Bridging Dynamics and Data: A Unified Diffusion Framework for Mechanistically-Informed Epidemic Forecasting

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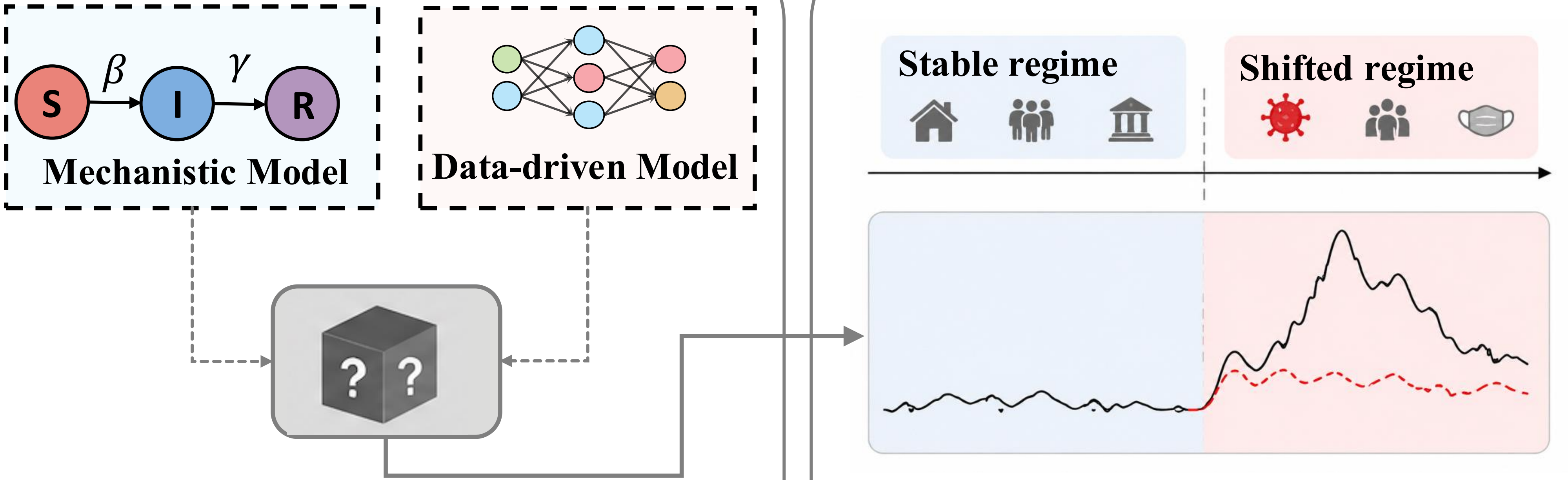
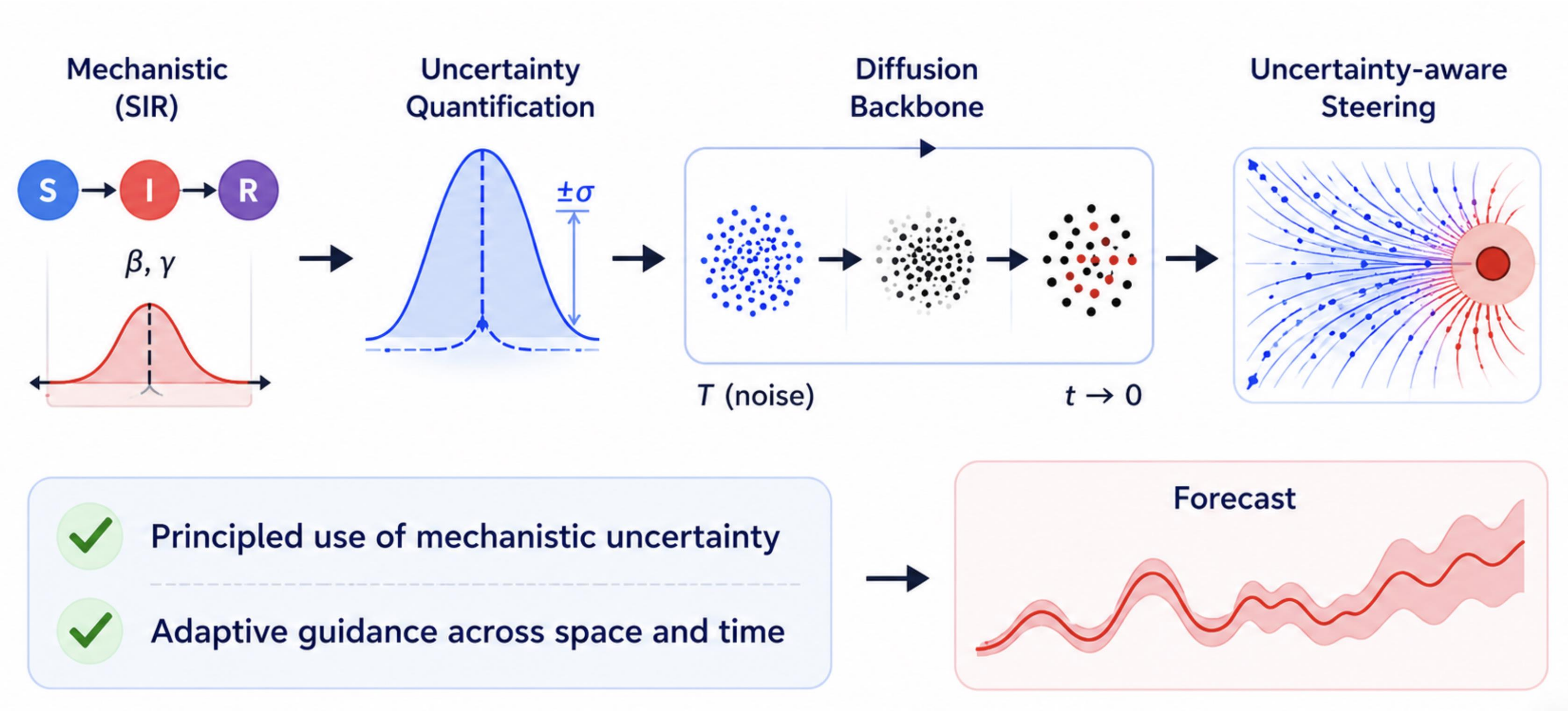
Motivation



