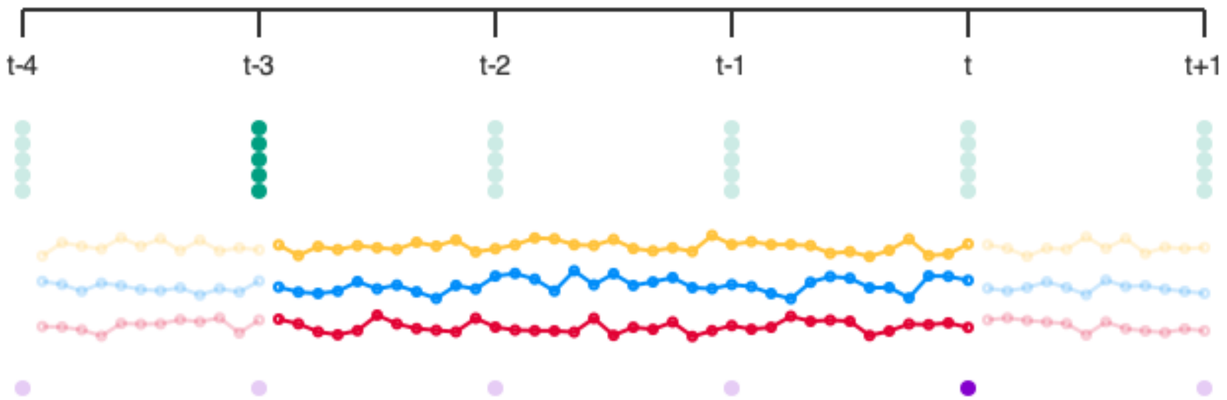
Methodology

Data Preparation

- FORMIND Calibration
  - Hainich Beech Forest, Germany
  - 51.08 degrees N, 10.51 degrees E
- 3 separate simulations
  - Beech, Pine and Spruce
  - Burn in period 2000 years
  - 160,000 years of simulations
  - Area 200 ha

Methodology

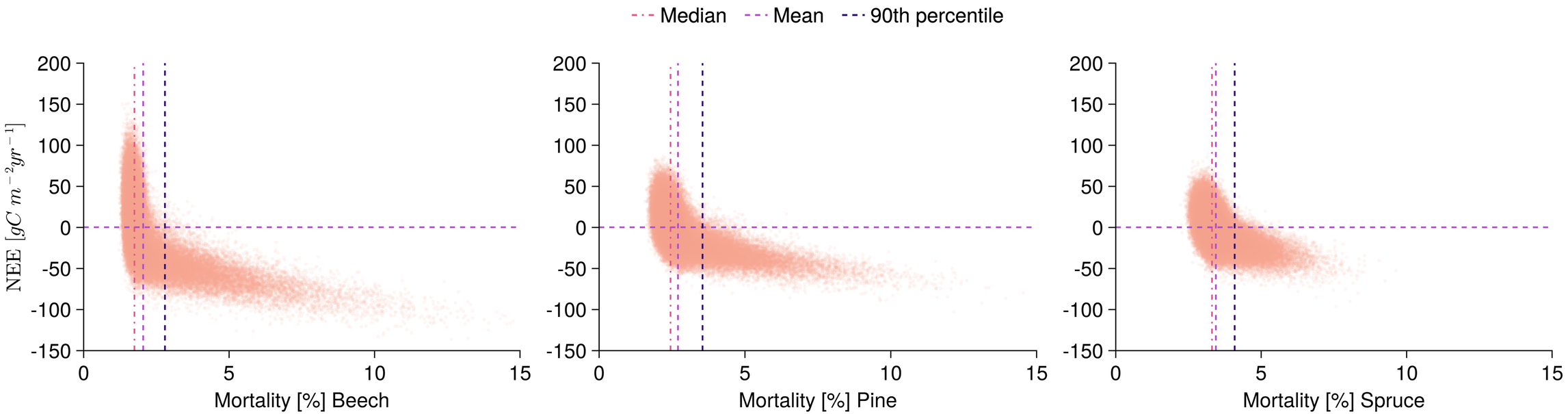
Data Preparation



- State variables (x_s)
  - Yearly values - $year_{t-3}$
- Dynamic variables (x_d)
  - Monthly values - $year_{t-2}$, $year_{t-1}$, and $year_t$
- Biomass Mortality Rate (MBR) (y)
  - Yearly Value - $year_t$
  - Binary (90th percentile)

