DiseaseModelPINN_notebook_simpleModel

December 17, 2022

```python
import deepxde as dde
from deepxde.backend import pytorch
import torch
import matplotlib.pyplot as plt
import numpy as np

from SIRD_deepxde_DiseaseModel import SIRD_deepxde_net
from DiseaseModel import SIR,SIRD,SIRDIm,SIRDImRel, SIRDImRelSimple, SIRD2Var,
    SIRD2VarRelSimple, GeneralModelSolver
from Plot import Plot

# %matplotlib widget

seed = 2
np.random.seed(seed)
dde.config.set_random_seed(seed)
```

Using backend: pytorch

default Torch device: cpu

```python
time_delta = [0,365] # use three values here for intro time of second variant

# initial_conditions = {
#     "S": 1000000,
#     "I": 1,
#     "R": 0,
#     }
# static_parameters = {
#     "alpha": (0.15),
#     "beta": (0.07),
#     }
# sird_model = SIR(initial_conditions, static_parameters, time_delta)

# initial_conditions = {
#     "S": 1000000,
#     "I": 1,
```

```python
#         "R": 0,
#         "D": 0,
#     }
# static_parameters = {
#     "alpha": (0.2),
#     "beta": (0.05),
#     "gamma": (0.001),
#     }
# sird_model = SIRD(initial_conditions, static_parameters, time_delta)

# initial_conditions = {
#     "S": 1000000,
#     "I": 15,
#     "R": 0,
#     "D": 0,
#     "Im": 0, # should be between 0 and 1
#     }
# static_parameters = {
#     "alpha": 0.12,
#     "beta": 0.07,
#     "gamma": 0.02,
#     "kappa": 0.2,
#     }
# sird_model = SIRDIm(initial_conditions, static_parameters, time_delta)
# initial_conditions = {
#     "S": 1000000,
#     "I": 15,
#     "R": 0,
#     "D": 0,
#     "Im": 0, # should be between 0 and 1
#     }
# static_parameters = {
#     "lambda_": 1.5,
#     "gamma": 0.000,
#     "kappa": 0.2,
#     }
# sird_model = SIRDImRel(initial_conditions, static_parameters, time_delta)
# initial_conditions = {
#     "S": 1000000,
#     "I": 15,
#     "R": 0,
#     "Im": 0, # should be between 0 and 1
#     }
# static_parameters = {
#     "lambda_": 1.5,
#     "kappa": 0.2,
#     }
```

```python
# sird_model = SIRDImRelSimple(initial_conditions, static_parameters,␣
 ↪time_delta)

# initial_conditions = {
#     "S": 1000000,
#     "Ia": 1,
#     "Ib": 0,
#     "Ra": 0,
#     "Rb": 0,
#     "D": 0,
#     "Im_a": 0, # should be between 0 and 1
#     "Im_b": 0, # should be between 0 and 1
#     }
# static_parameters = {
#     "alpha_a": 0.23  ,
#     "alpha_b": 0.18,
#     "beta_a": 0.1,
#     "beta_b": 0.08,
#     "gamma_a": 0.00,
#     "gamma_b": 0.00,
#     "kappa_a": 0.8,
#     "kappa_b": 0.5,
#     }
# static_parameters = {
#     "alpha_a": 0.11,
#     "alpha_b": 0.12,
#     "beta_a": 0.08,
#     "beta_b": 0.08,
#     "gamma_a": 0.00,
#     "gamma_b": 0.00,
#     "kappa_a": 0.1,
#     "kappa_b": 0.2,
#     }
# sird_model = SIRD2Var(initial_conditions, static_parameters, time_delta)

initial_conditions = {
    "S": 1000000,
    "Ia": 1,
    "Ib": 0,
    "Ra": 0,
    "Rb": 0,
    "Im_a": 0,
    "Im_b": 0,
    }
static_parameters = {
    "lambda_a": 2.2  ,
    "lambda_b": 1.9,
```
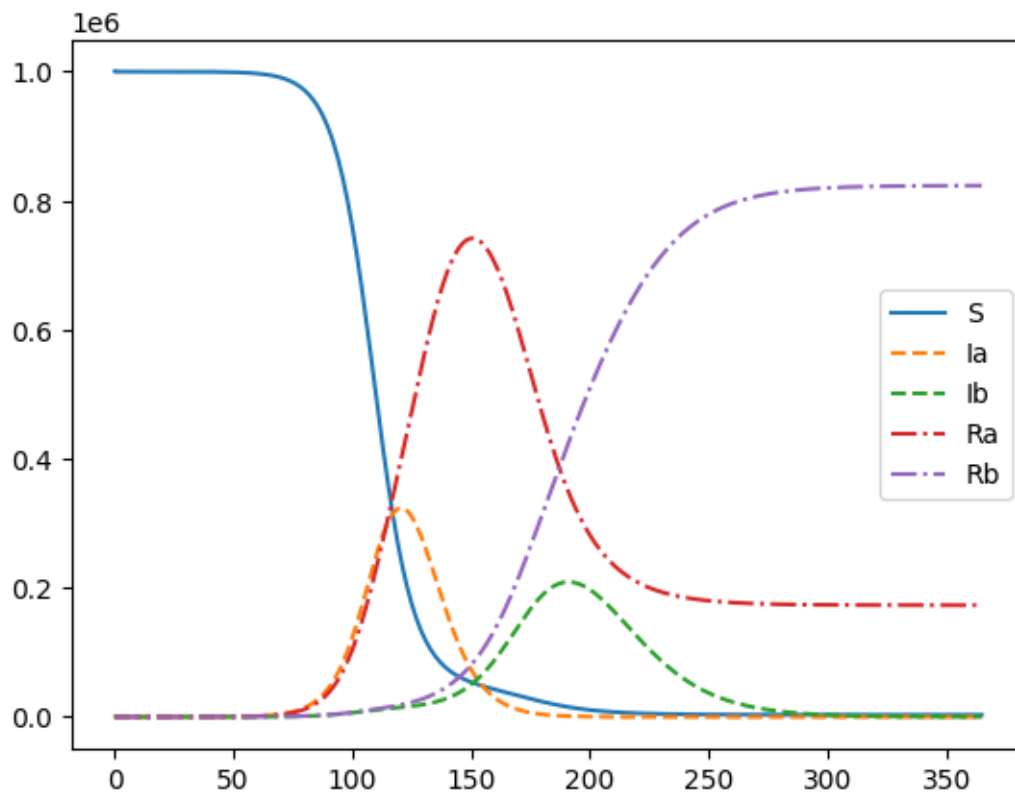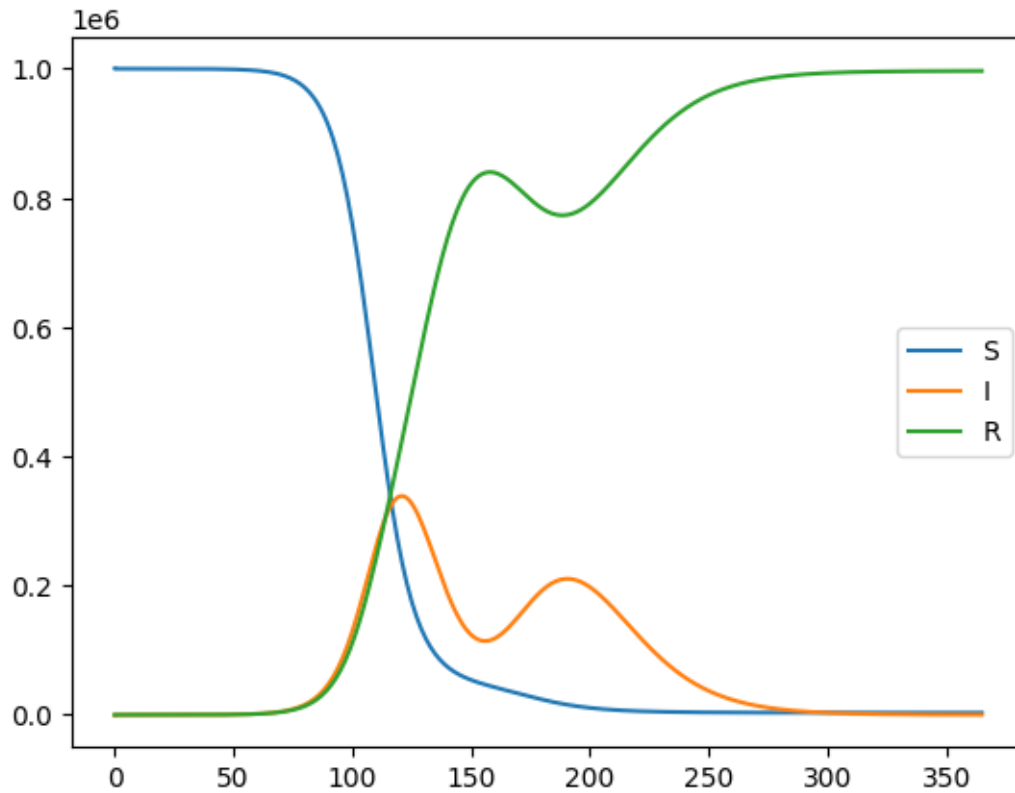
```
    "kappa_a": 0.8, # should be between 0 and 1
    "kappa_b": 0.5,
    }

sird_model = SIRD2VarRelSimple(initial_conditions, static_parameters,␣
 ↪time_delta)


t_synth, solution_synth_full = sird_model.simulate()
t_synth, solution_synth = sird_model.get_solution_as_sird()
sird_model.plot_solution()
sird_model.plot_sird()
```

```
[ ]: print(sird_model)
```