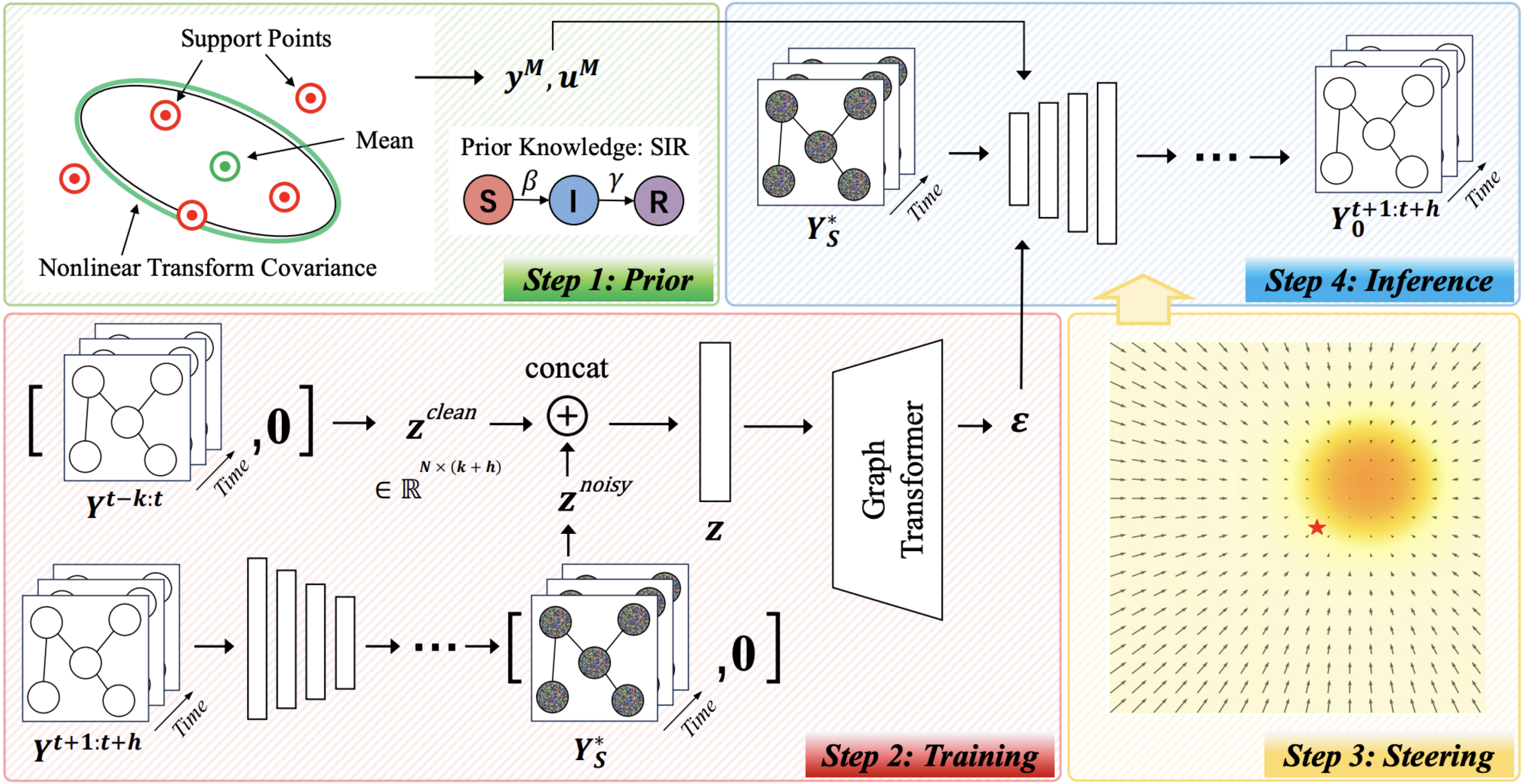
How much does the forecast rely on mechanistic dynamics?