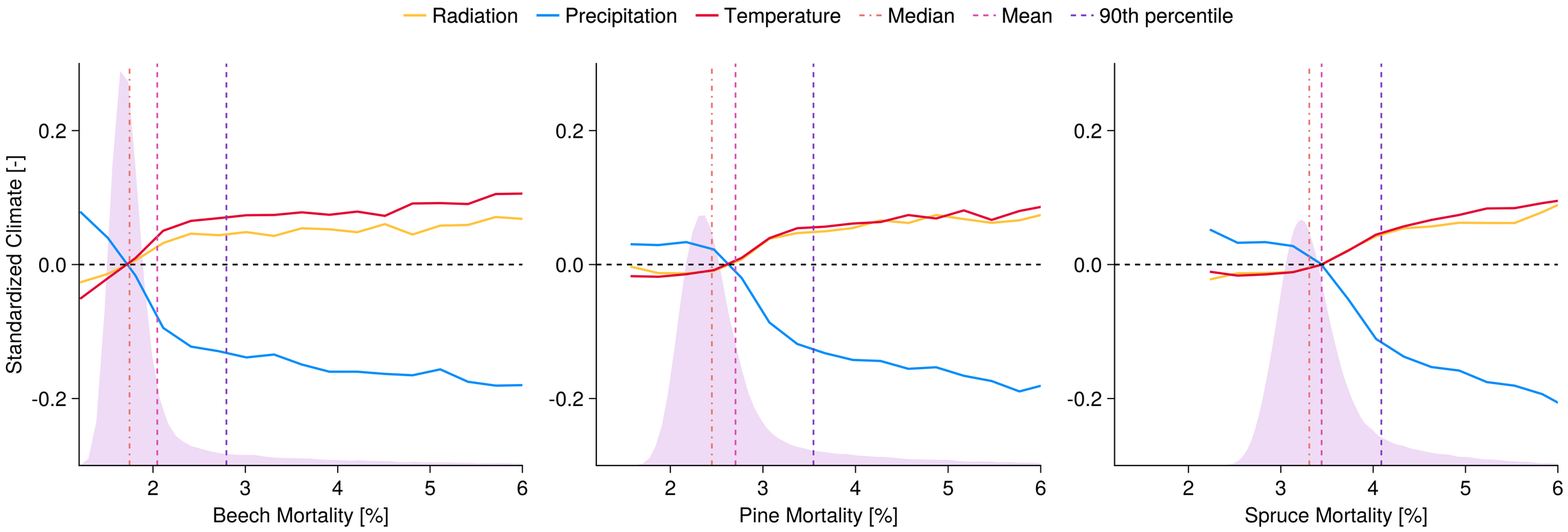
FORMIND Simulation

Net Ecosystem Exchange vs Mortality



FORMIND Simulation

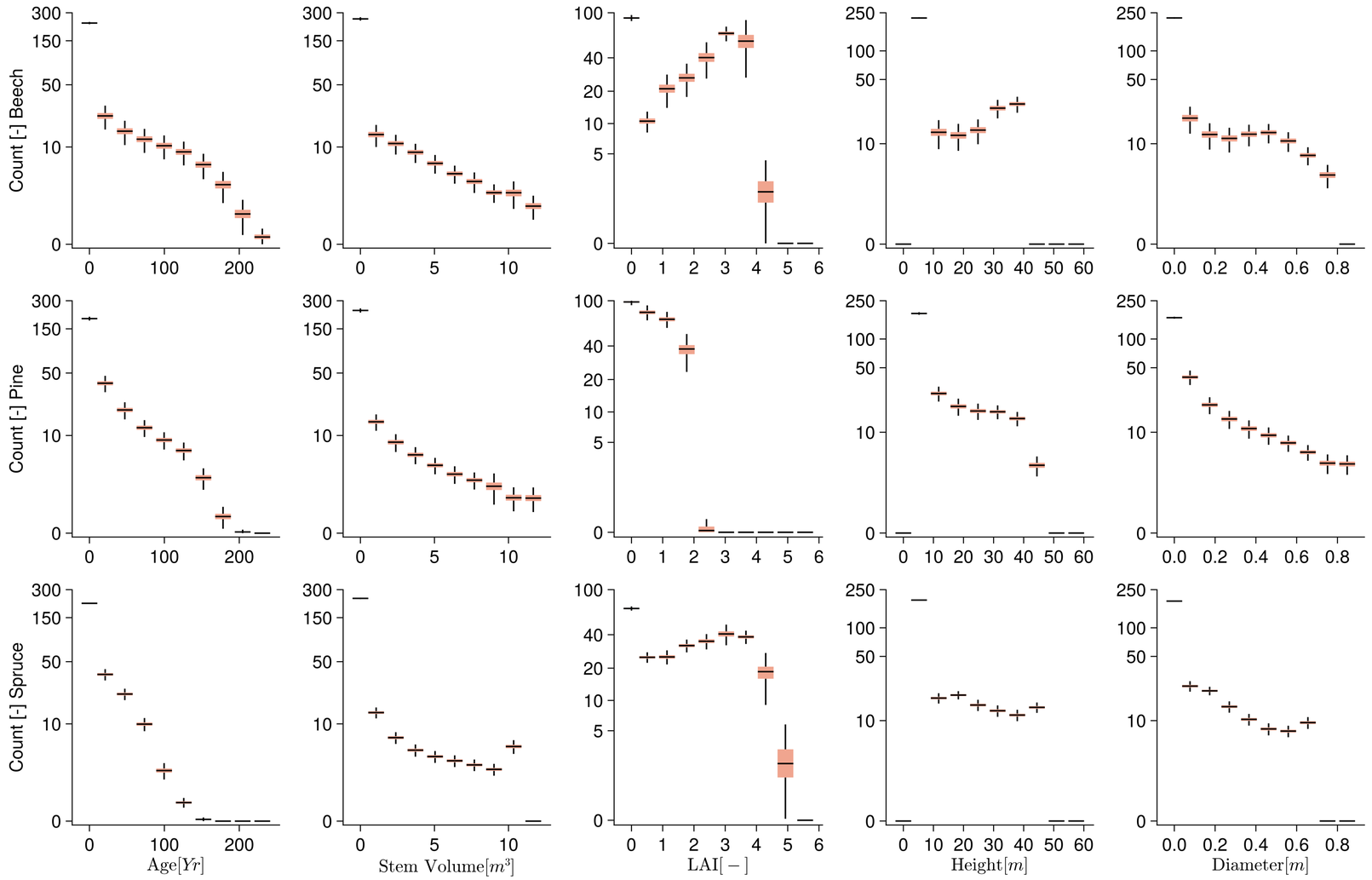
Forest Mortality



FORMIND Simulation

State Variables

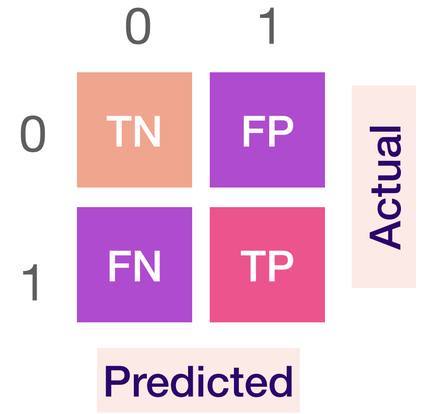
- State variables are PFT dependent
- LAI has a very different pattern



Extreme Mortality

Logistic Regression

Metrics	CSI	f1-score	Average Precision