A Disease Model with description: 'A model that simulates two concurrent
diseases and natural herd immunity as a factor of the amount of recovered for
each variant':
Parameters:
        lambda_a = 2.2
        lambda_b = 1.9
        kappa_a = 0.8
        kappa_b = 0.5

PDE groups and initial conditions:
        S = 1000000
        Ia = 1
        Ib = 0
        Ra = 0
        Rb = 0
        Im_a = 0
        Im_b = 0

PDE equations:

```
        dS/dt = -(0.1*lambda_a/N)*Ia*S - (0.1*lambda_b/N)*Ib*S
        dIa/dt = (0.1*lambda_a/N)*S*Ia + (0.1*lambda_a/N)*(1 - Im_a)*(Ra +
Rb)*Ia - 0.1*Ia
        dIb/dt = (0.1*lambda_b/N)*S*Ib + (0.1*lambda_b/N)*(1 - Im_b)*(Ra +
Rb)*Ib - 0.1*Ib
        dRa/dt = 0.1*Ia - (0.1*lambda_a/N)*(1 - (Im_a))*(Ra)*(Ia) -
(0.1*lambda_b/N)*(1 - (Im_b))*(Ra)*(Ib)
        dRb/dt = 0.1*Ib - (0.1*lambda_a/N)*(1 - (Im_a))*(Rb)*(Ia) -
(0.1*lambda_b/N)*(1 - (Im_b))*(Rb)*(Ib)
        dIm_a/dt = kappa_a*0.1*Ia/N
        dIm_b/dt = kappa_b*0.1*Ib/N
PINN PDE loss equations:
        dS_t - (-(0.1*lambda_a/N)*Ia*S - (0.1*lambda_b/N)*Ib*S)
        dIa_t - ((0.1*lambda_a/N)*S*Ia + (0.1*lambda_a/N)*(1 - Im_a)*(Ra +
Rb)*Ia - 0.1*Ia)
        dIb_t - ((0.1*lambda_b/N)*S*Ib + (0.1*lambda_b/N)*(1 - Im_b)*(Ra +
Rb)*Ib - 0.1*Ib )
        dRa_t - (0.1*Ia - (0.1*lambda_a/N)*(1 - (Im_a))*(Ra)*(Ia) -
(0.1*lambda_b/N)*(1 - (Im_b))*(Ra)*(Ib))
        dRb_t - (0.1*Ib - (0.1*lambda_a/N)*(1 - (Im_a))*(Rb)*(Ia) -
(0.1*lambda_b/N)*(1 - (Im_b))*(Rb)*(Ib))
        dIm_a_t - (kappa_a*0.1*Ia/N)
        dIm_b_t - (kappa_b*0.1*Ib/N)
```

```python
# keep this even if not subsetting
t = t_synth
wsol = solution_synth

solver = GeneralModelSolver(sird_model)
# subset
# max_timestep = 300
# t_bool = t_synth < max_timestep
# t = t_synth[t_bool]
# wsol = wsol_synth[t_bool]
```

```python
model = SIRD_deepxde_net(t, wsol,disease_model=sird_model, with_neumann=True,
  ↪model_name="diseasemodel_test", with_softadapt=True)
print(model)
hyper_print_every = 100
model.init_model(lr=0.01, print_every=hyper_print_every, activation="tanh",
  ↪nn_layers=2, nn_layer_width=32)
```

```
PINN model:
Parameters: ['lambda_a', 'lambda_b', 'kappa_a', 'kappa_b']
Loss measures: ['dS_t', 'dIa_t', 'dIb_t', 'dRa_t', 'dRb_t', 'dIm_a_t',
'dIm_b_t', 'ic_Ia', 'ic_Ib', 'ic_Ra', 'ic_Rb', 'ic_Im_a', 'ic_Im_b', 'ic_S',
'observe_S', 'observe_I', 'observe_R', 'observe_SUM', 'sign_Ia', 'sign_Ib',
'sign_Ra', 'sign_Rb', 'sign_Im_a', 'sign_Im_b', 'L1_norm_Ia', 'L1_norm_Ib',
```

```
'L1_norm_Ra', 'L1_norm_Rb', 'L1_norm_Im_a', 'L1_norm_Im_b', 'ic_neumann_S',
'ic_neumann_Ia', 'ic_neumann_Ib', 'ic_neumann_Ra', 'ic_neumann_Rb',
'ic_neumann_Im_a', 'ic_neumann_Im_b']
Compiling model…
'compile' took 0.000061 s
```

```python
prev_best_step = 0
iters = 0
plot_every=2000
```

```python
TOTAL_ITER = 100_000
try:
    while True:
        # for n in range(TOTAL_ITER//plot_every):
        model.train_model(iterations=plot_every, print_every=hyper_print_every,
 ↪use_LBFGSB=False)
        params_nn, best_step = model.get_best_params(out_func=np.exp) #
 ↪parameters need to be extracted with the exponential functino as they have
 ↪been modelled in logspace
        if best_step > prev_best_step:
            prev_best_step = best_step
            break
        elif iters >= TOTAL_ITER:
            break
except KeyboardInterrupt:
    print("Training ended prematurely")

params_nn, best_step = model.get_best_params(out_func=np.exp) # parameters need
 ↪to be extracted with the exponential functino as they have been modelled in
 ↪logspace
print(static_parameters, sep="\n")
t_nn_param, wsol_nn_param, wsol_sird_nn_param = solver(*params_nn)
# params_nn= tuple(np.exp([*params_nn]))
# print(*params_nn)
model.set_synthetic_data(t_synth, solution_synth_full)
model.set_nn_synthetic_data(t_nn_param, wsol_nn_param, wsol_sird_nn_param)
plot = Plot(model, values_to_plot=sird_model.initial_conditions_keys) # class
 ↪that contains plotting functions
plot.show_known_and_prediction()
# plot.plot_param_history()
# plot.plot_loss_history()
```

```
Training model…

Step      Train loss
Test loss
```