When should the model trust mechanistic vs. data-driven signals?

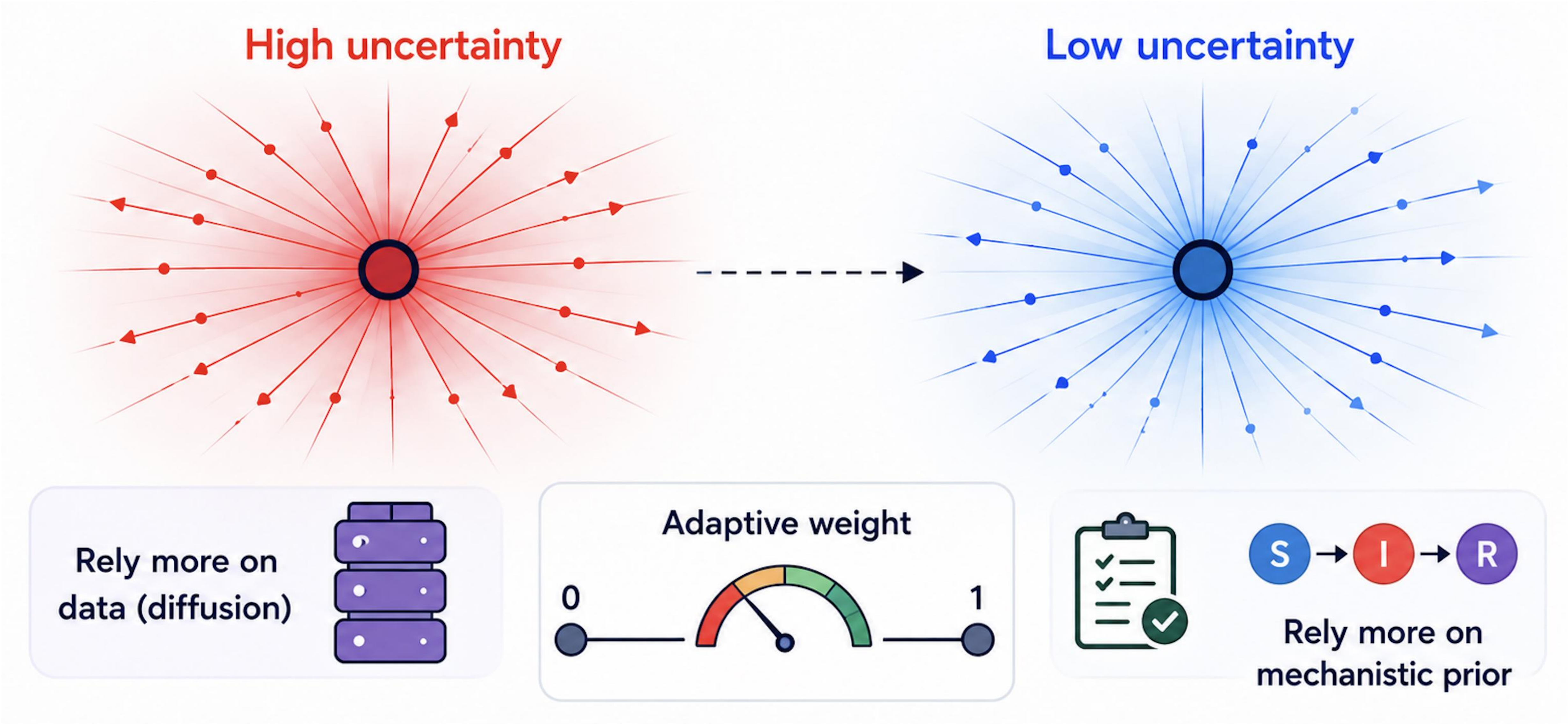
Our Solution: EpiDiff



EpiDiff Pipeline



Intuition: Uncertainty Is the Switch



Model Components