Beech Logistic Regression with x_d	0.43	0.60	0.65
Beech Logistic Regression with x_d and x_s	0.53	0.69	0.77
Pine Logistic Regression with x_d	0.46	0.64	0.70
Pine Logistic Regression with x_d and x_s	0.60	0.75	0.85
Spruce Logistic Regression with x_d	0.46	0.63	0.69
Spruce Logistic Regression with x_d and x_s	0.59	0.74	0.84



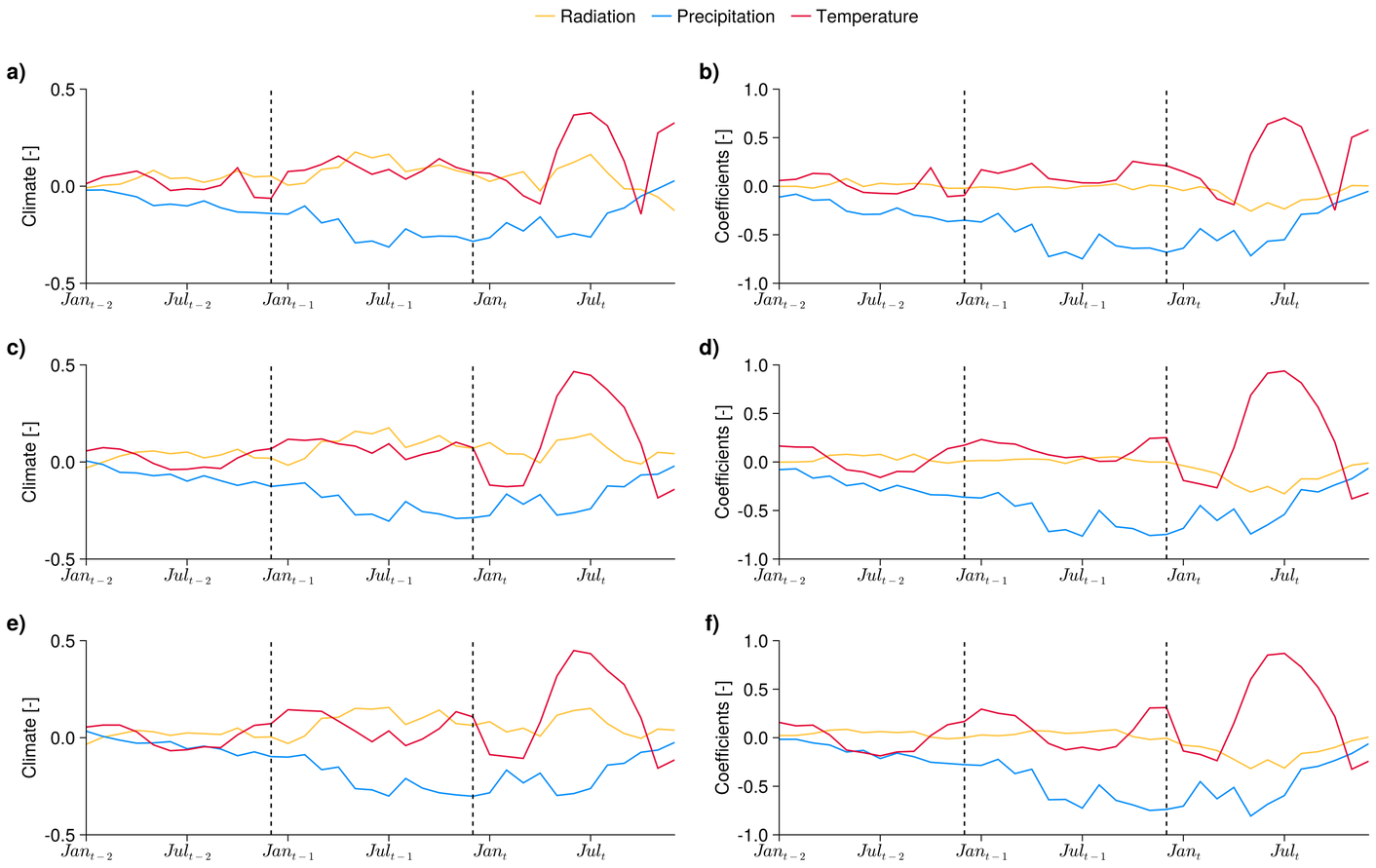
- Predictability
  - Spruce == Pine >> Beech
  - Static variables help