Test metric

30000   [5.98e-04, 1.95e-04, 1.48e-05, 9.66e-05, 2.63e-04, 1.32e-04, 2.13e-04,
6.49e-02, 1.41e-02, 1.15e-03, 2.87e-02, 1.81e-02, 3.43e-02, 1.33e-02, 3.35e-01,
8.49e-02, 5.03e-01, 2.11e-01, 1.03e-02, 9.59e-03, 0.00e+00, 0.00e+00, 2.93e-04,
1.03e-03, 1.71e-02, 1.04e-02, 6.69e-04, 1.73e-03, 1.43e-03, 3.60e-03, 2.44e-02,
2.44e-02, 2.44e-02, 2.44e-02, 2.44e-02, 2.44e-02, 2.44e-02]   [5.98e-04,
1.95e-04, 1.48e-05, 9.66e-05, 2.63e-04, 1.32e-04, 2.13e-04, 6.49e-02, 1.41e-02,
1.15e-03, 2.87e-02, 1.81e-02, 3.43e-02, 1.33e-02, 3.35e-01, 8.49e-02, 5.03e-01,
2.11e-01, 1.03e-02, 9.59e-03, 0.00e+00, 0.00e+00, 2.93e-04, 1.03e-03, 1.71e-02,
1.04e-02, 6.69e-04, 1.73e-03, 1.43e-03, 3.60e-03, 2.44e-02, 2.44e-02, 2.44e-02,
2.44e-02, 2.44e-02, 2.44e-02, 2.44e-02]   []
30100   [3.95e-04, 1.65e-05, 2.43e-04, 1.36e-04, 6.55e-04, 5.58e-06, 1.46e-04,
6.05e-05, 1.12e-05, 8.09e-04, 7.35e-03, 6.15e-05, 1.99e-04, 7.35e-03, 2.17e-01,
3.78e-02, 3.02e-01, 9.99e-04, 3.55e-03, 6.09e-08, 3.04e-04, 0.00e+00, 1.04e-06,
2.43e-02, 1.15e-03, 2.58e-02, 5.87e-03, 8.53e-03, 7.38e-04, 2.09e-02, 8.05e-05,
8.05e-05, 8.05e-05, 8.05e-05, 8.05e-05, 8.05e-05, 8.05e-05]   [3.95e-04,
1.65e-05, 2.43e-04, 1.36e-04, 6.55e-04, 5.58e-06, 1.46e-04, 6.05e-05, 1.12e-05,
8.09e-04, 7.35e-03, 6.15e-05, 1.99e-04, 7.35e-03, 2.17e-01, 3.78e-02, 3.02e-01,
9.99e-04, 3.55e-03, 6.09e-08, 3.04e-04, 0.00e+00, 1.04e-06, 2.43e-02, 1.15e-03,
2.58e-02, 5.87e-03, 8.53e-03, 7.38e-04, 2.09e-02, 8.05e-05, 8.05e-05, 8.05e-05,
8.05e-05, 8.05e-05, 8.05e-05, 8.05e-05]   []
30200   [1.99e-04, 5.82e-06, 3.73e-05, 3.77e-05, 7.91e-05, 4.71e-07, 7.14e-06,
3.84e-04, 1.80e-04, 1.32e-03, 3.18e-03, 8.65e-05, 2.16e-04, 7.13e-03, 1.41e-01,
1.16e-02, 1.40e-01, 3.31e-02, 2.35e-04, 2.16e-03, 1.15e-04, 2.26e-04, 5.88e-07,
0.00e+00, 2.10e-04, 1.05e-02, 2.79e-03, 3.92e-03, 1.04e-05, 1.80e-04, 2.34e-03,
2.34e-03, 2.34e-03, 2.34e-03, 2.34e-03, 2.34e-03, 2.34e-03]   [1.99e-04,
5.82e-06, 3.73e-05, 3.77e-05, 7.91e-05, 4.71e-07, 7.14e-06, 3.84e-04, 1.80e-04,
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3.31e-02, 2.35e-04, 2.16e-03, 1.15e-04, 2.26e-04, 5.88e-07, 0.00e+00, 2.10e-04,
1.05e-02, 2.79e-03, 3.92e-03, 1.04e-05, 1.80e-04, 2.34e-03, 2.34e-03, 2.34e-03,
2.34e-03, 2.34e-03, 2.34e-03, 2.34e-03]   []
30300   [5.20e-05, 3.03e-06, 1.22e-05, 7.32e-05, 6.51e-05, 4.07e-07, 6.94e-06,
1.42e-06, 7.69e-05, 9.11e-05, 2.36e-07, 3.56e-07, 3.35e-05, 4.49e-04, 4.02e-03,
5.89e-03, 5.79e-03, 9.46e-04, 1.31e-03, 2.69e-06, 3.09e-05, 1.68e-08, 5.55e-08,
1.71e-06, 2.88e-04, 1.28e-04, 8.00e-04, 1.08e-04, 3.30e-06, 5.69e-05, 2.60e-05,
2.60e-05, 2.60e-05, 2.60e-05, 2.60e-05, 2.60e-05, 2.60e-05]   [5.20e-05,
3.03e-06, 1.22e-05, 7.32e-05, 6.51e-05, 4.07e-07, 6.94e-06, 1.42e-06, 7.69e-05,
9.11e-05, 2.36e-07, 3.56e-07, 3.35e-05, 4.49e-04, 4.02e-03, 5.89e-03, 5.79e-03,
9.46e-04, 1.31e-03, 2.69e-06, 3.09e-05, 1.68e-08, 5.55e-08, 1.71e-06, 2.88e-04,
1.28e-04, 8.00e-04, 1.08e-04, 3.30e-06, 5.69e-05, 2.60e-05, 2.60e-05, 2.60e-05,
2.60e-05, 2.60e-05, 2.60e-05, 2.60e-05]   []
30400   [3.57e-05, 1.54e-06, 9.57e-06, 2.99e-05, 2.02e-05, 1.02e-07, 2.33e-06,
2.66e-04, 2.95e-04, 2.59e-05, 1.68e-04, 7.21e-10, 1.01e-05, 2.80e-04, 2.85e-03,
4.33e-03, 4.81e-03, 1.49e-03, 1.54e-05, 2.06e-05, 7.93e-06, 1.62e-06, 2.48e-13,
9.77e-07, 8.27e-05, 5.40e-04, 2.01e-04, 5.17e-05, 1.24e-06, 2.72e-05, 2.23e-05,
2.23e-05, 2.23e-05, 2.23e-05, 2.23e-05, 2.23e-05, 2.23e-05]   [3.57e-05,
1.54e-06, 9.57e-06, 2.99e-05, 2.02e-05, 1.02e-07, 2.33e-06, 2.66e-04, 2.95e-04,
2.59e-05, 1.68e-04, 7.21e-10, 1.01e-05, 2.80e-04, 2.85e-03, 4.33e-03, 4.81e-03,