Mechanistic Prior (SIR)

$$\frac{dS}{dt} = -\beta SI, \quad \frac{dI}{dt} = \beta SI - \gamma I, \ldots$$

Uncertainty Quantification

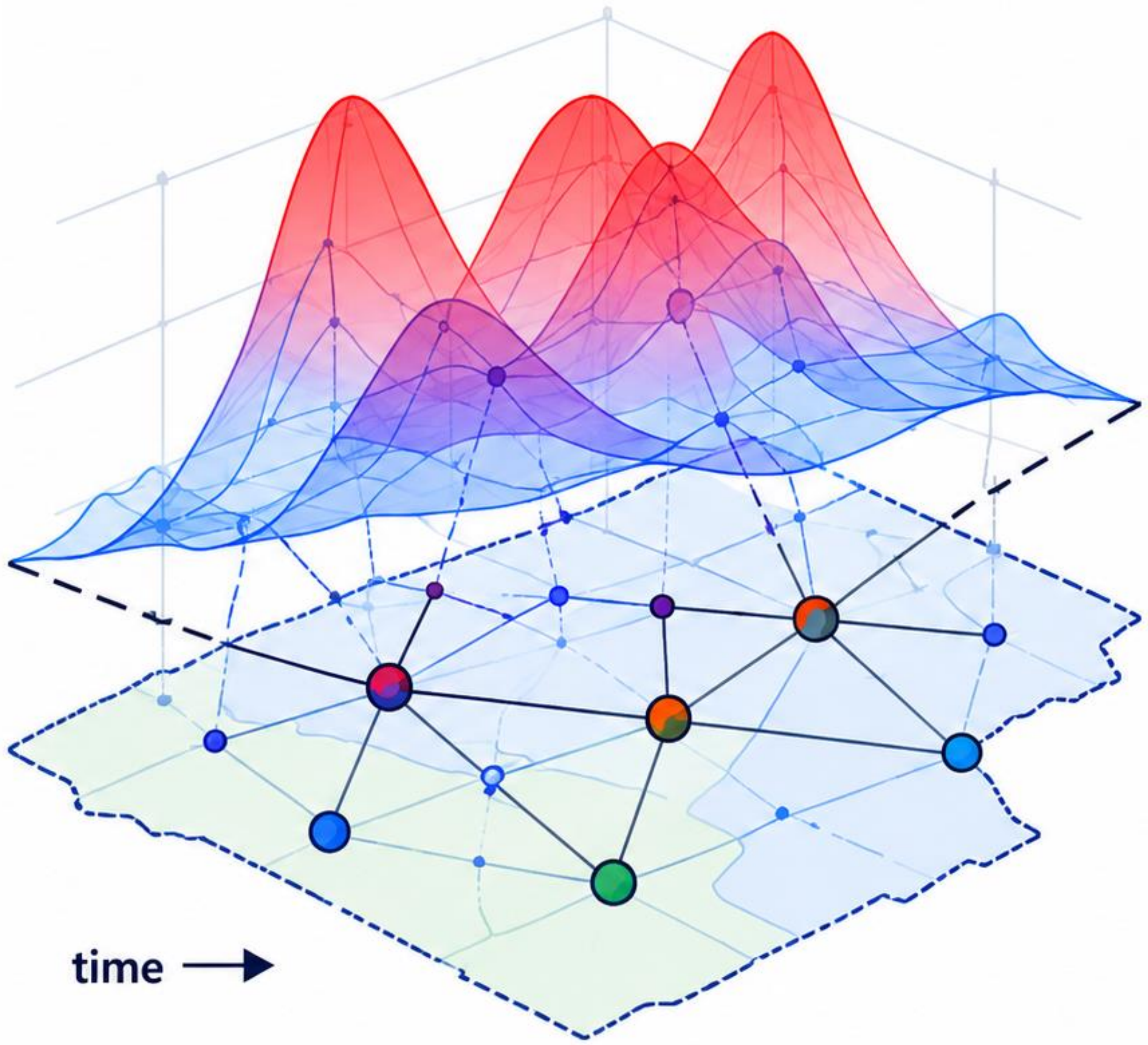
Posterior $p(\theta | D) \rightarrow$ mean μ, std σ