$$CSI = \frac{TP}{TP + FP + FN}$$

Extreme Mortality

Composites & Logistic Regression

- Extreme mortality > 90th percentile
- Drier years with higher temperature and solar radiation
- Pine and Spruce has similar behaviour



Composites are nice

We want to know more!

- Composite and Logistic Regression show one dominant (superimposed) mechanisms for extreme forest mortality
- Pathways leading to high forest mortality

VAE

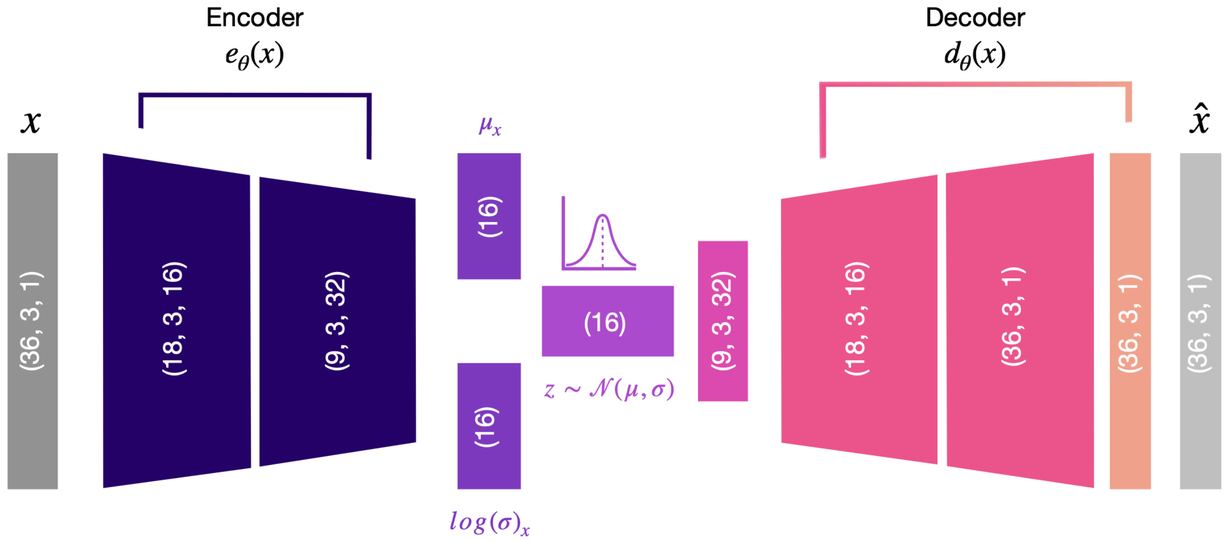
Generative Modelling Approach

- VAE has two parts
  - Encoder
  - Decoder
- Input space is reduced to latent space (Encoder)
- Reconstruction is done again from the latent space (Decoder)
- Latent dimensions are independent and normal (approximately)

VAE

Architecture

- Input
  - 3 years (monthly), radiation, temperature and precipitation
  - 16 latent dimensions
  - Loss has 2 components



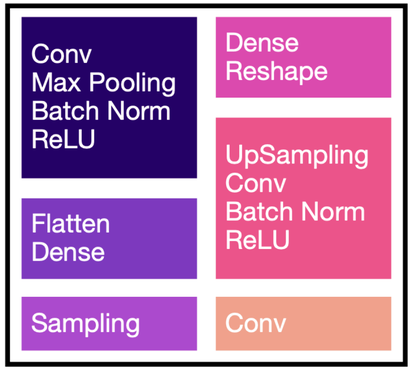
ReconstructionLoss

$$||x - \hat{x}||_2 = ||x - d_\phi(z)||_2 = ||x - d_\phi(\mu_x + \sigma_x \epsilon)||_2$$