1.49e-03, 1.54e-05, 2.06e-05, 7.93e-06, 1.62e-06, 2.48e-13, 9.77e-07, 8.27e-05,
5.40e-04, 2.01e-04, 5.17e-05, 1.24e-06, 2.72e-05, 2.23e-05, 2.23e-05, 2.23e-05,
2.23e-05, 2.23e-05, 2.23e-05, 2.23e-05]   []
30500   [3.00e-05, 1.31e-06, 1.19e-05, 2.58e-05, 2.02e-05, 1.76e-07, 2.21e-06,
3.64e-04, 6.50e-07, 4.47e-07, 1.78e-05, 2.55e-08, 9.80e-07, 1.23e-04, 1.17e-03,
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6.44e-05, 1.48e-04, 1.12e-04, 1.06e-04, 1.32e-04, 1.75e-05, 8.09e-05, 6.10e-06,
6.10e-06, 6.10e-06, 6.10e-06, 6.10e-06, 6.10e-06, 6.10e-06]   [3.00e-05,
1.31e-06, 1.19e-05, 2.58e-05, 2.02e-05, 1.76e-07, 2.21e-06, 3.64e-04, 6.50e-07,
4.47e-07, 1.78e-05, 2.55e-08, 9.80e-07, 1.23e-04, 1.17e-03, 3.59e-03, 3.74e-03,
8.48e-04, 3.24e-06, 5.48e-06, 4.97e-06, 1.50e-05, 6.29e-05, 6.44e-05, 1.48e-04,
1.12e-04, 1.06e-04, 1.32e-04, 1.75e-05, 8.09e-05, 6.10e-06, 6.10e-06, 6.10e-06,
6.10e-06, 6.10e-06, 6.10e-06, 6.10e-06]   []
30600   [2.78e-05, 1.55e-06, 1.26e-05, 2.49e-05, 1.94e-05, 1.26e-07, 1.90e-06,
4.41e-04, 1.26e-06, 2.14e-05, 2.81e-05, 7.62e-07, 2.07e-06, 1.23e-04, 6.45e-04,
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5.44e-06, 5.44e-06, 5.44e-06, 5.44e-06, 5.44e-06, 5.44e-06]   [2.78e-05,
1.55e-06, 1.26e-05, 2.49e-05, 1.94e-05, 1.26e-07, 1.90e-06, 4.41e-04, 1.26e-06,
2.14e-05, 2.81e-05, 7.62e-07, 2.07e-06, 1.23e-04, 6.45e-04, 3.32e-03, 3.56e-03,
4.12e-04, 2.59e-06, 7.63e-06, 7.97e-07, 2.86e-05, 3.42e-05, 3.40e-05, 1.37e-04,
1.62e-04, 2.49e-05, 5.89e-05, 8.84e-06, 4.69e-05, 5.44e-06, 5.44e-06, 5.44e-06,
5.44e-06, 5.44e-06, 5.44e-06, 5.44e-06]   []
30700   [2.49e-05, 1.34e-06, 1.25e-05, 2.95e-05, 2.23e-05, 9.61e-08, 1.90e-06,
1.87e-04, 1.14e-05, 2.78e-06, 4.27e-05, 6.69e-06, 7.86e-06, 1.18e-04, 4.40e-04,
3.22e-03, 3.53e-03, 2.61e-04, 5.15e-06, 3.68e-06, 1.30e-06, 1.35e-05, 3.51e-05,
1.39e-05, 1.42e-04, 5.84e-05, 3.23e-05, 6.92e-05, 1.07e-05, 4.18e-05, 9.56e-06,
9.56e-06, 9.56e-06, 9.56e-06, 9.56e-06, 9.56e-06, 9.56e-06]   [2.49e-05,
1.34e-06, 1.25e-05, 2.95e-05, 2.23e-05, 9.61e-08, 1.90e-06, 1.87e-04, 1.14e-05,
2.78e-06, 4.27e-05, 6.69e-06, 7.86e-06, 1.18e-04, 4.40e-04, 3.22e-03, 3.53e-03,
2.61e-04, 5.15e-06, 3.68e-06, 1.30e-06, 1.35e-05, 3.51e-05, 1.39e-05, 1.42e-04,
5.84e-05, 3.23e-05, 6.92e-05, 1.07e-05, 4.18e-05, 9.56e-06, 9.56e-06, 9.56e-06,
9.56e-06, 9.56e-06, 9.56e-06, 9.56e-06]   []
30800   [2.28e-05, 1.19e-06, 1.26e-05, 4.33e-05, 3.22e-05, 1.16e-07, 2.10e-06,
4.99e-06, 2.26e-04, 3.88e-07, 9.30e-05, 1.17e-05, 1.28e-05, 9.55e-05, 3.44e-04,
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2.96e-06, 2.96e-06, 2.96e-06, 2.96e-06]   []

Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 46.255551 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step   Train loss
Test loss
Test metric
32000   [1.46e-05, 9.54e-07, 8.57e-06, 2.50e-05, 1.79e-05, 5.34e-08, 7.13e-07,
1.52e-05, 1.06e-05, 6.97e-06, 4.33e-06, 1.16e-06, 2.95e-07, 1.32e-05, 1.57e-04,
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Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 47.423085 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step   Train loss
Test loss
Test metric
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Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 44.281615 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step   Train loss
Test loss
Test metric
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2.65e-06, 2.65e-06, 2.65e-06, 2.65e-06]     []


Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 40.082856 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…


Step     Train loss
Test loss
```

Test metric
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2.72e-03, 3.00e-03, 9.54e-05, 0.00e+00, 2.54e-08, 7.44e-06, 6.34e-07, 6.99e-09,
0.00e+00, 1.52e-05, 8.34e-06, 1.11e-04, 1.42e-05, 2.21e-06, 2.12e-07, 2.65e-06,
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2.10e-04, 4.95e-05, 7.05e-07, 1.35e-07, 2.89e-05, 1.64e-04, 2.72e-03, 3.00e-03,
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2.22e-04, 7.61e-06, 1.07e-03, 5.35e-06, 1.56e-07, 5.70e-06, 5.70e-06, 5.70e-06,
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2.57e-03, 2.52e-03, 3.11e-04, 4.64e-06, 0.00e+00, 0.00e+00, 1.50e-04, 3.63e-08,
0.00e+00, 1.14e-05, 6.42e-04, 1.01e-04, 1.13e-03, 8.88e-06, 8.48e-08, 7.38e-06,
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3.11e-04, 4.64e-06, 0.00e+00, 0.00e+00, 1.50e-04, 3.63e-08, 0.00e+00, 1.14e-05,
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1.81e-03, 1.98e-03, 6.35e-04, 3.79e-06, 0.00e+00, 0.00e+00, 1.75e-04, 9.49e-08,
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1.73e-03, 1.81e-03, 5.81e-04, 1.88e-05, 0.00e+00, 0.00e+00, 1.60e-04, 7.63e-08,
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1.74e-03, 1.69e-03, 6.03e-04, 4.95e-05, 0.00e+00, 0.00e+00, 1.52e-04, 7.19e-08,
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6.03e-04, 4.95e-05, 0.00e+00, 0.00e+00, 1.52e-04, 7.19e-08, 2.04e-12, 1.44e-04,
4.27e-04, 1.08e-05, 1.16e-03, 2.80e-05, 2.56e-07, 8.64e-06, 8.64e-06, 8.64e-06,
8.64e-06, 8.64e-06, 8.64e-06, 8.64e-06]   []
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1.67e-03, 1.65e-03, 4.74e-04, 7.25e-05, 0.00e+00, 0.00e+00, 1.24e-04, 4.94e-08,
7.82e-12, 1.80e-04, 3.68e-04, 1.01e-05, 9.96e-04, 2.95e-05, 2.60e-07, 7.00e-06,
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1.37e-05, 1.46e-03, 6.44e-06, 1.43e-09, 4.39e-06, 1.85e-04, 1.67e-03, 1.65e-03,
4.74e-04, 7.25e-05, 0.00e+00, 0.00e+00, 1.24e-04, 4.94e-08, 7.82e-12, 1.80e-04,
3.68e-04, 1.01e-05, 9.96e-04, 2.95e-05, 2.60e-07, 7.00e-06, 7.00e-06, 7.00e-06,
7.00e-06, 7.00e-06, 7.00e-06, 7.00e-06]   []

Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 42.610279 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step   Train loss
Test loss
Test metric
40000   [2.07e-05, 7.78e-07, 4.56e-06, 3.09e-05, 2.03e-05, 1.12e-06, 1.47e-07,
1.19e-04, 8.42e-04, 1.37e-05, 1.46e-03, 6.44e-06, 1.43e-09, 4.39e-06, 1.85e-04,
1.67e-03, 1.65e-03, 4.74e-04, 7.25e-05, 0.00e+00, 0.00e+00, 1.24e-04, 4.94e-08,
7.82e-12, 1.80e-04, 3.68e-04, 1.01e-05, 9.96e-04, 2.95e-05, 2.60e-07, 7.00e-06,
7.00e-06, 7.00e-06, 7.00e-06, 7.00e-06, 7.00e-06, 7.00e-06]   [2.07e-05,
7.78e-07, 4.56e-06, 3.09e-05, 2.03e-05, 1.12e-06, 1.47e-07, 1.19e-04, 8.42e-04,
1.37e-05, 1.46e-03, 6.44e-06, 1.43e-09, 4.39e-06, 1.85e-04, 1.67e-03, 1.65e-03,
4.74e-04, 7.25e-05, 0.00e+00, 0.00e+00, 1.24e-04, 4.94e-08, 7.82e-12, 1.80e-04,
3.68e-04, 1.01e-05, 9.96e-04, 2.95e-05, 2.60e-07, 7.00e-06, 7.00e-06, 7.00e-06,
7.00e-06, 7.00e-06, 7.00e-06, 7.00e-06]   []
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8.22e-03, 5.86e-03, 9.73e-04, 0.00e+00, 0.00e+00, 1.82e-05, 8.60e-06, 4.84e-07,
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6.19e-04, 1.06e-04, 6.05e-05, 4.45e-06, 2.92e-09, 7.16e-09, 7.16e-09, 7.16e-09,
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3.16e-02, 3.14e-02, 8.23e-02, 4.09e-02, 1.24e-06, 1.22e-06, 4.03e-01, 1.86e-01,
8.68e-02, 1.84e-01, 4.39e-02, 0.00e+00, 0.00e+00, 0.00e+00, 0.00e+00, 1.10e-06,

0.00e+00, 3.16e-02, 3.14e-02, 8.23e-02, 4.09e-02, 1.23e-06, 1.08e-06, 7.46e-08,
7.46e-08, 7.46e-08, 7.46e-08, 7.46e-08, 7.46e-08, 7.46e-08]   [6.61e-05,
7.60e-05, 6.02e-05, 1.30e-04, 1.75e-04, 6.03e-06, 1.36e-06, 3.16e-02, 3.14e-02,
8.23e-02, 4.09e-02, 1.24e-06, 1.22e-06, 4.03e-01, 1.86e-01, 8.68e-02, 1.84e-01,
4.39e-02, 0.00e+00, 0.00e+00, 0.00e+00, 0.00e+00, 1.10e-06, 0.00e+00, 3.16e-02,
3.14e-02, 8.23e-02, 4.09e-02, 1.23e-06, 1.08e-06, 7.46e-08, 7.46e-08, 7.46e-08,
7.46e-08, 7.46e-08, 7.46e-08, 7.46e-08]   []

Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 48.690258 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step   Train loss
Test loss
Test metric
42000   [6.61e-05, 7.60e-05, 6.02e-05, 1.30e-04, 1.75e-04, 6.03e-06, 1.36e-06,
3.16e-02, 3.14e-02, 8.23e-02, 4.09e-02, 1.24e-06, 1.22e-06, 4.03e-01, 1.86e-01,
8.68e-02, 1.84e-01, 4.39e-02, 0.00e+00, 0.00e+00, 0.00e+00, 0.00e+00, 1.10e-06,
0.00e+00, 3.16e-02, 3.14e-02, 8.23e-02, 4.09e-02, 1.23e-06, 1.08e-06, 7.46e-08,
7.46e-08, 7.46e-08, 7.46e-08, 7.46e-08, 7.46e-08, 7.46e-08]   [6.61e-05,
7.60e-05, 6.02e-05, 1.30e-04, 1.75e-04, 6.03e-06, 1.36e-06, 3.16e-02, 3.14e-02,
8.23e-02, 4.09e-02, 1.24e-06, 1.22e-06, 4.03e-01, 1.86e-01, 8.68e-02, 1.84e-01,
4.39e-02, 0.00e+00, 0.00e+00, 0.00e+00, 0.00e+00, 1.10e-06, 0.00e+00, 3.16e-02,
3.14e-02, 8.23e-02, 4.09e-02, 1.23e-06, 1.08e-06, 7.46e-08, 7.46e-08, 7.46e-08,
7.46e-08, 7.46e-08, 7.46e-08, 7.46e-08]   []
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7.49e-02, 2.03e-01, 3.12e-01, 0.00e+00, 0.00e+00, 0.00e+00, 7.85e-03, 2.80e-08,
0.00e+00, 2.92e-02, 2.90e-02, 2.59e-01, 8.63e-03, 5.40e-07, 1.21e-05, 9.11e-08,
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2.90e-02, 2.59e-01, 8.63e-03, 5.40e-07, 1.21e-05, 9.11e-08, 9.11e-08, 9.11e-08,
9.11e-08, 9.11e-08, 9.11e-08, 9.11e-08]   []
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9.82e-03, 5.26e-01, 1.75e-01, 0.00e+00, 0.00e+00, 1.21e-01, 0.00e+00, 1.22e-06,

0.00e+00, 2.59e-03, 2.64e-03, 1.21e-01, 1.31e-01, 1.25e-06, 9.09e-07, 2.10e-07,
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1.51e-01, 2.02e-01, 2.39e-01, 0.00e+00, 0.00e+00, 0.00e+00, 0.00e+00, 1.36e-06,
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1.19e-01, 2.75e-01, 8.12e-02, 0.00e+00, 0.00e+00, 0.00e+00, 0.00e+00, 4.81e-07,
0.00e+00, 4.03e-02, 4.20e-02, 6.51e-02, 8.82e-04, 9.07e-07, 2.15e-06, 6.27e-06,
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6.69e-02, 1.05e-03, 3.75e-07, 2.03e-05, 1.63e-01, 2.60e-01, 1.19e-01, 2.75e-01,
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0.00e+00, 5.37e-03, 1.86e-02, 2.93e-02, 2.45e-02, 3.12e-04, 2.21e-02, 5.21e-11,
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6.91e-03, 2.05e-05, 3.83e-04, 3.24e-03, 2.33e-02, 2.17e-01, 8.67e-02, 1.62e-01,
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9.04e-03, 6.97e-03, 9.37e-04, 0.00e+00, 9.17e-04, 1.79e-04, 0.00e+00, 4.44e-10,
0.00e+00, 2.00e-03, 5.66e-04, 2.61e-03, 4.84e-05, 2.46e-08, 1.22e-07, 1.35e-10,
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Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []
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'train' took 51.012227 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step   Train loss
Test loss
Test metric
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Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 45.719898 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step     Train loss
Test loss
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Test metric
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Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 48.978525 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step   Train loss
Test loss
Test metric
48000   [1.14e-05, 4.53e-07, 2.99e-06, 1.24e-05, 3.77e-06, 6.34e-07, 2.05e-07,
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1.71e-10, 1.71e-10, 1.71e-10, 1.71e-10]   []

Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 43.183387 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step   Train loss
Test loss
Test metric
50000   [6.64e-05, 1.68e-05, 7.10e-06, 4.33e-05, 1.54e-05, 2.48e-06, 3.17e-06,
5.62e-03, 6.56e-03, 1.05e-04, 1.83e-04, 4.80e-08, 5.67e-07, 1.09e-03, 3.26e-03,
2.61e-02, 6.10e-03, 3.42e-02, 0.00e+00, 0.00e+00, 0.00e+00, 0.00e+00, 0.00e+00,
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Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []
```