Diffusion Backbone

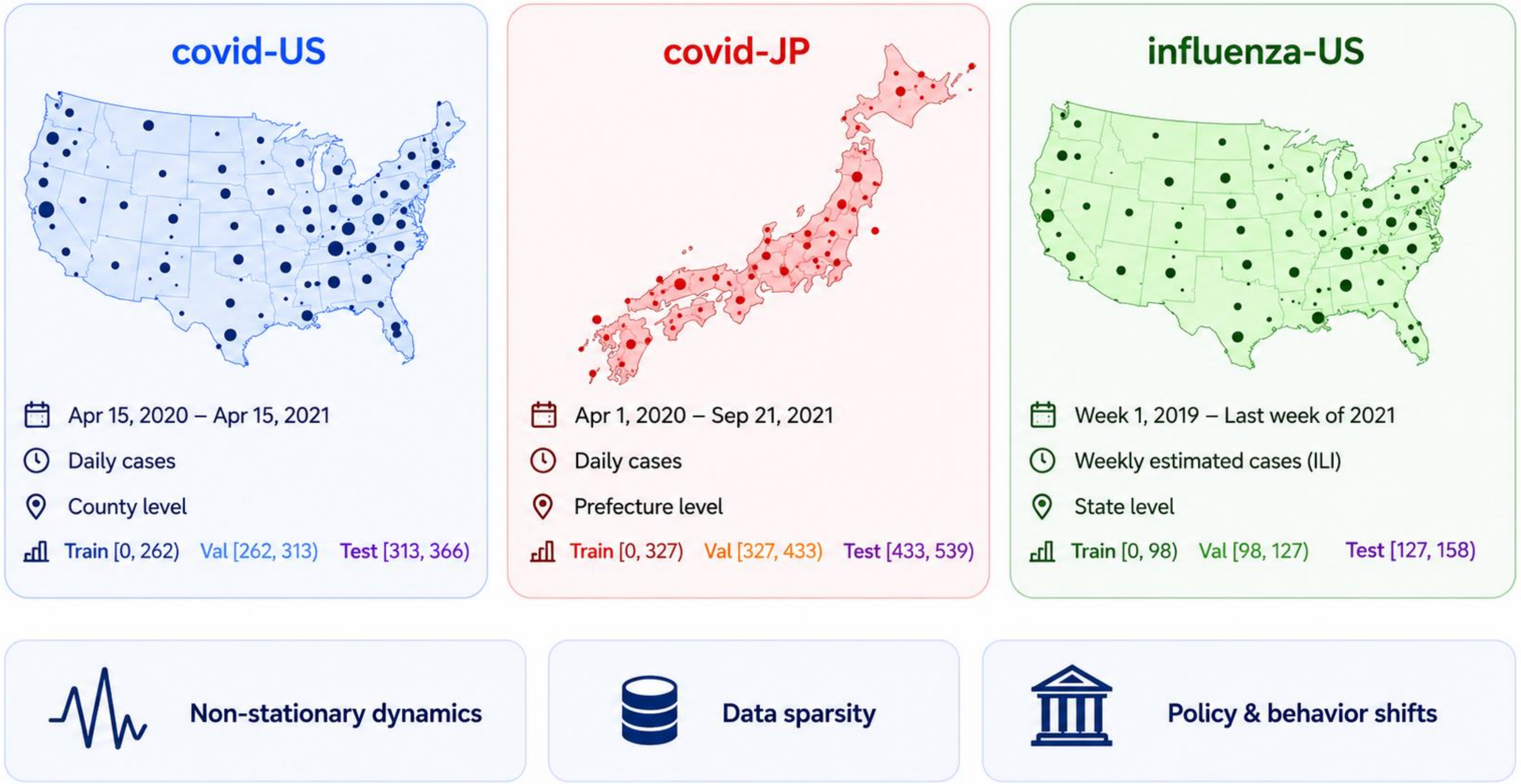
Spatiotemporal Graph Transformer

Steering Rule

Guidance $\propto$ Uncertainty $\sigma(x, t)$



Dataset


covid-US
Apr 15, 2020 – Apr 15, 2021
Daily cases
County level
Train [0, 262) Val [262, 313) Test [313, 366)
covid-JP
Apr 1, 2020 – Sep 21, 2021
Daily cases
Prefecture level
Train [0, 327) Val [327, 433) Test [433, 539)
influenza-US
Week 1, 2019 – Last week of 2021
Weekly estimated cases (ILI)
State level
Train [0, 98) Val [98, 127) Test [127, 158)
Non-stationary dynamics
Data sparsity
Policy & behavior shifts

Performance

Table 1. Performance comparison on ***covid-US***, ***covid-JP***, and ***influenza-US*** in RMSE and MAE ($\mathcal{R}$ and $\mathcal{P}$, lower is better). Best results are **in bold** and runner-ups are underlined.

Methods	*covid-US*				*covid-JP*				*influenza-US*			
	$h=7$		$h=14$		$h=7$		$h=14$		$h=7$		$h=14$	
	$\mathcal{R}\downarrow$	$\mathcal{P}\downarrow$	$\mathcal{R}\downarrow$	$\mathcal{P}\downarrow$	$\mathcal{R}\downarrow$	$\mathcal{P}\downarrow$	$\mathcal{R}\downarrow$	$\mathcal{P}\downarrow$	$\mathcal{R}\downarrow$	$\mathcal{P}\downarrow$	$\mathcal{R}\downarrow$	$\mathcal{P}\downarrow$
PatchSIR	1791±0	891±0	2077±0	886±0	313±0	98±0	332±0	106±0	323±0	82±0	454±0	138±0