KLDivergence

$$D_{KL}(\mathcal{N}(\mu_x, \sigma_x) || \mathcal{N}(0, I))$$

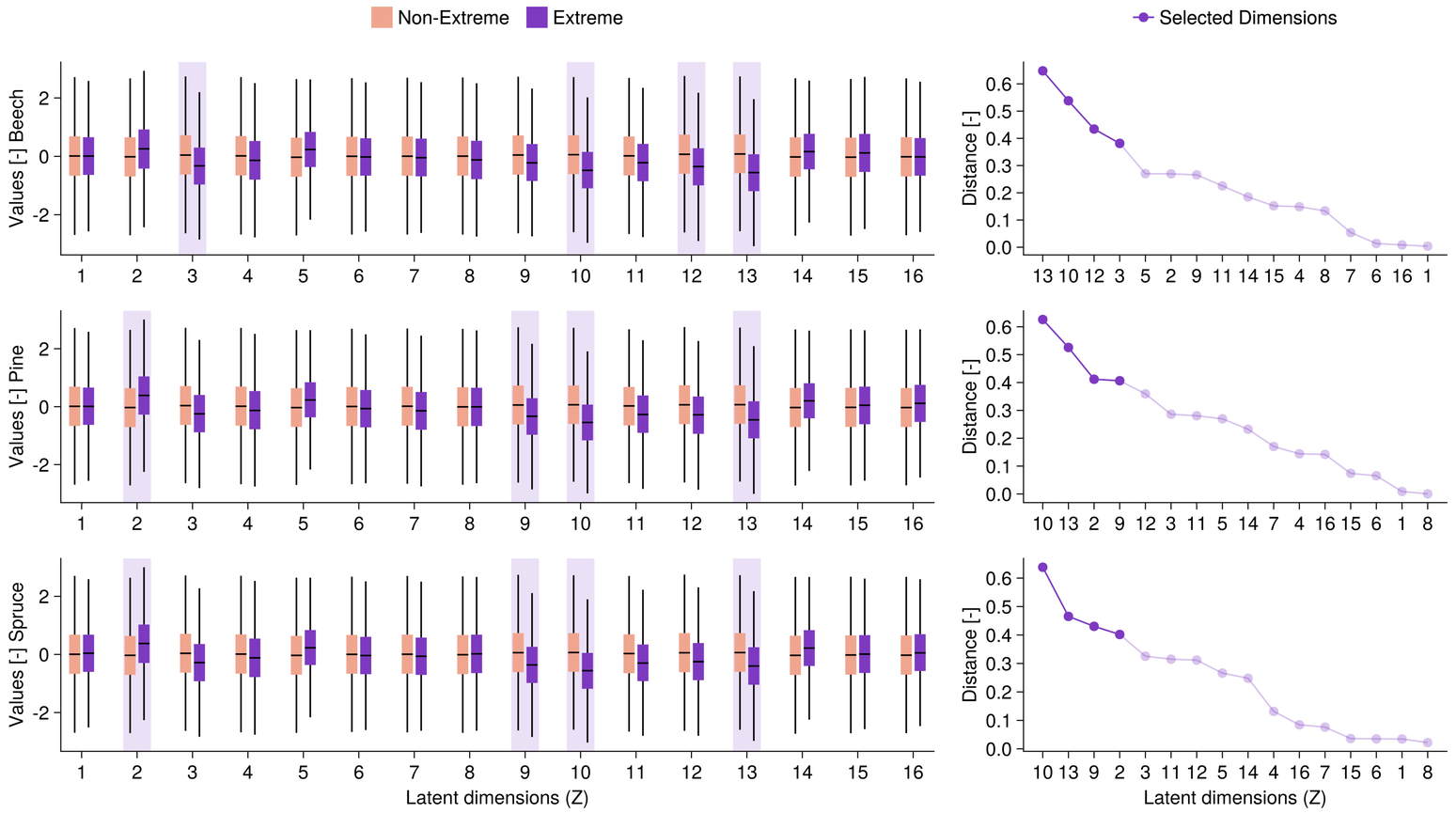
Total Loss = ReconstructionLoss + β x KLDivergence



Results

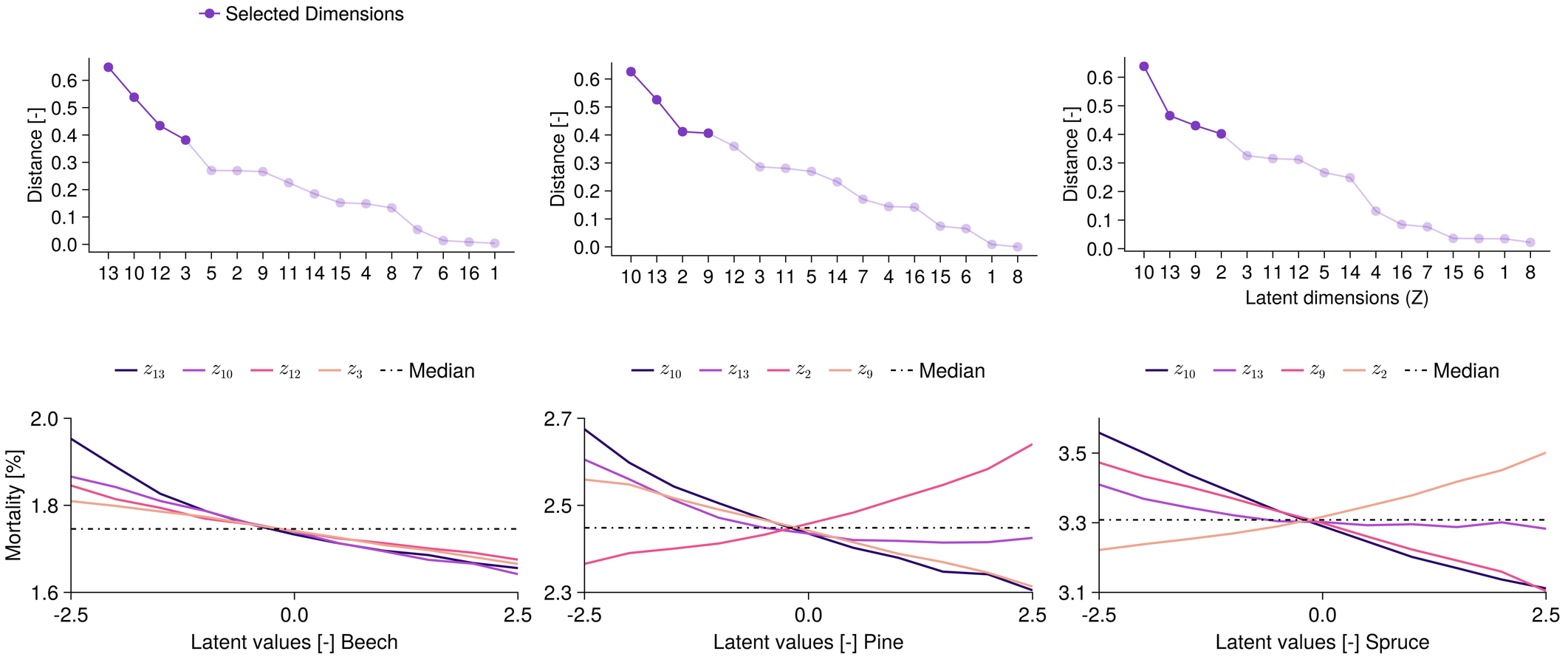
Latent Dimensions

- Extreme vs Non-Extreme latent values
- Difference between latent values
- Pine and Spruce have similar behaviour



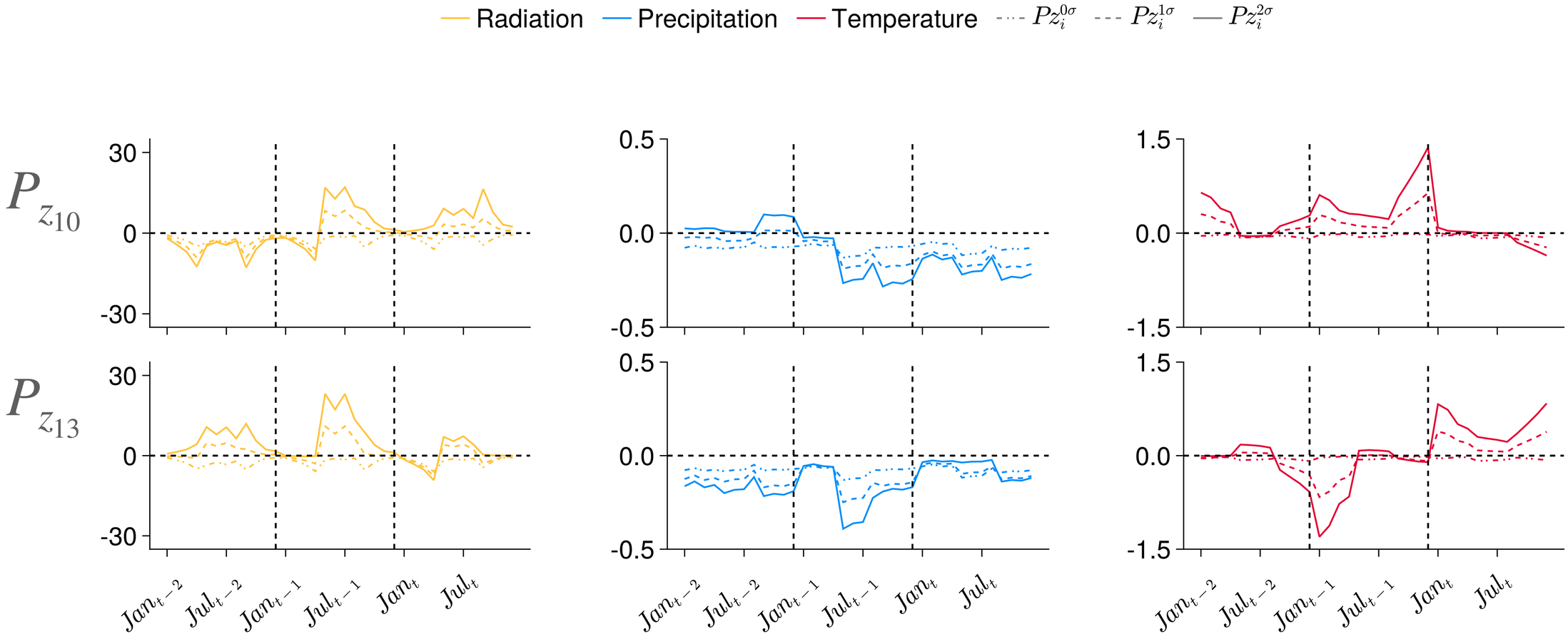
Results

Latent dimensions vs Mortality



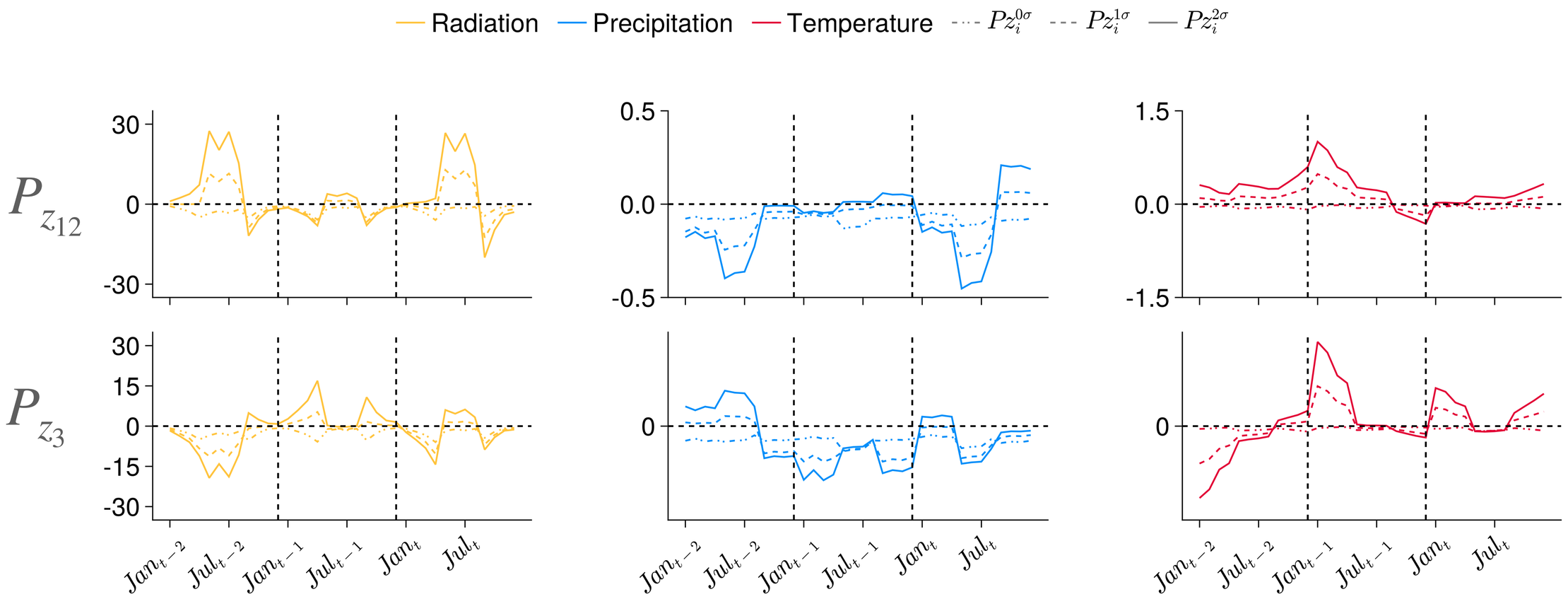
Results

All


Radiation
Precipitation
Temperature
$Pz_i^{0\sigma}$
$Pz_i^{1\sigma}$
$Pz_i^{2\sigma}$
$P_{z_{10}}$
$P_{z_{13}}$
30
0
-30
0.5
0.0
-0.5
1.5
0.0
-1.5
Jan_{t-2}
Jul_{t-2}
Jan_{t-1}
Jul_{t-1}
Jan_t
Jul_t

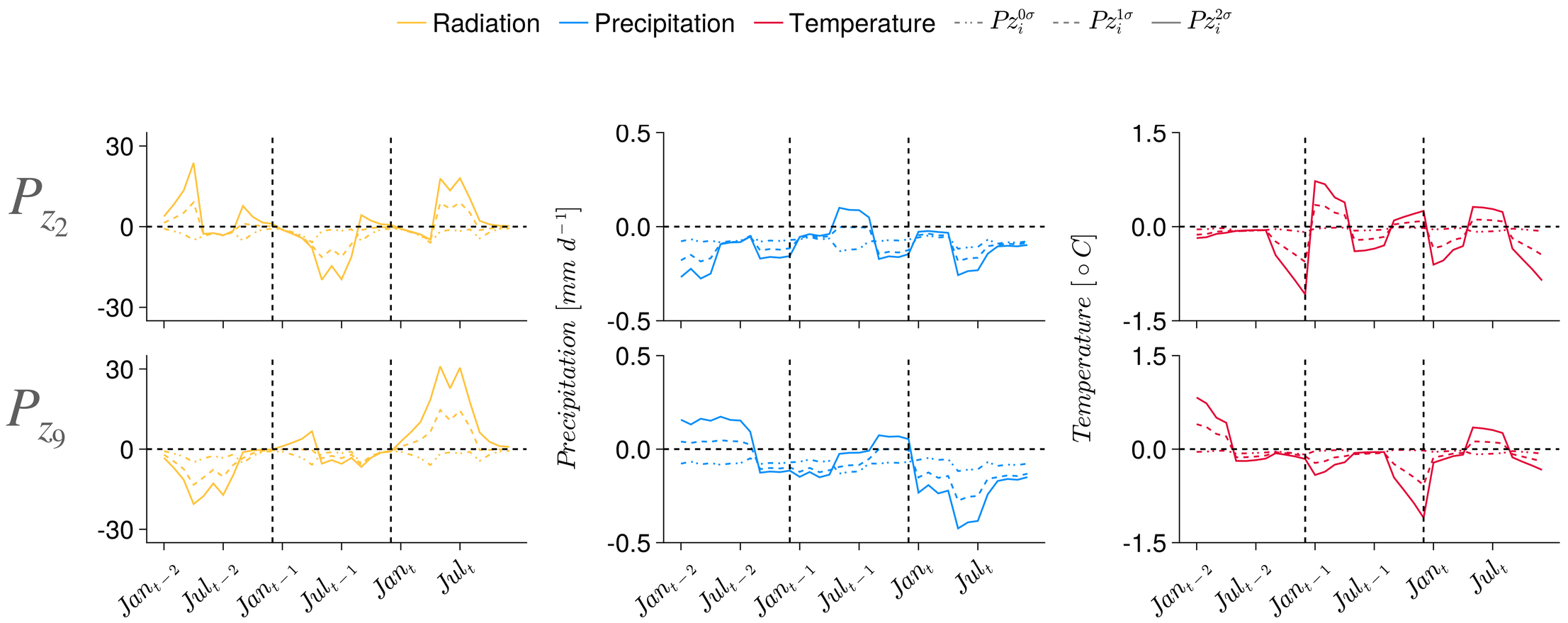
Results

Beech



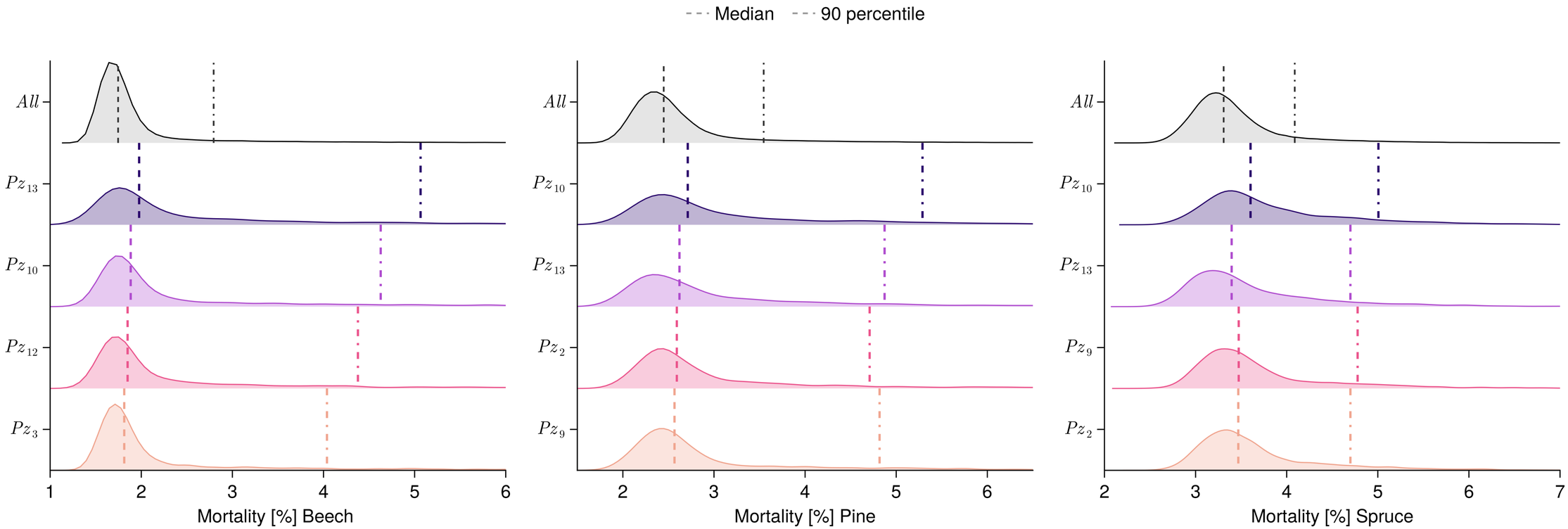
Results

Pine and Spruce



Results

Mortality density



Conclusion

- Forest mortality is a complex phenomenon
- Weather far in past matters for mortality
- State variables matter
- Composite analysis/Logistic regression identifies the dominant average
- VAEs identify climate prototypes of forest mortality
- Identified prototypes are associated with higher forest mortality (on average)

Thank You!