'train' took 43.103287 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step   Train loss
Test loss
Test metric
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Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 49.360314 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step      Train loss
Test loss
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Test metric
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Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 43.516946 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step   Train loss
Test loss
Test metric
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1.39e-06, 9.41e-05, 1.34e-05, 1.37e-05, 3.81e-08, 7.57e-08, 2.41e-05, 1.11e-04,
2.48e-03, 2.62e-03, 4.32e-05, 3.35e-07, 0.00e+00, 1.99e-06, 2.04e-06, 0.00e+00,
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Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 45.731935 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step   Train loss
Test loss
Test metric
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5.20e-07, 2.25e-08, 3.46e-07, 4.80e-12, 2.99e-07, 8.94e-05, 5.16e-05, 6.40e-05,
3.87e-05, 4.48e-07, 2.77e-07, 7.27e-09, 8.89e-08, 4.45e-07, 3.56e-07, 5.13e-07,
1.55e-06, 2.06e-06, 2.31e-07, 3.64e-07, 2.55e-07, 2.29e-08, 2.29e-08, 2.29e-08,
2.29e-08, 2.29e-08, 2.29e-08, 2.29e-08]   []
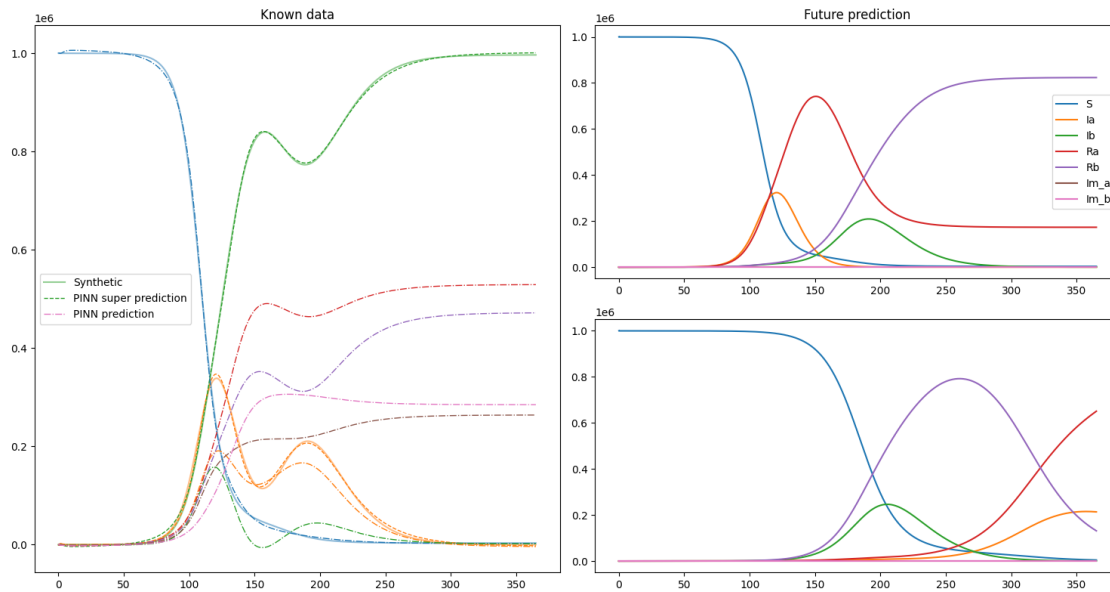