AR	1791±16	835±16	1943±23	865±7	457±57	159±11	476±11	158±4	4579±2429	2040±1814	2328±236	1172±84
ARMA	1832±29	843±2	1906±18	852±9	460±32	156±8	496±6	166±3	4423±1971	2289±1271	2314±150	1174±68
LSTM	1797±59	867±48	1956±49	962±52	408±10	135±3	398±19	135±7	353±29	119±21	354±42	133±7
GRU	1654±81	771±52	1949±38	974±30	364±12	120±3	383±8	130±3	377±41	142±13	498±303	192±75
STGCN	2131±12	877±23	2446±51	1107±12	315±83	96±23	326±24	103±9	414±93	160±42	588±128	248±56
ColaGNN	2740±758	1175±339	3055±356	1403±181	213±20	63±4	305±47	88±11	**250**±17	85±9	**347**±228	129±27
STGODE	1763±96	719±34	2716±107	1010±40	269±10	79±2	309±23	96±7	643±194	261±94	1415±460	570±200
DiffSTG	1236±28	443±11	1284±20	444±14	246±28	81±9	423±35	147±13	344±29	151±69	520±44	254±54
STAN	1364±196	1150±174	1265±98	1046±90	222±87	127±40	**224**±88	128±41	4599±42	4306±32	3750±79	3270±79
EARTH	2145±324	603±103	2664±272	794±79	303±73	100±13	394±102	134±21	539±172	190±47	2027±1160	629±302
EpiColaGNN	1825±84	745±58	2653±22	1235±9	282±33	83±11	327±19	99±6	1311±67	693±36	1514±64	807±36
`EpiDiff`	**1096**±5	**374**±1	**1232**±5	**422**±16	**188**±7	**62**±2	247±2	**86**±1	304±1	**82**±0.4	423±1	**125**±0.1

Ablation

Table 2. Ablation study of different variants. Best results are **in bold** and runner-ups are <u>underlined</u>.

Variants	*covid-US*				*covid-JP*				*influenza-US*			
	$h=7$		$h=14$		$h=7$		$h=14$		$h=7$		$h=14$	
	$\mathcal{R}\downarrow$	$\mathcal{P}\downarrow$	$\mathcal{R}\downarrow$	$\mathcal{P}\downarrow$	$\mathcal{R}\downarrow$	$\mathcal{P}\downarrow$	$\mathcal{R}\downarrow$	$\mathcal{P}\downarrow$	$\mathcal{R}\downarrow$	$\mathcal{P}\downarrow$	$\mathcal{R}\downarrow$	$\mathcal{P}\downarrow$
`w/o` Diffusion	1791	891	2077	886	313	98	332	106	<u>323</u>	<u>82</u>	454	<u>138</u>
`w/o` Steering	**1080**±2	**348**±1	**1199**±6	**386**±11	370±22	94±5	417±4	<u>121</u>±1	438±19	224±7	1787±87	928±59
`w/o` Uncertainty	1099±5	376±1	1253±5	438±18	<u>316</u>±5	<u>97</u>±2	<u>365</u>±1	122±1	328±1	147±1	<u>446</u>±0.4	155±0.3
`EpiDiff`	<u>1096</u>±5	<u>374</u>±1	<u>1232</u>±5	<u>422</u>±16	**188**±7	**62**±2	**247**±2	**86**±1	**304**±1	**82**±0.4	**423**±1	**125**±0.1

Mechanistic Uncertainty Visualization

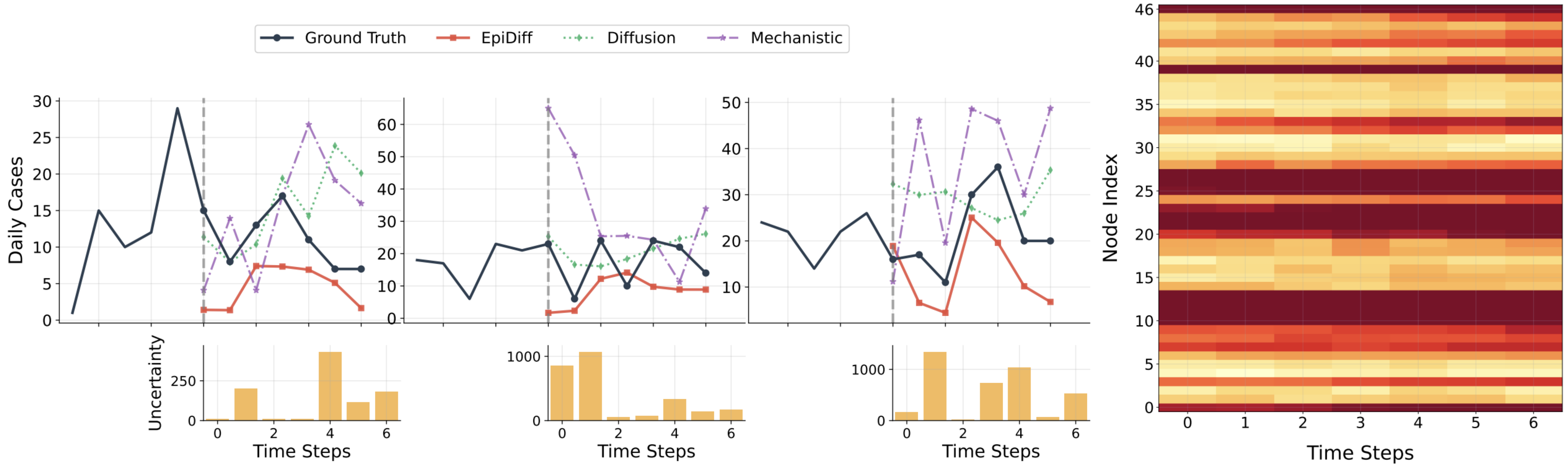


Figure 4. **Left:** Node 30 prediction and uncertainty at windows 30, 60, and 70 on ***covid-JP***. **Right:** Uncertainty heatmap for nodes and steps on ***covid-JP***. Darker squares indicate greater uncertainty.

Thanks for listening!