Best model at step 28867:
  train loss: 1.03e-04
  test loss: 1.03e-04
  test metric: []

'train' took 43.086333 s

Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
Training model…

Step   Train loss
Test loss
Test metric
60000   [1.17e-06, 8.31e-06, 1.90e-06, 9.31e-06, 8.79e-06, 3.88e-06, 1.93e-06,
2.81e-07, 9.33e-12, 5.20e-07, 2.25e-08, 3.46e-07, 4.80e-12, 2.99e-07, 8.94e-05,
5.16e-05, 6.40e-05, 3.87e-05, 4.48e-07, 2.77e-07, 7.27e-09, 8.89e-08, 4.45e-07,
3.56e-07, 5.13e-07, 1.55e-06, 2.06e-06, 2.31e-07, 3.64e-07, 2.55e-07, 2.29e-08,
2.29e-08, 2.29e-08, 2.29e-08, 2.29e-08, 2.29e-08, 2.29e-08]   [1.17e-06,
8.31e-06, 1.90e-06, 9.31e-06, 8.79e-06, 3.88e-06, 1.93e-06, 2.81e-07, 9.33e-12,
5.20e-07, 2.25e-08, 3.46e-07, 4.80e-12, 2.99e-07, 8.94e-05, 5.16e-05, 6.40e-05,
3.87e-05, 4.48e-07, 2.77e-07, 7.27e-09, 8.89e-08, 4.45e-07, 3.56e-07, 5.13e-07,
1.55e-06, 2.06e-06, 2.31e-07, 3.64e-07, 2.55e-07, 2.29e-08, 2.29e-08, 2.29e-08,
2.29e-08, 2.29e-08, 2.29e-08, 2.29e-08]   []
60100   [9.43e-07, 8.51e-06, 2.04e-06, 9.23e-06, 8.77e-06, 4.13e-06, 1.90e-06,
1.98e-07, 6.67e-11, 3.74e-07, 1.05e-07, 6.36e-08, 3.59e-07, 2.32e-07, 6.72e-05,
3.58e-05, 5.27e-05, 3.12e-05, 5.65e-07, 4.01e-07, 6.64e-09, 8.87e-08, 4.60e-07,
1.33e-07, 5.82e-07, 1.48e-06, 1.60e-06, 2.52e-07, 2.42e-07, 2.36e-07, 1.94e-10,
1.94e-10, 1.94e-10, 1.94e-10, 1.94e-10, 1.94e-10, 1.94e-10]   [9.43e-07,
8.51e-06, 2.04e-06, 9.23e-06, 8.77e-06, 4.13e-06, 1.90e-06, 1.98e-07, 6.67e-11,
3.74e-07, 1.05e-07, 6.36e-08, 3.59e-07, 2.32e-07, 6.72e-05, 3.58e-05, 5.27e-05,
3.12e-05, 5.65e-07, 4.01e-07, 6.64e-09, 8.87e-08, 4.60e-07, 1.33e-07, 5.82e-07,
1.48e-06, 1.60e-06, 2.52e-07, 2.42e-07, 2.36e-07, 1.94e-10, 1.94e-10, 1.94e-10,
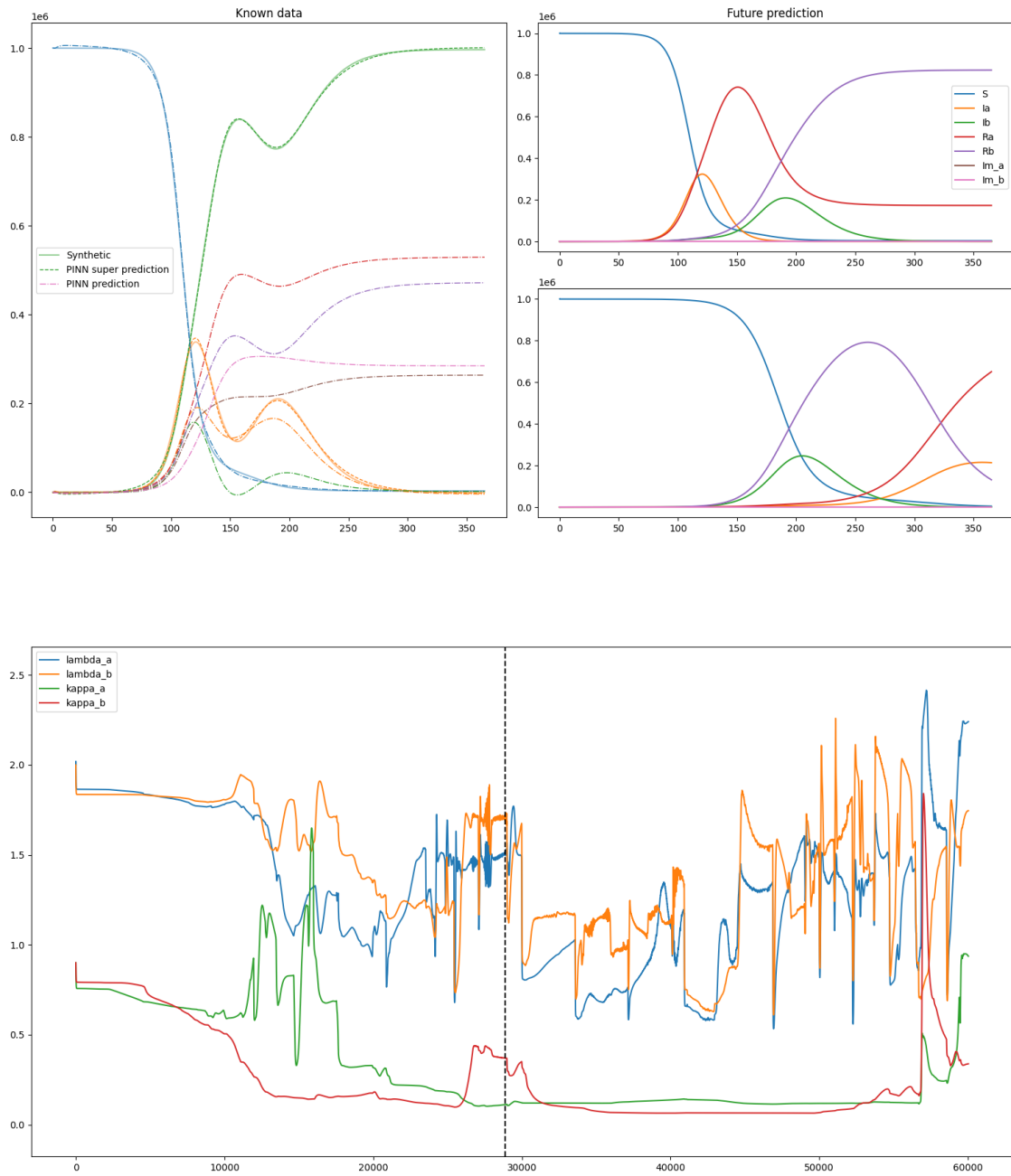1.94e-10, 1.94e-10, 1.94e-10, 1.94e-10]   []
Training ended prematurely
Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
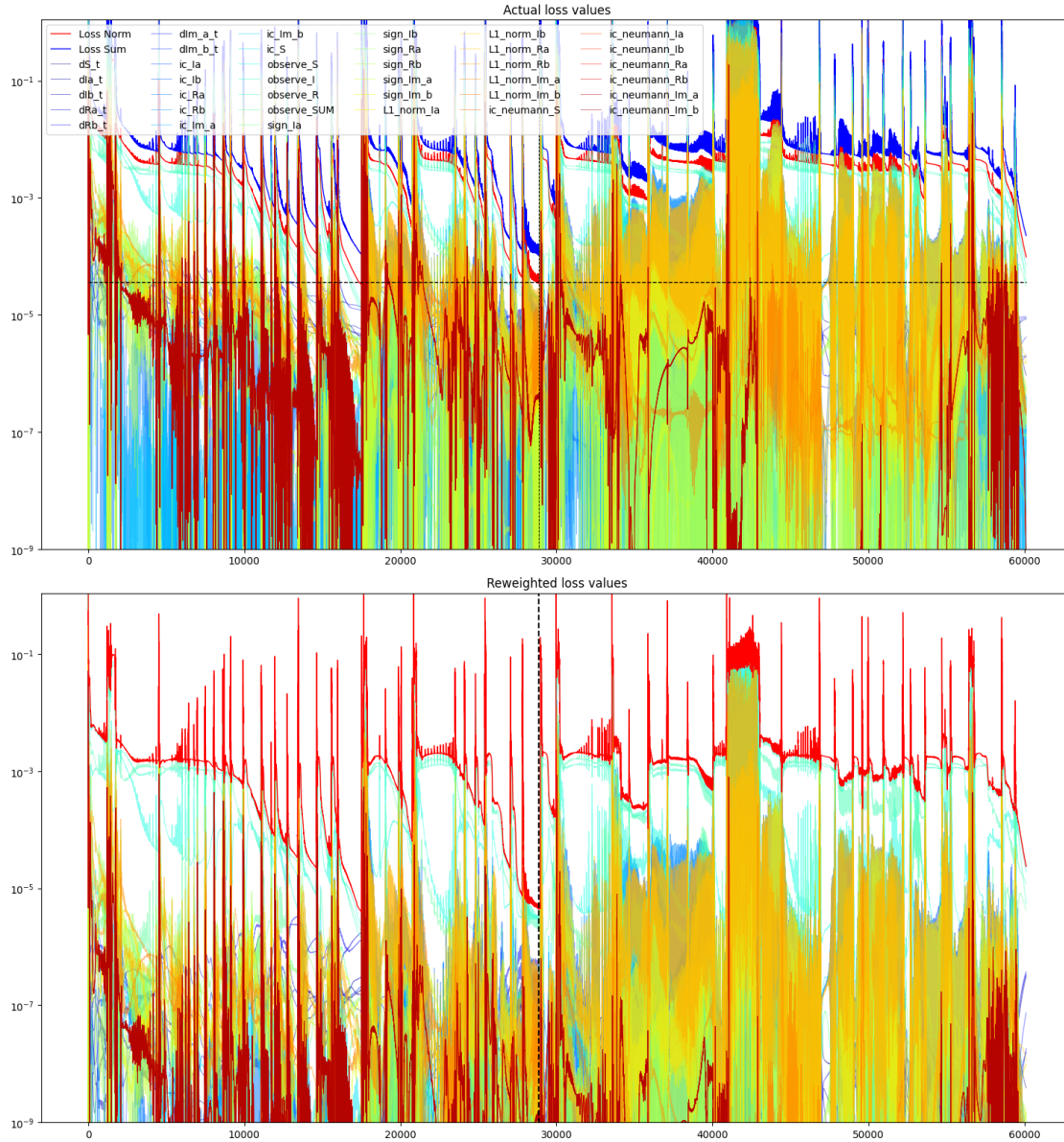{'lambda_a': 2.2, 'lambda_b': 1.9, 'kappa_a': 0.8, 'kappa_b': 0.5}

```
params_nn, best_step = model.get_best_params(out_func=np.exp) # parameters need
 ↪to be extracted with the exponential functino as they have been modelled in
 ↪logspace
print(static_parameters, sep="\n")
t_nn_param, wsol_nn_param, wsol_sird_nn_param = solver(*params_nn)

model.set_synthetic_data(t_synth, solution_synth_full)
model.set_nn_synthetic_data(t_nn_param, wsol_nn_param, wsol_sird_nn_param)
plot = Plot(model, values_to_plot=sird_model.initial_conditions_keys) # class
 ↪that contains plotting functions
plot.show_known_and_prediction()
plot.plot_param_history()
plot.plot_loss_history()
```

```
Best train step: 28867
lambda_a: 1.5008877759545223
lambda_b: 1.6943118629846954
kappa_a: 0.11167805260458141
kappa_b: 0.3695164855562565
{'lambda_a': 2.2, 'lambda_b': 1.9, 'kappa_a': 0.8, 'kappa_b': 0.5}
```

Actual loss values

Reweighted loss values

```
# model.set_synthetic_data(t_synth, solution_synth_full)
# model.set_nn_synthetic_data(t_nn_param, wsol_nn_param, wsol_sird_nn_param)
# plot = Plot(model, values_to_plot=sird_model.initial_conditions_keys) # class
  ↪that contains plotting functions
# plot.show_known_and_prediction()
# plot.plot_param_history()
# plot.plot_loss_history()
```

```
# from SIRD_normal_nn import SIRD_net
# max_timestep = 100000
# t_bool = t_synth < max_timestep
```

```
# t = t_synth[t_bool]
# wsol = solution_synth[t_bool]

# net = SIRD_net(t, wsol, init_num_people=1e6)
# net.train()
# net.plot(t_synth, solution_synth)
```

[ ]:
```
# fig, ax = plt.subplots()
# net.plot(ax, t_synth)
```

[ ]: