Fusing disparate measurement data for forecasting the growth of trees via Hidden Markov Models

Prof. Albert Y. Kim

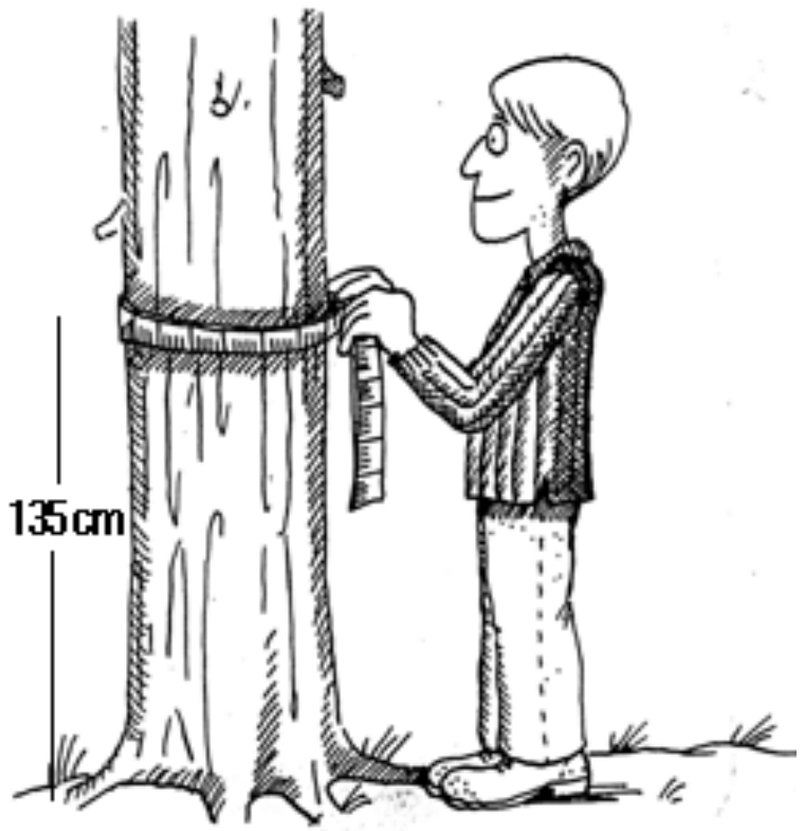
UMass Amherst Statistics Seminar Series

Friday, January 22, 2021

Context

Diameter at Breast Height (dbh)

After species & location, one of the most informative variables about a tree is dbh



Smithsonian Conservation Biology Institute

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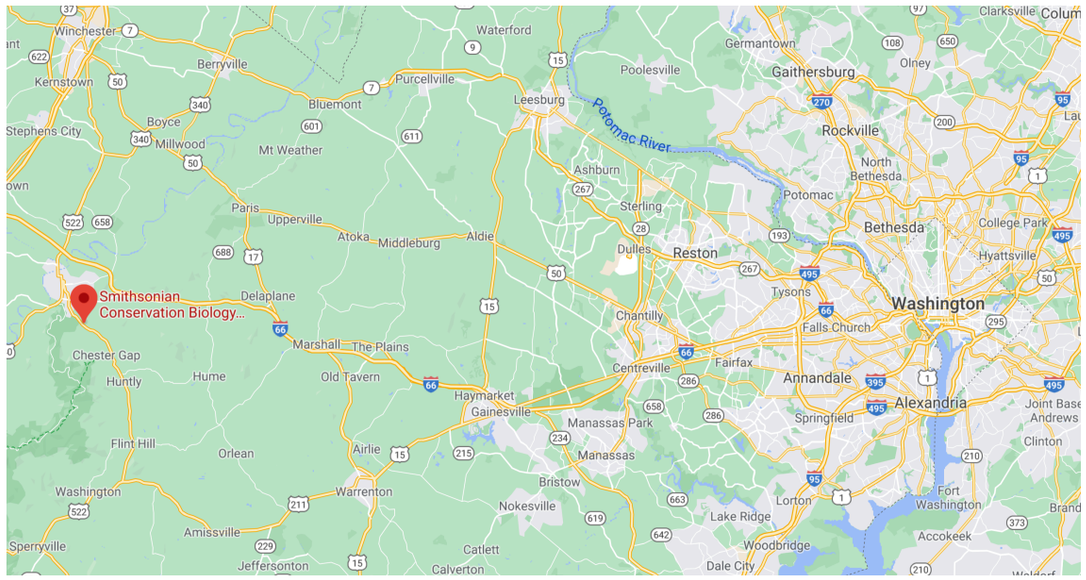

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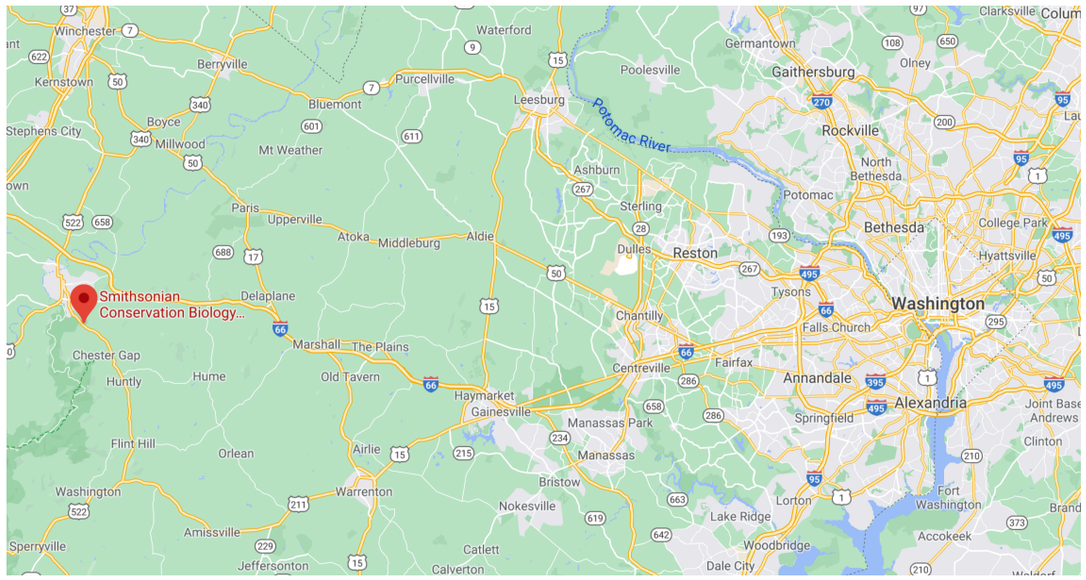
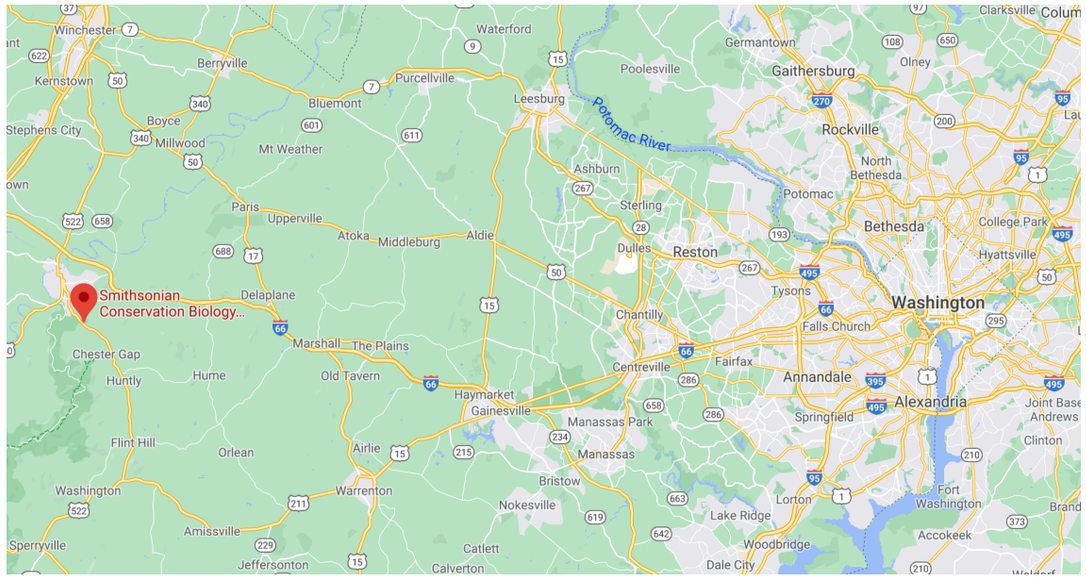
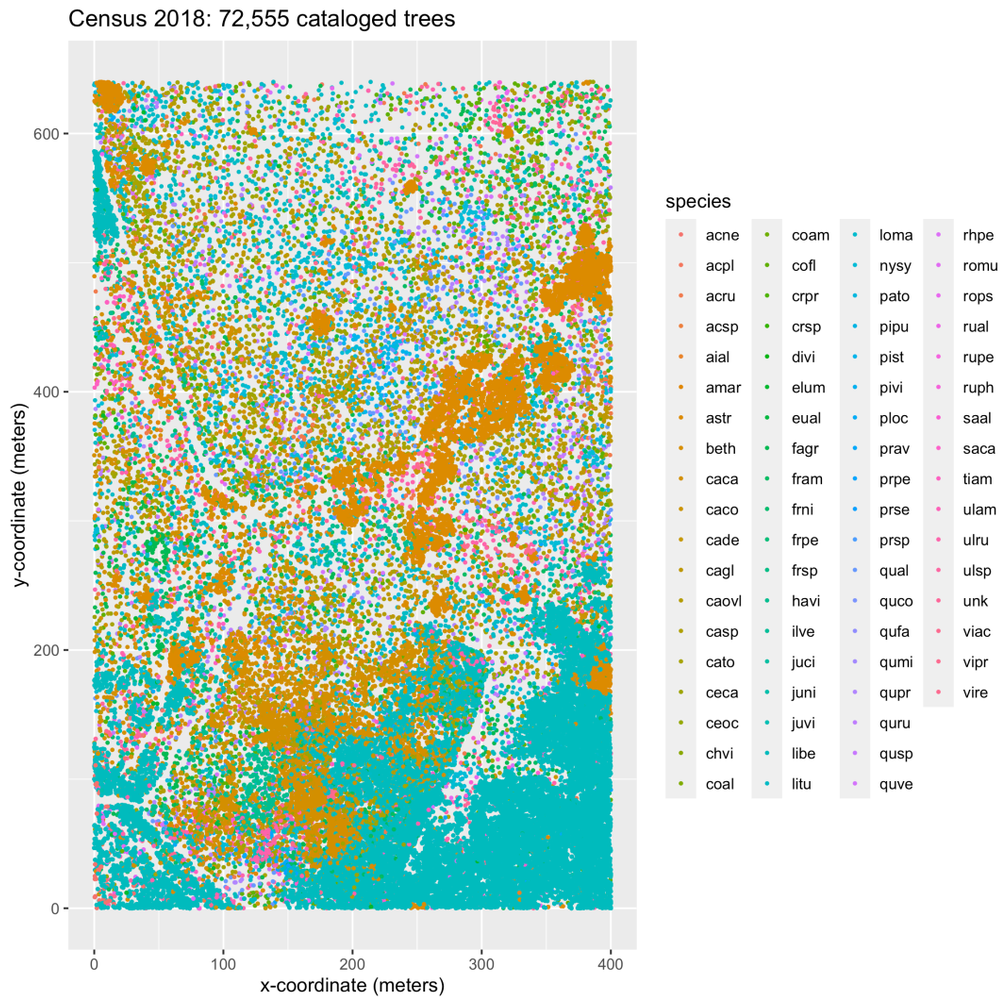


25.6 ha = 35.85 soccer fields

Smithsonian Conservation Biology Institute





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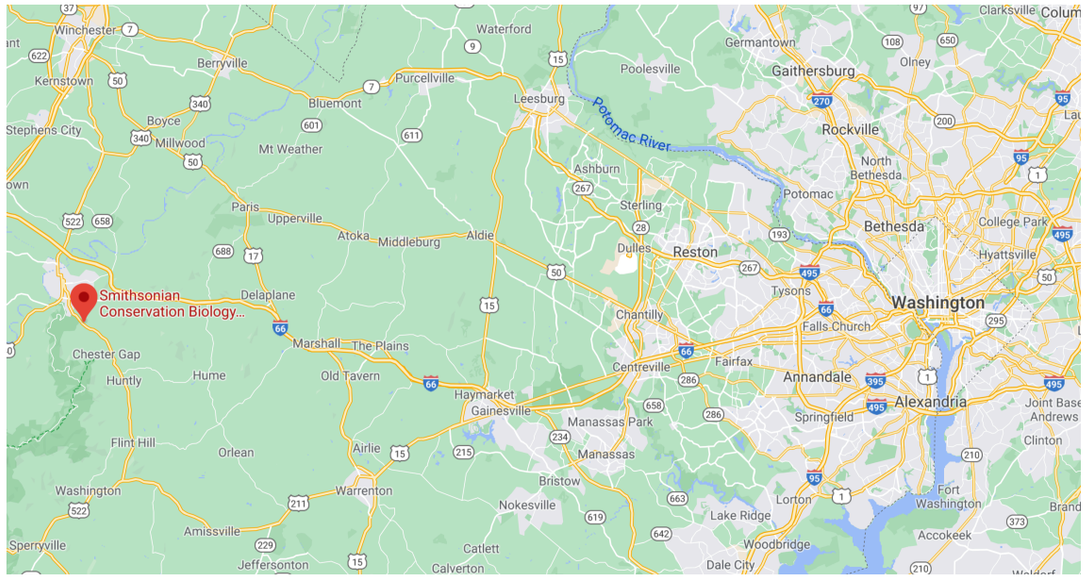

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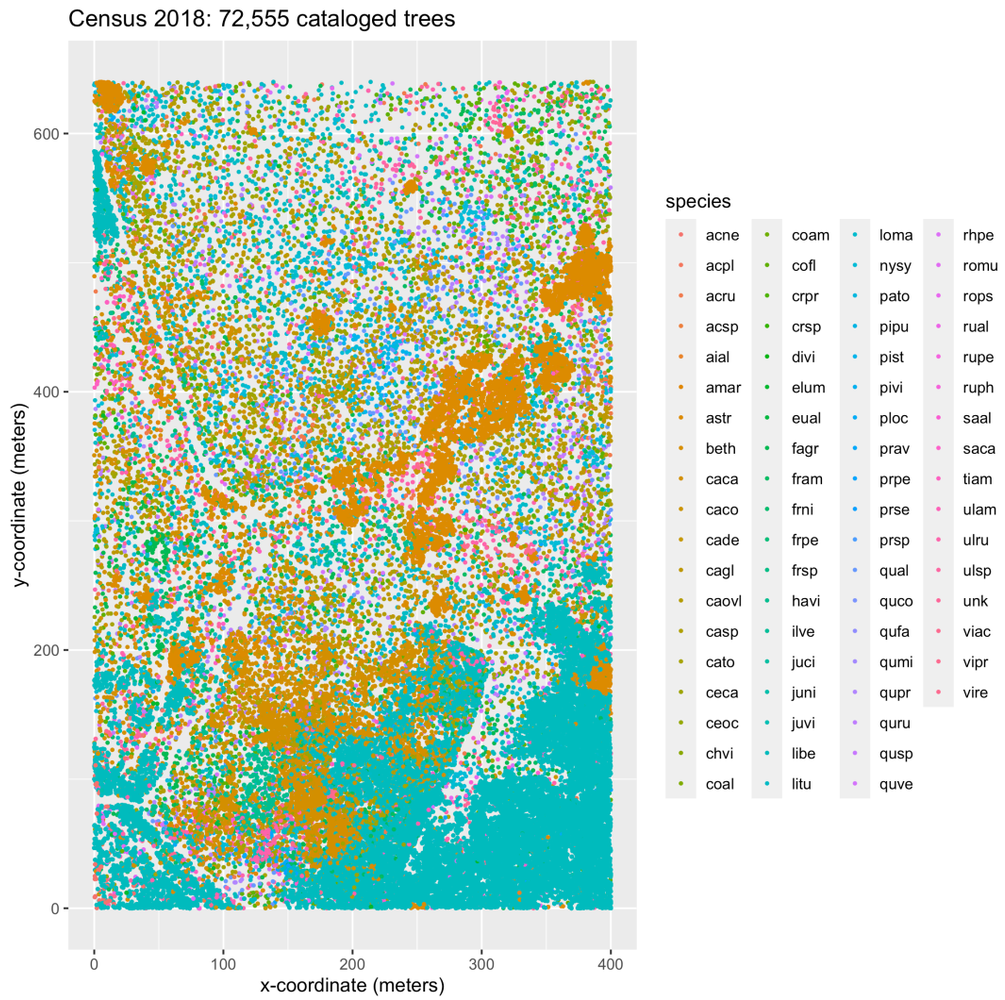

dbh >10mm are tagged

Data on GitHub

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SCBI-ForestGEO / Dendrobands

Unwatch 5 Star 0 Fork 0

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master

Dendrobands / data / scbi.dendroAll_2020.csv

Go to file ...

rudeboybert Replace text month coding with integer month coding for 2019 & 2020. F... ...

Latest commit aa41236 on Jul 3 History

4 contributors

1280 lines (1280 sloc) | 190 KB

Raw Blame

Search this file...

	tag	stemtag	survey.ID	year	month	day	biannual	intraannual	sp	quadrat	lx	ly	measure	codes	notes
2	10469	1	2020.01	2020	3	11	1	0	litu	109	9.7	1	NA	RE	window too large to measure
3	10587	1	2020.01	2020	3	11	1	0	litu	113	2.6	13	61.41	NA	NA
4	10609	1	2020.01	2020	3	11	1	0	cagl	111	19.5	2.9	81.03	NA	double-checked

Equipment to measure doh

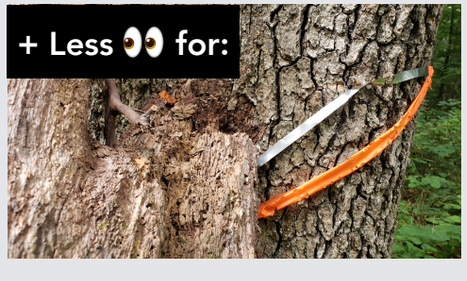
1. Measuring tape. Call this “census” data

2. Tree coring + dendrochronology. Call this “core” data

Equipment to measure doh

3. Dendrobands + Calipers:
Call this “dendro” data

Comparison Chart

	Data source	Measurement	Cost	Sources of Error?
	**Census via tape**	Diameter	Cheap	Large variation in dbh 📏 technique
	**Tree coring**	Ring width increment	Expensive	Standardized, cores are dried, no bark effects
	**Intraannual dendroband (every 2 weeks)**	Increment (from baseline)	High setup, rapid follow-up	Climate induced variation in bark & device (-'ve growth)
	**Biannual dendroband (start & end of year)**	same	same	+ Less 👀 for: 

Goal 🎯🎯🎯

Can we fuse these disparate data sources into a single model to forecast the growth of trees?

Model

Hidden Markov Models

Hidden Markov Models

- Hidden: “Data fusion” via latent variables
  In our case: “true” dbh

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- Partition sources of error into those that
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  - Are "one and done" i.e. measurement error
  - Propagate when forecasting

Minimum Viable Product

$$dbh_{i,t} = dbh_{i,t-1} + \beta_0 + \beta_i + \beta_t + \epsilon$$

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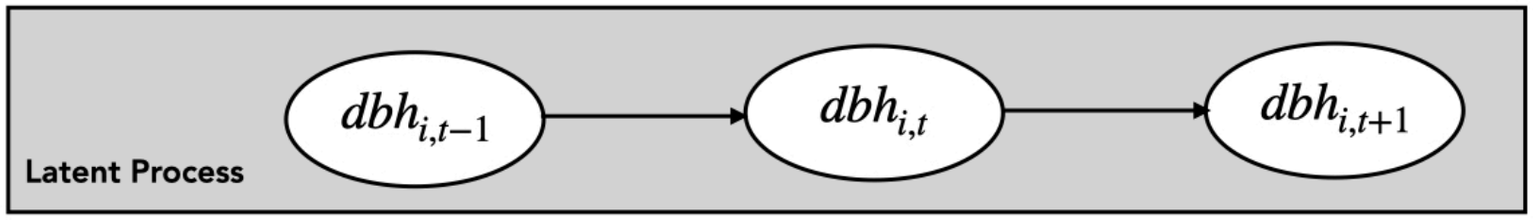
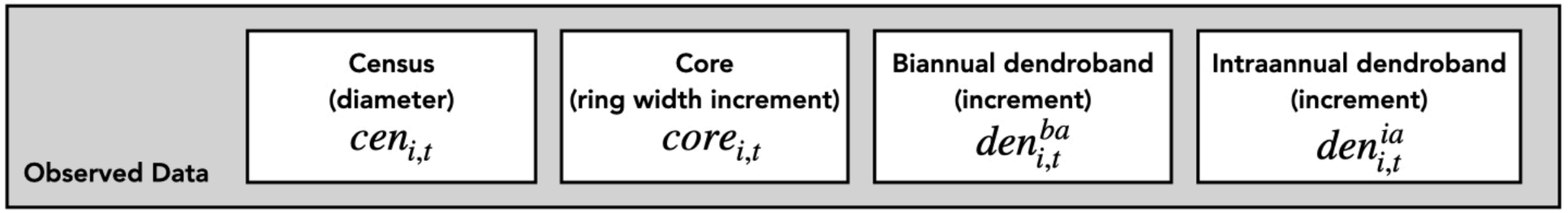
- $\epsilon \sim$ Normal $\left(0, \sigma_\epsilon^2\right)$

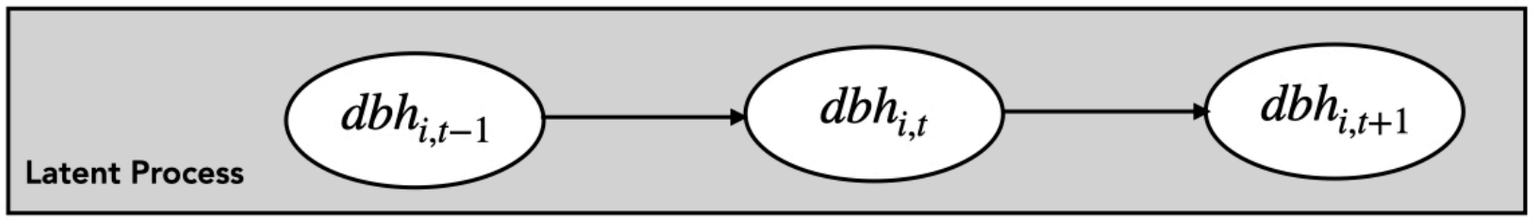
Model



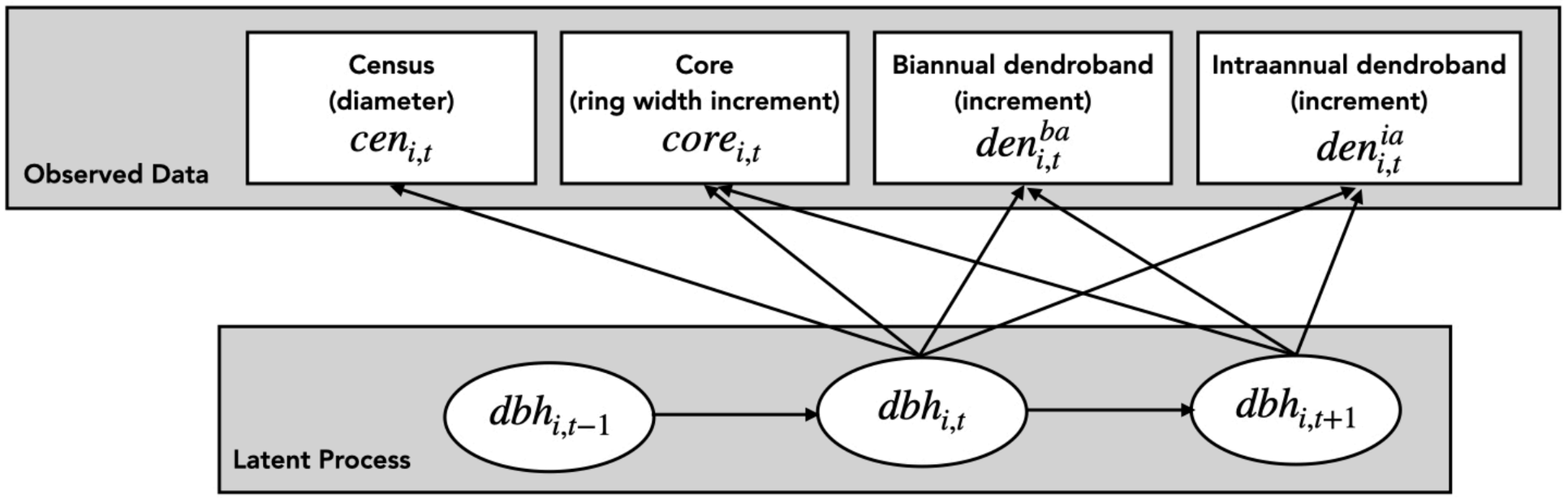
Clark 2007

Model


Observed Data
Census
(diameter)
$cen_{i,t}$
Core
(ring width increment)
$core_{i,t}$
Biannual dendroband
(increment)
$den_{i,t}^{ba}$
Intraannual dendroband
(increment)
$den_{i,t}^{ia}$


Latent Process
$dbh_{i,t-1}$
$dbh_{i,t}$
$dbh_{i,t+1}$

Model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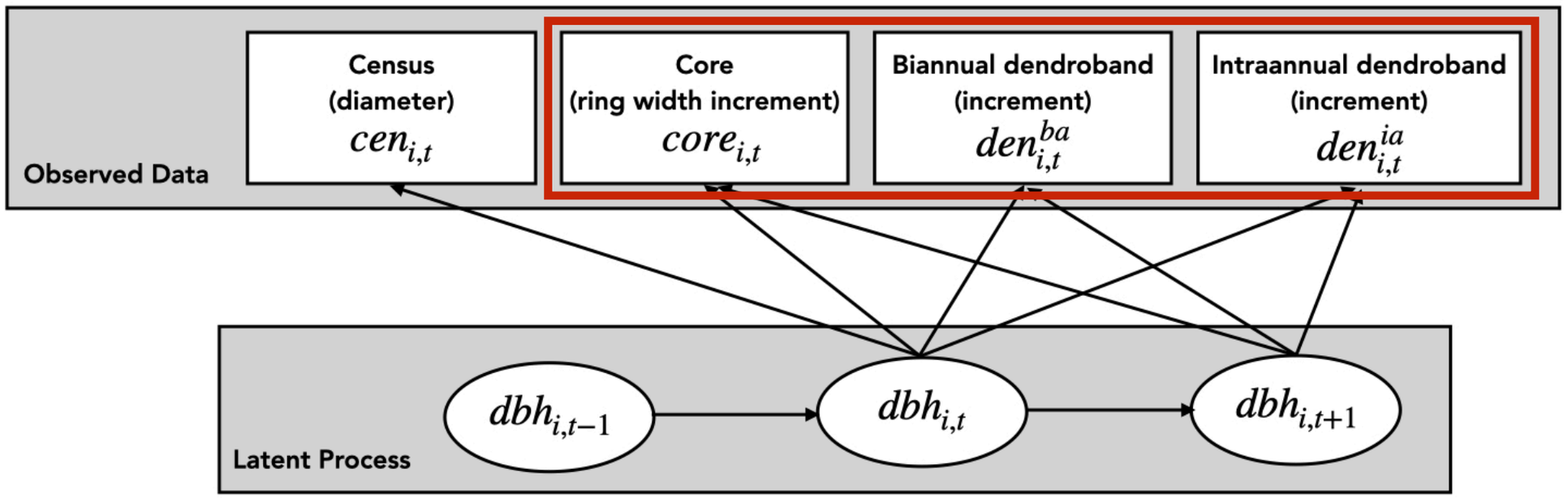
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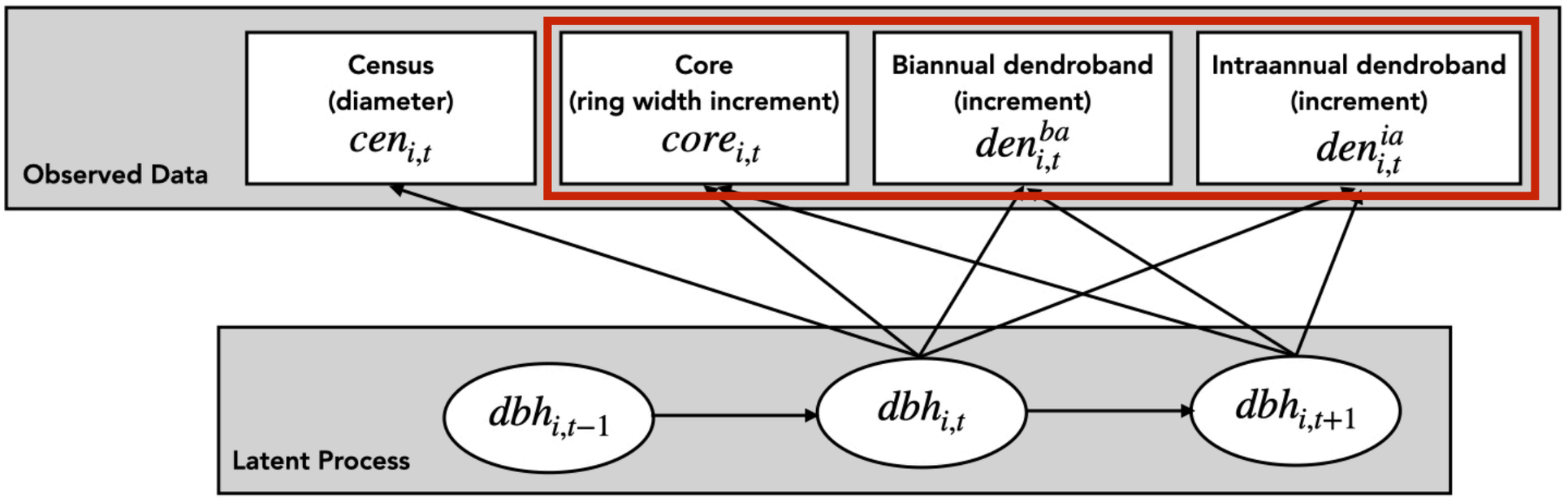
Model

Increments = $dbh_{i,t-1} - dbh_{i,t}$



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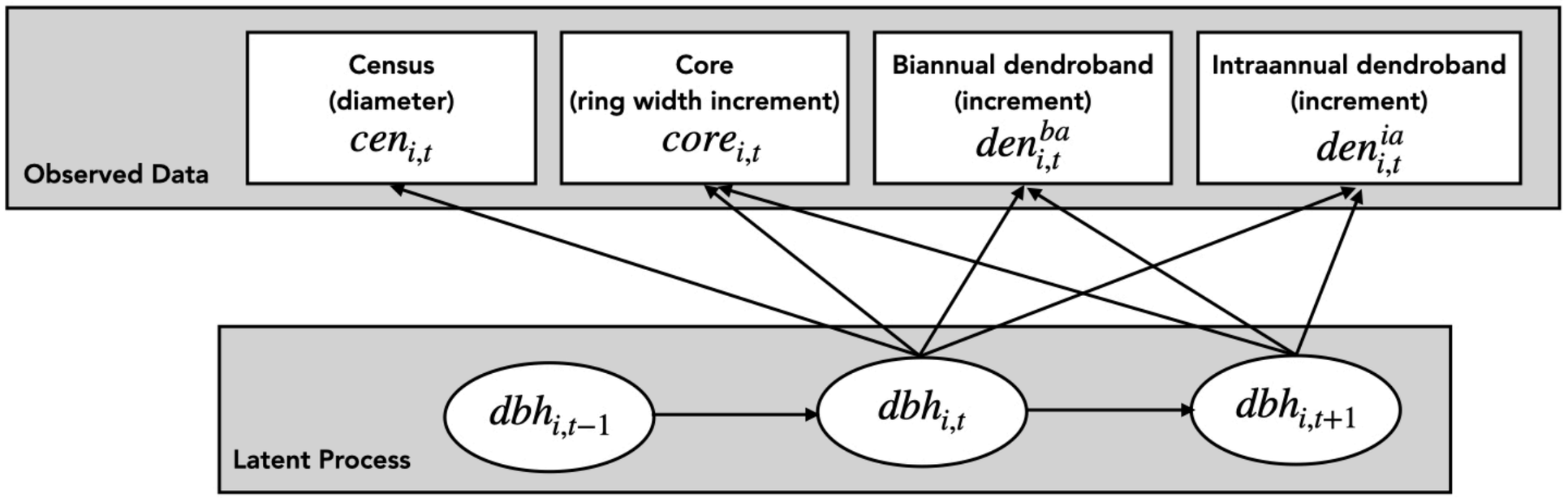
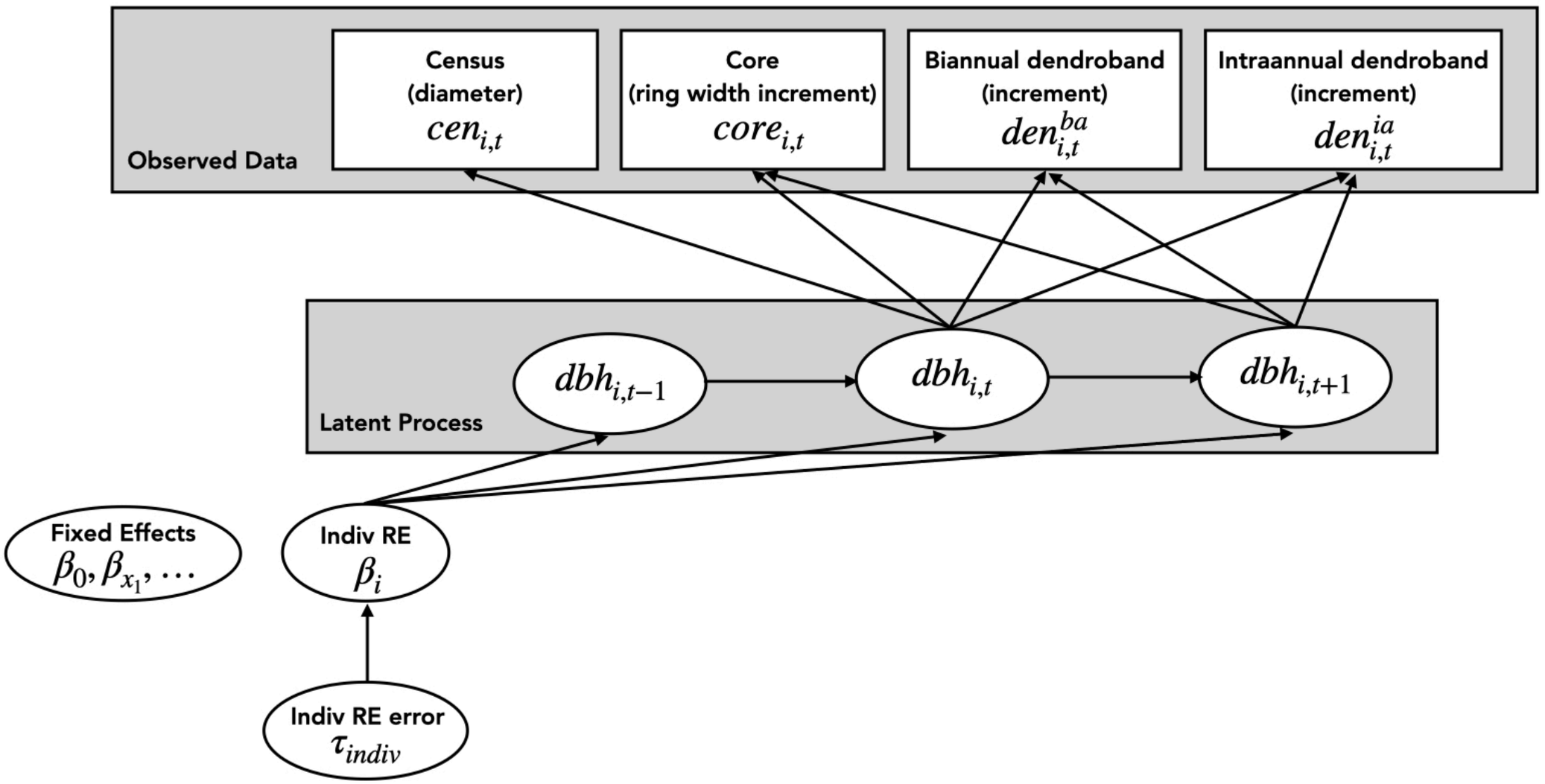


Fixed Effects
$\beta_0, \beta_{x_1}, \ldots$

Model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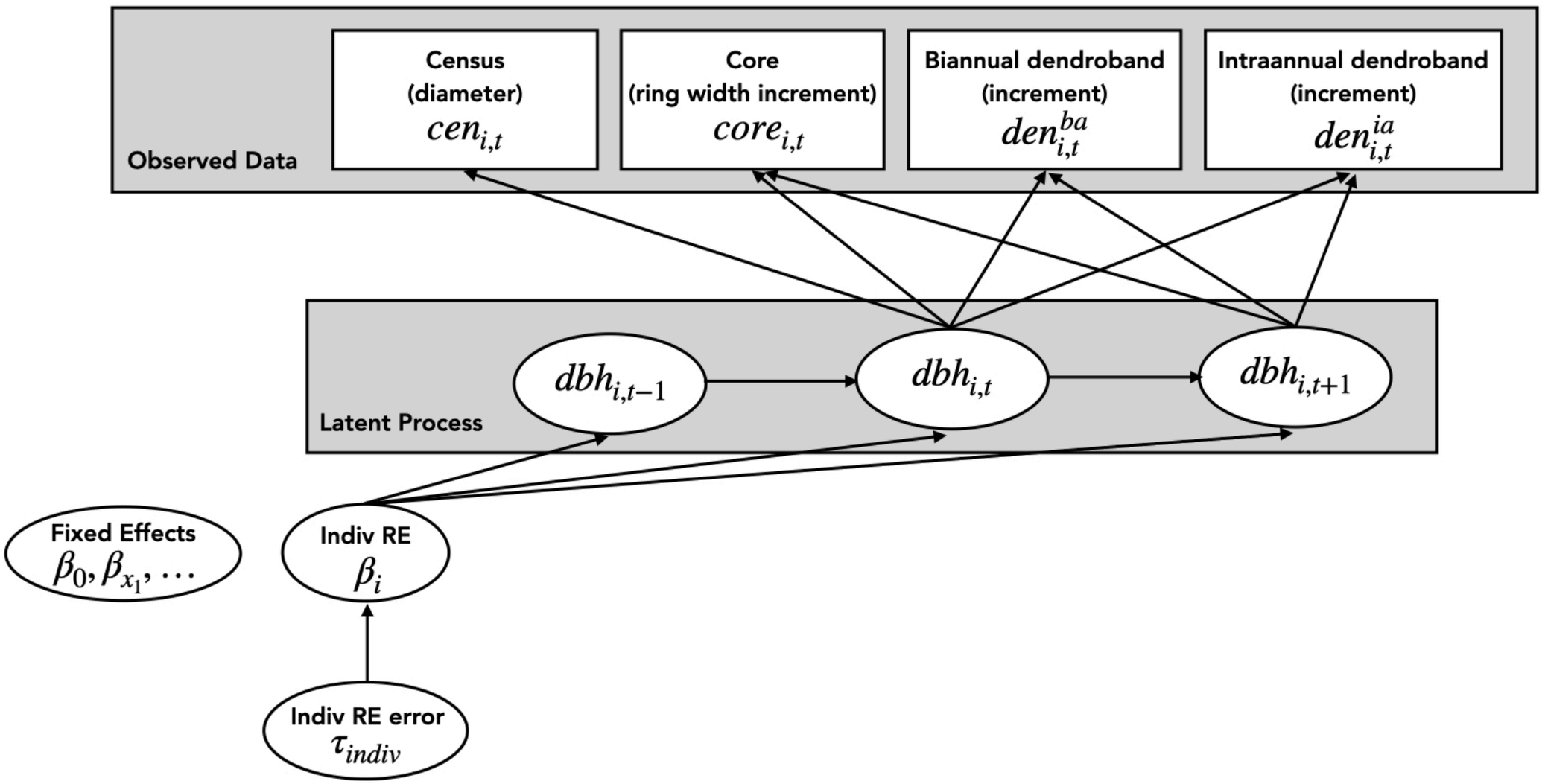
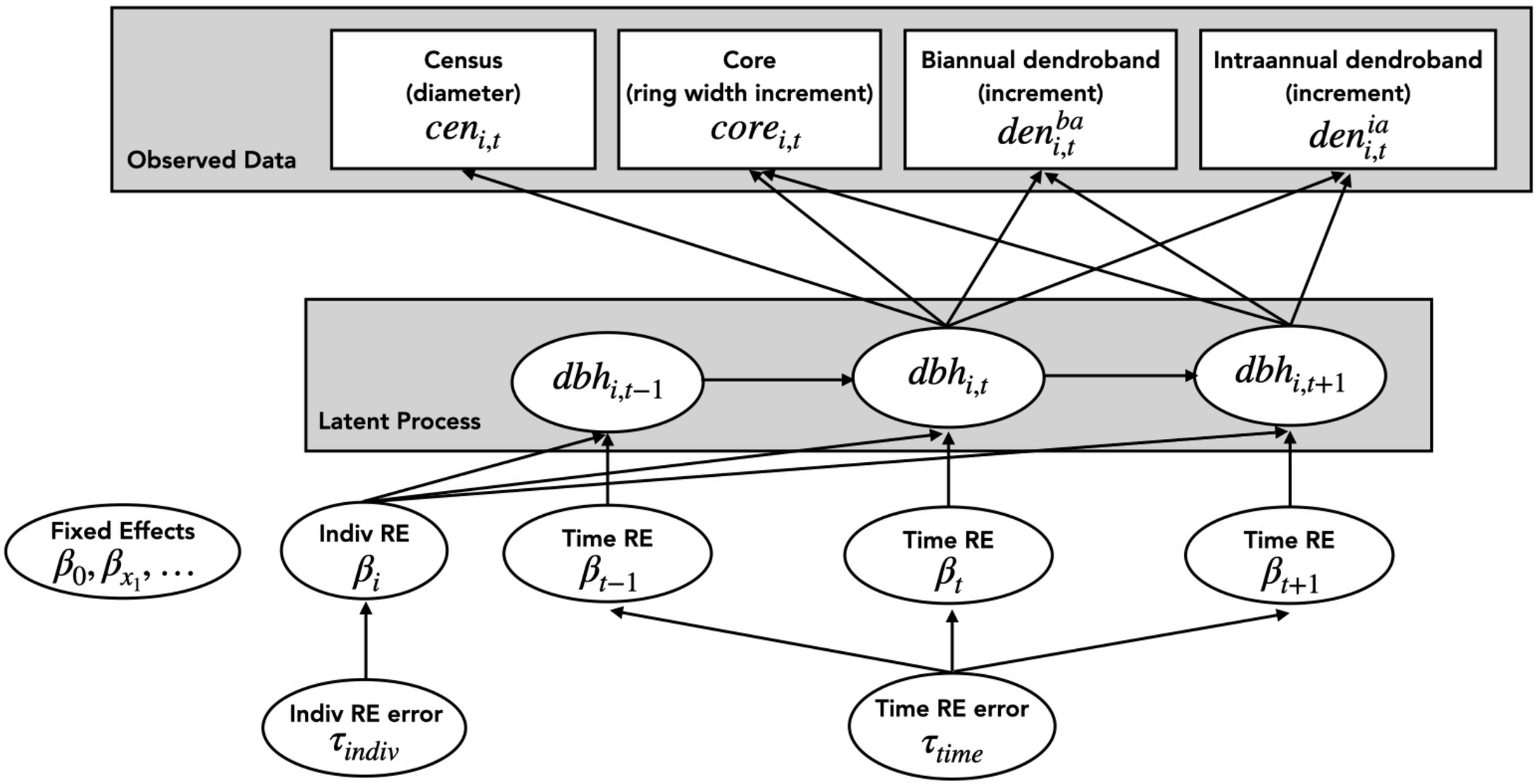
Indiv RE
β_i
Indiv RE error
τ_{indiv}

Model



FYI: Express variances via precision $\tau = \frac{1}{\sigma^2}$

Model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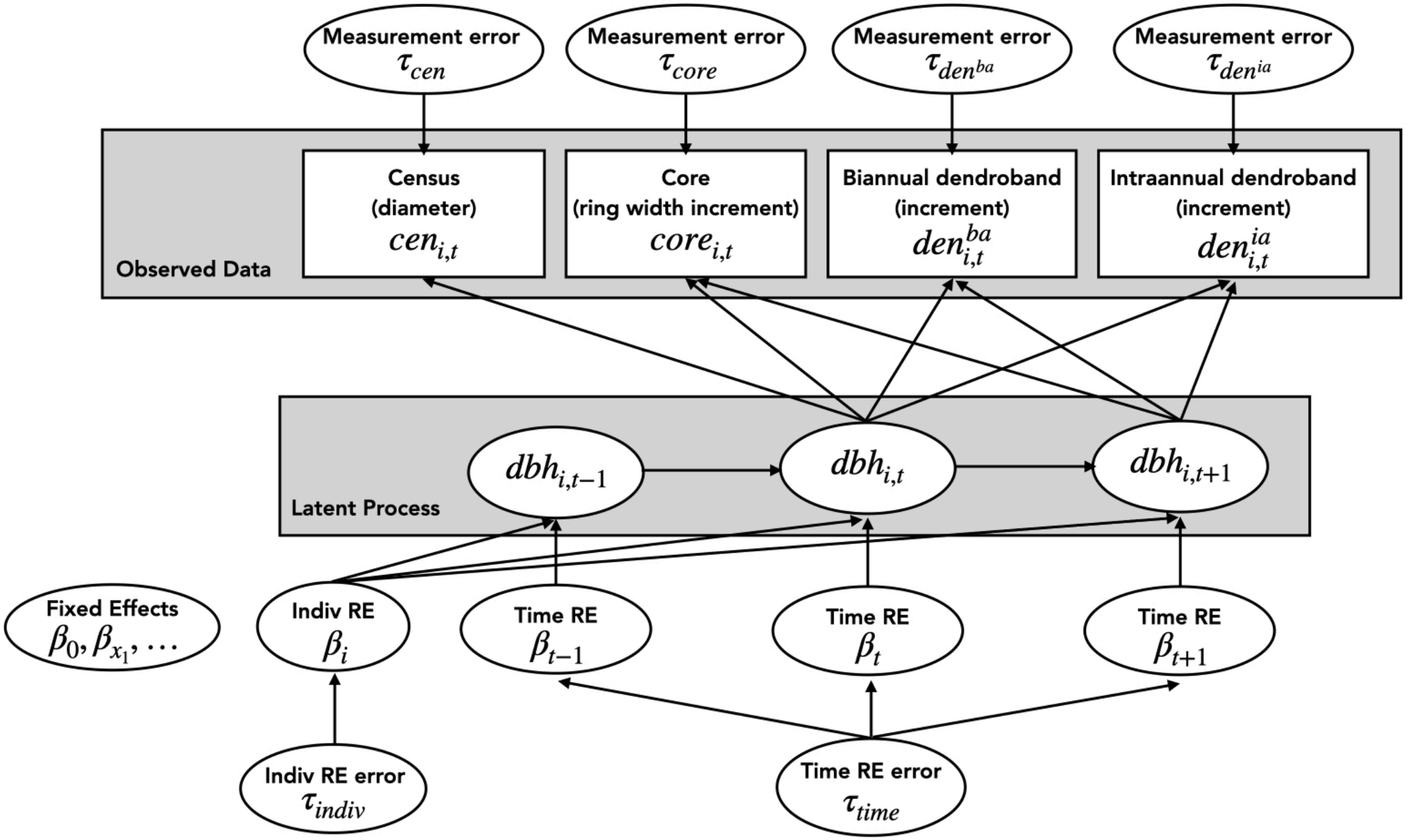
Time RE
β_{t-1}
Time RE
β_t
Time RE
β_{t+1}
Indiv RE error
τ_{indiv}
Time RE error
τ_{time}

Model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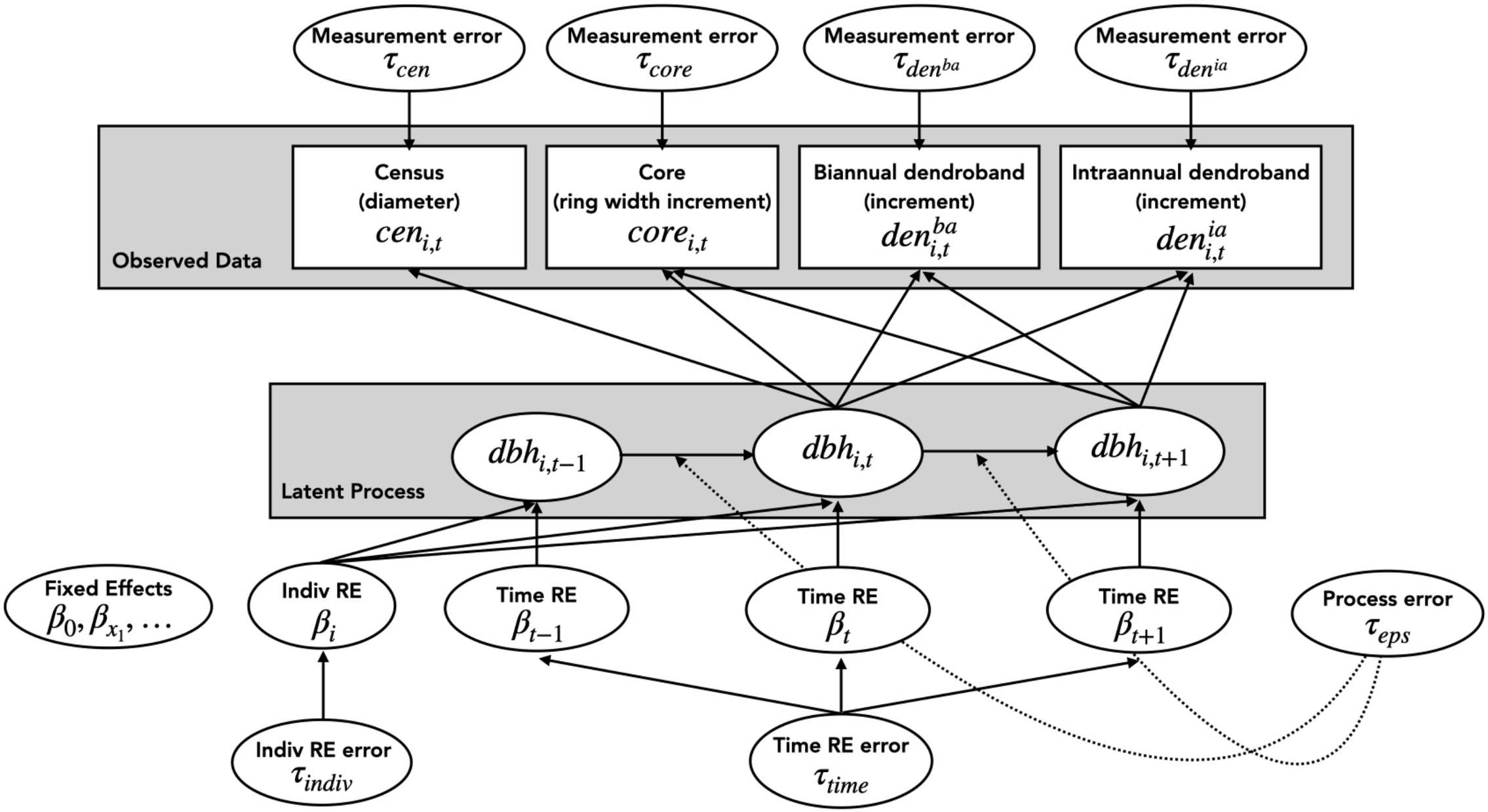
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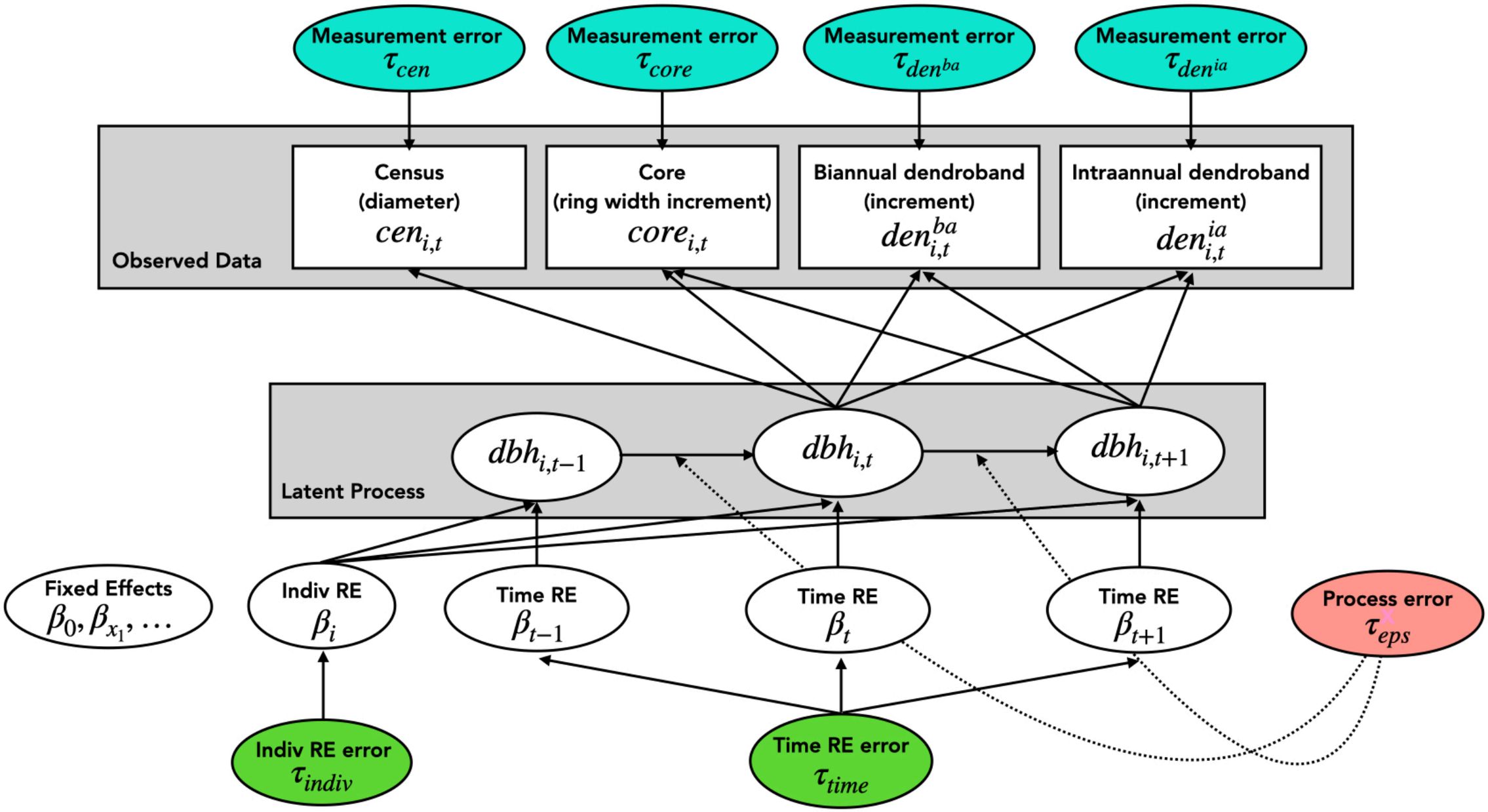
Time RE
β_{t-1}
Time RE
β_t
Time RE
β_{t+1}
Process error
τ_{eps}
Indiv RE error
τ_{indiv}
Time RE error
τ_{time}

Model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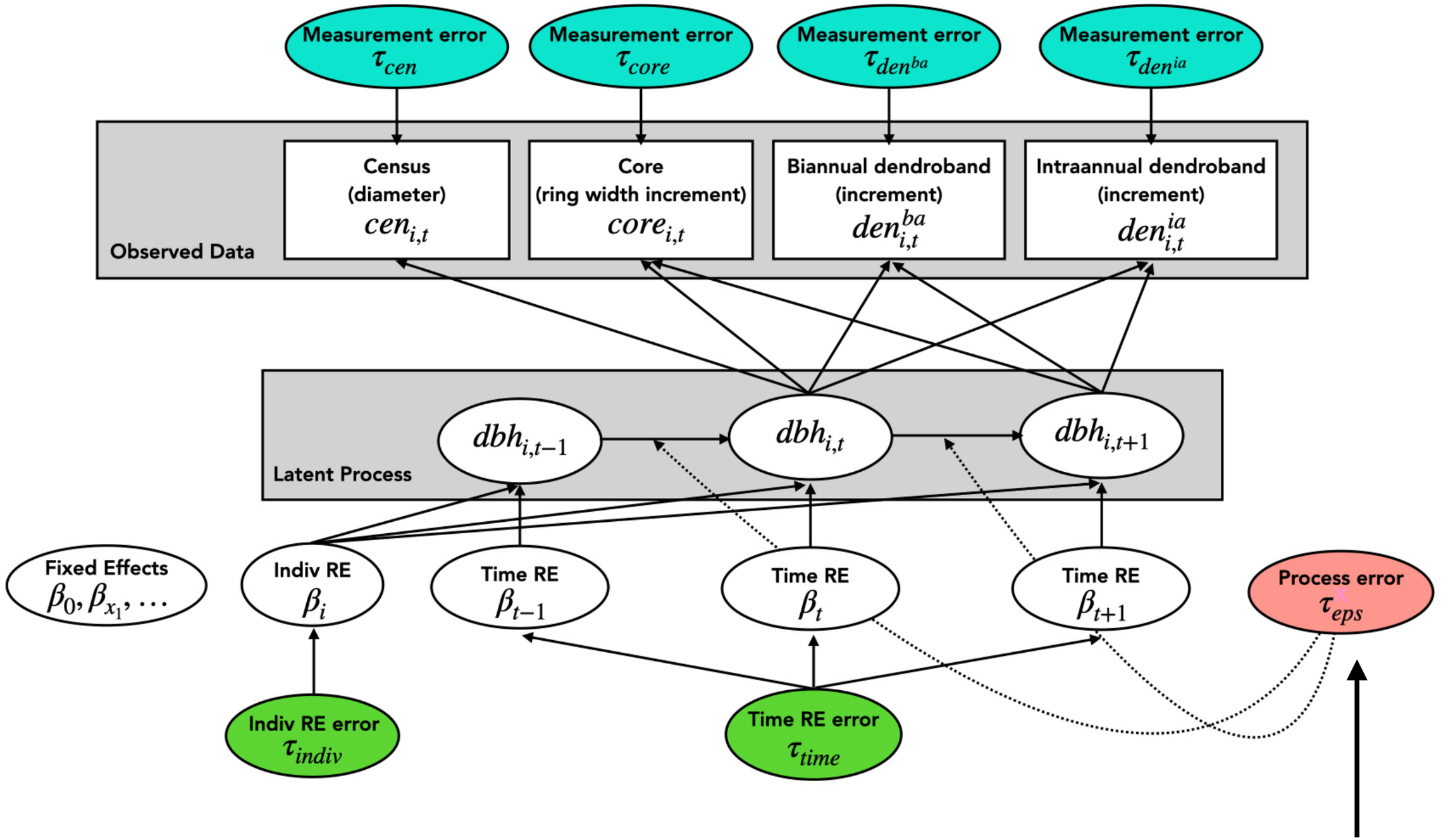
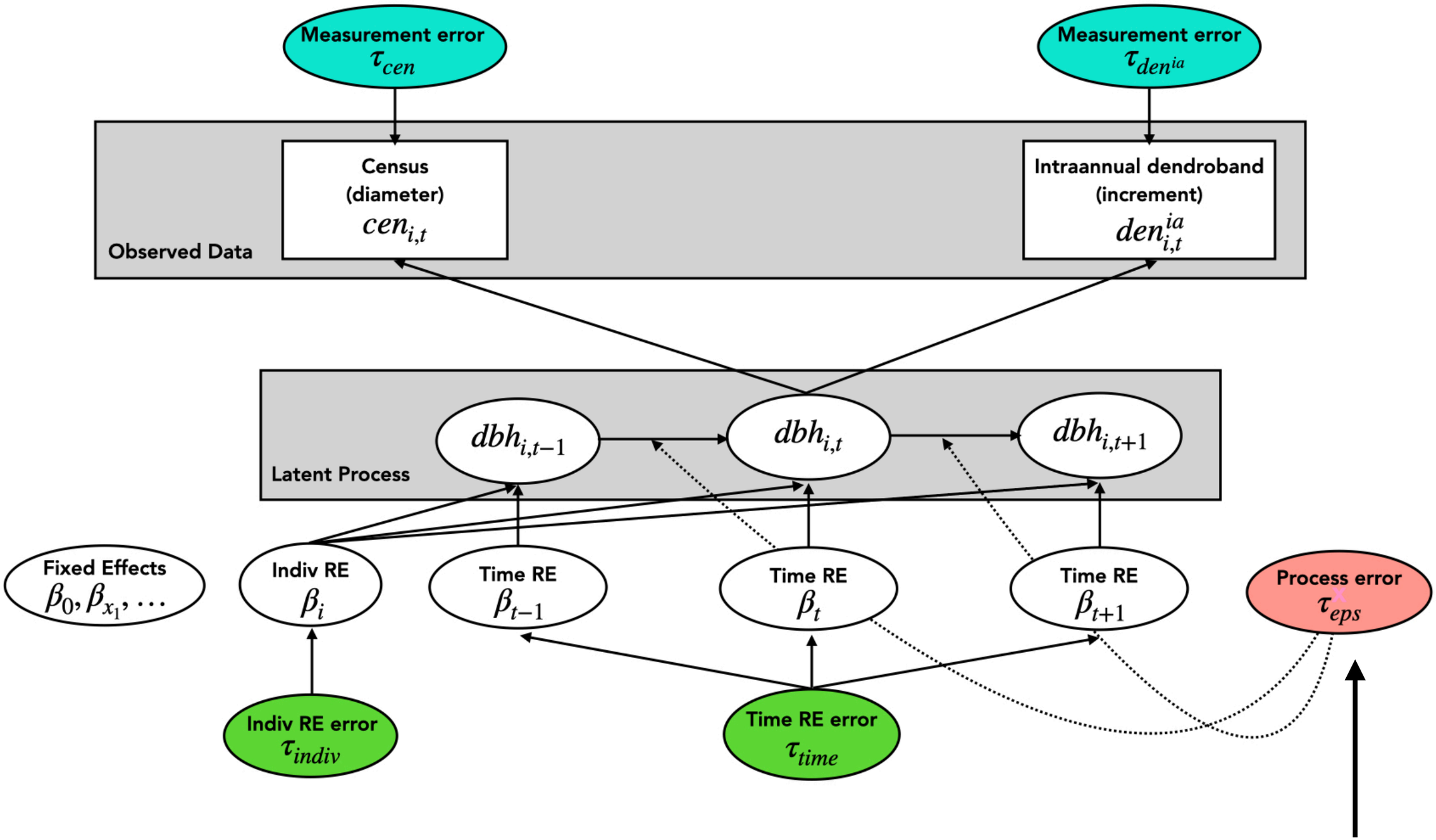


Moral: only error this propagates across time in forecasts

Model as of 2021/1/22



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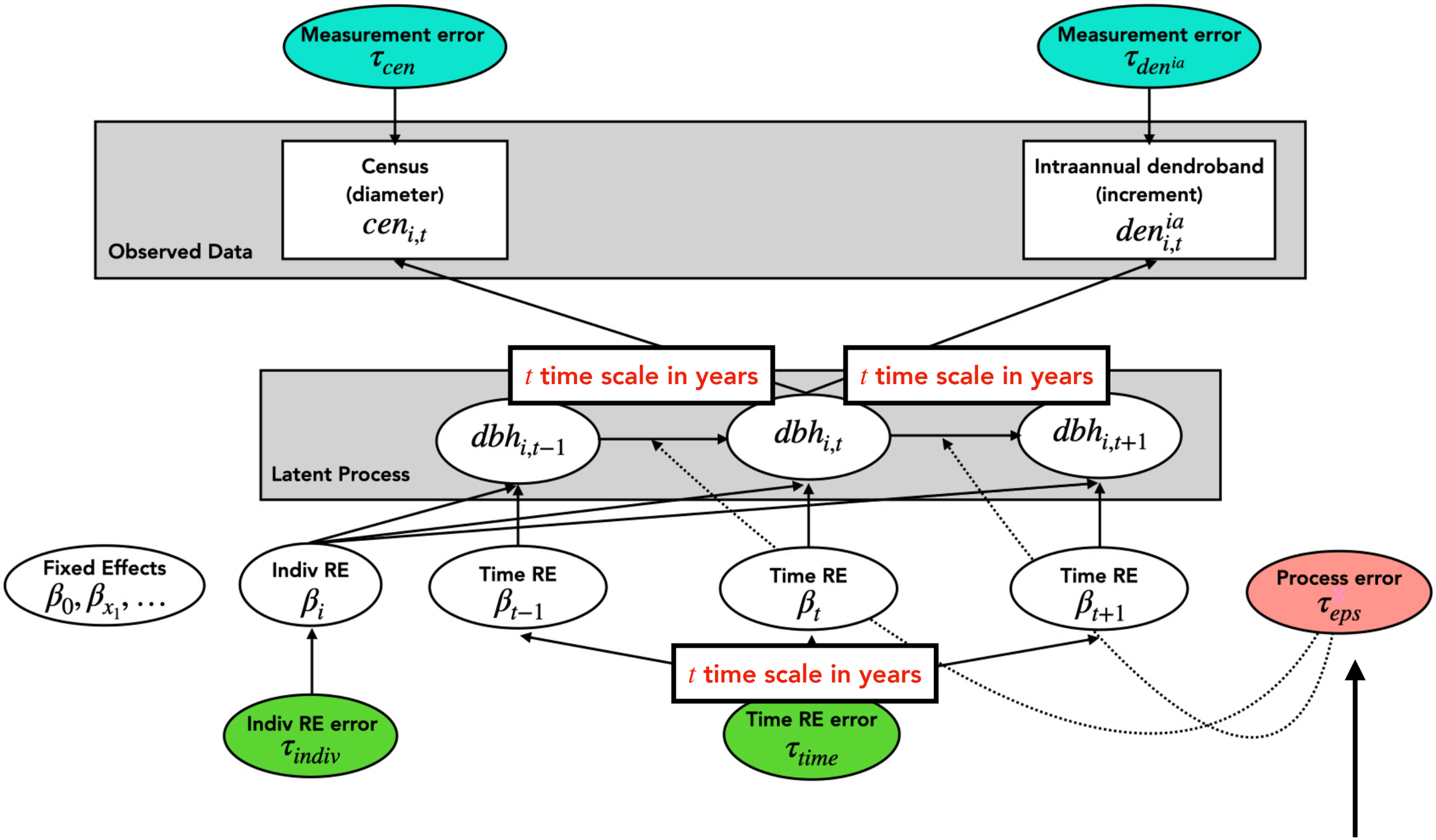

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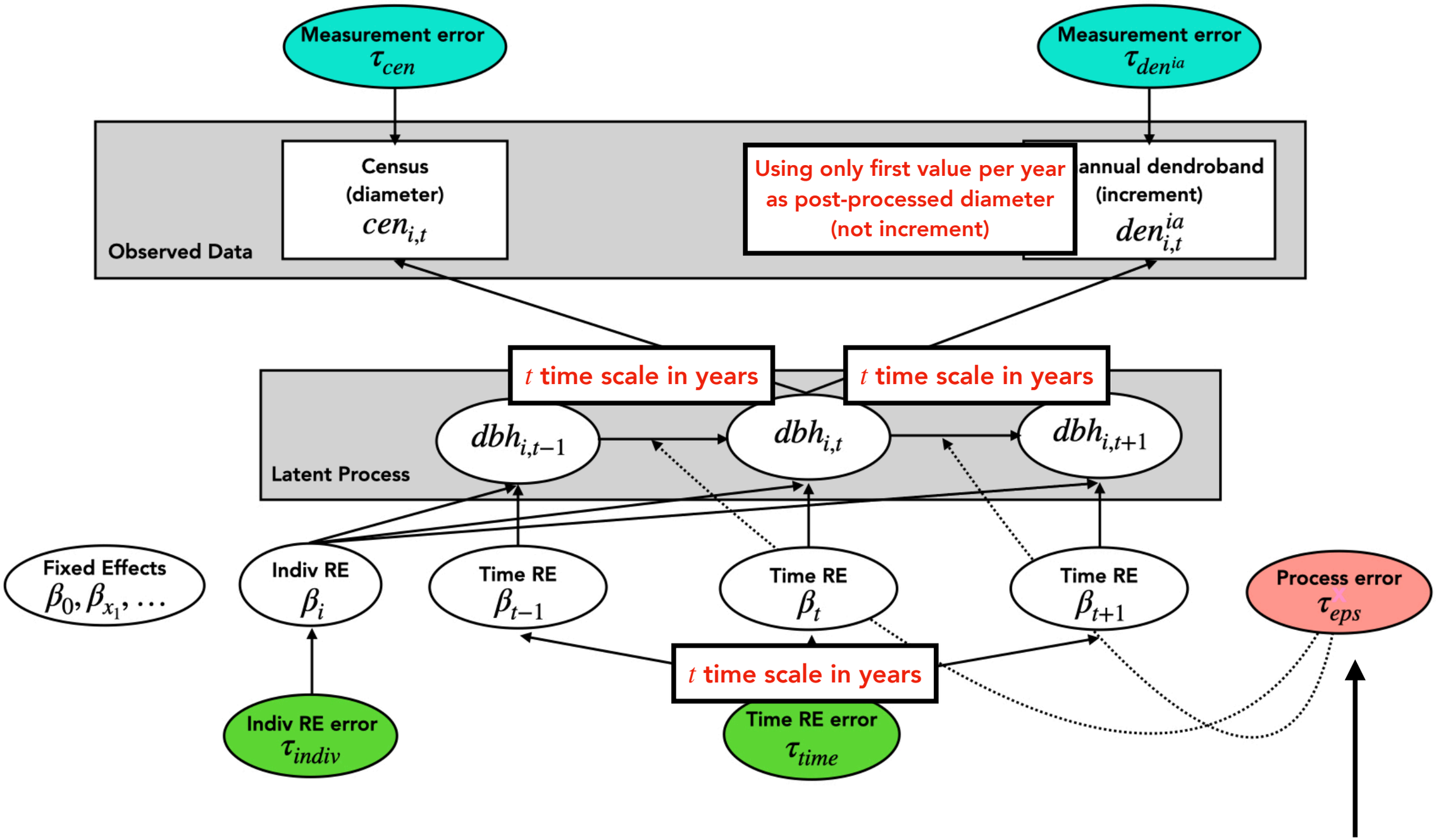

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Results

MCMC specifications

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- n = 155 trees with intraannual dendrobands (tend to be larger canopy trees)

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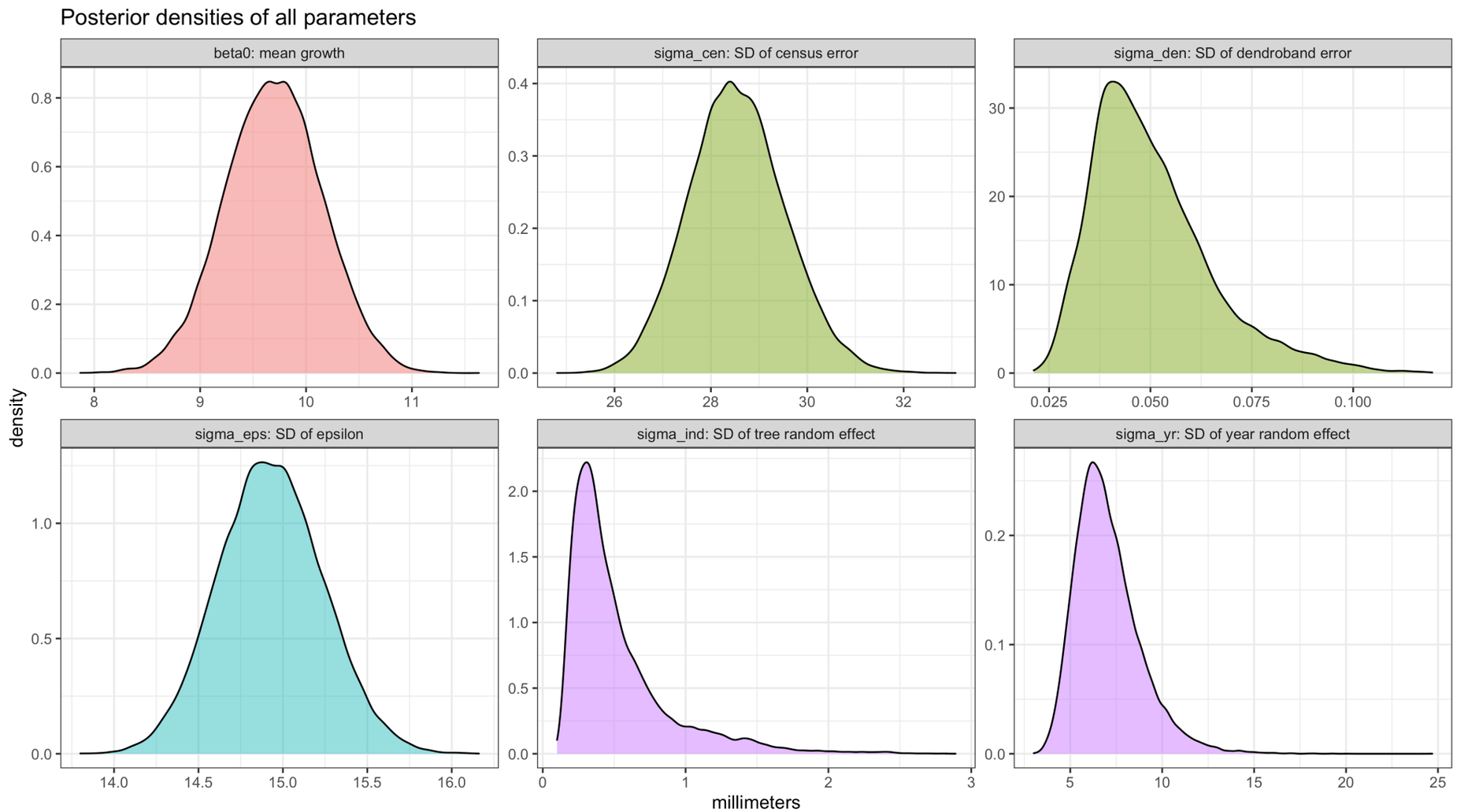
- Forecast into 2020 - 2022 by treating these years as missing values

Posterior Distributions



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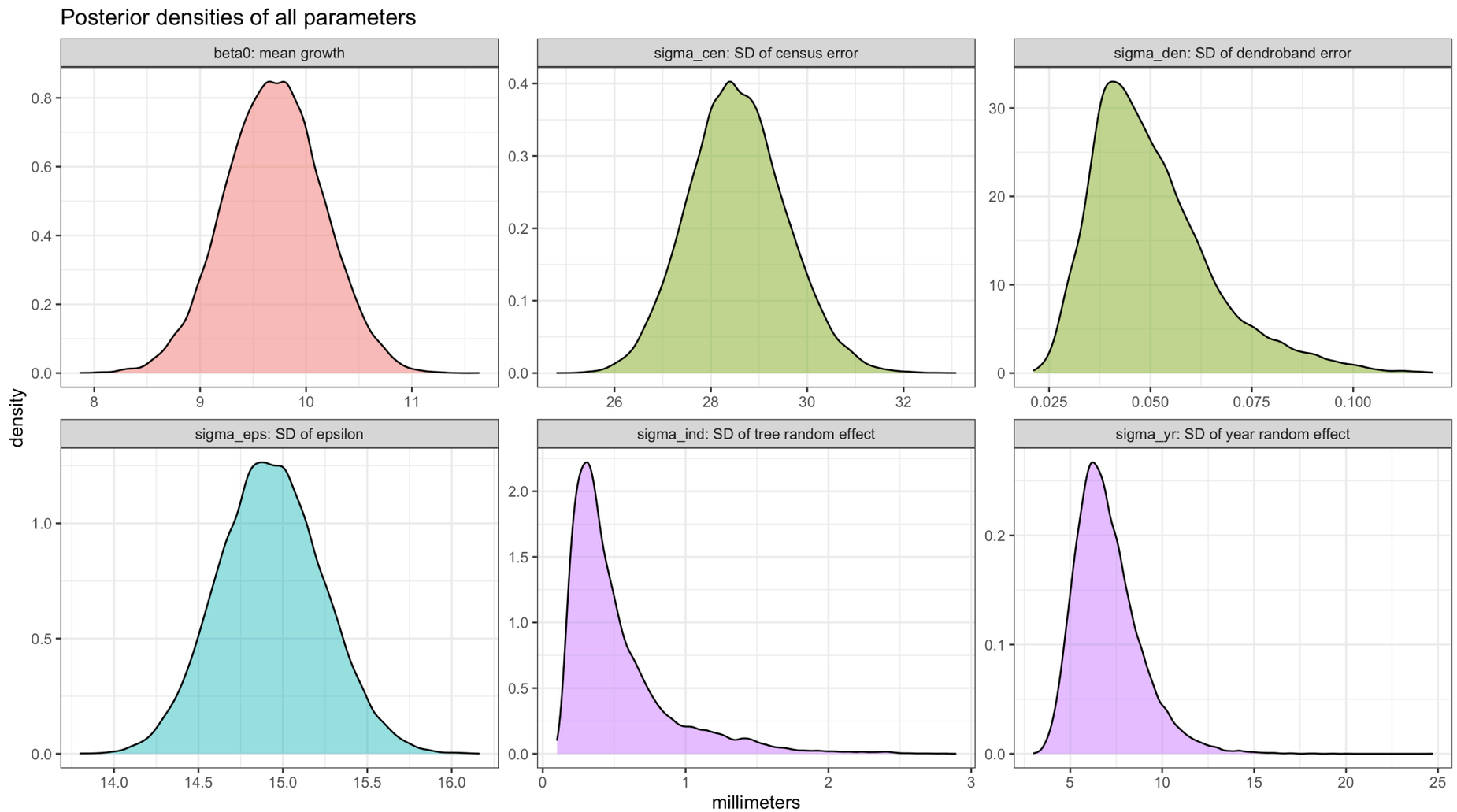
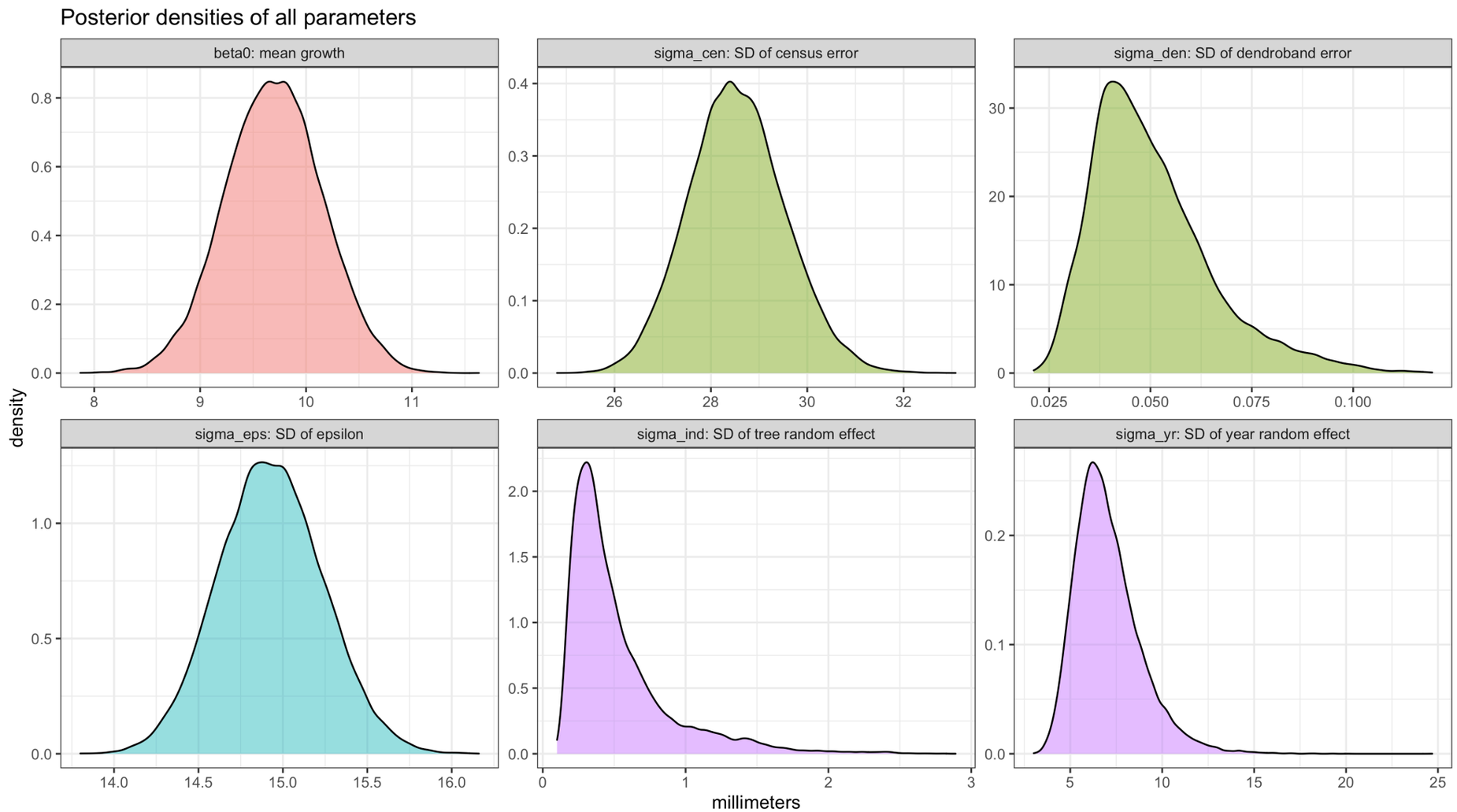


- mean β_0 ~ 1cm growth per year (needs sanity checking)

Posterior Distributions



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- $\sigma_{cen} >> \sigma_{den}$

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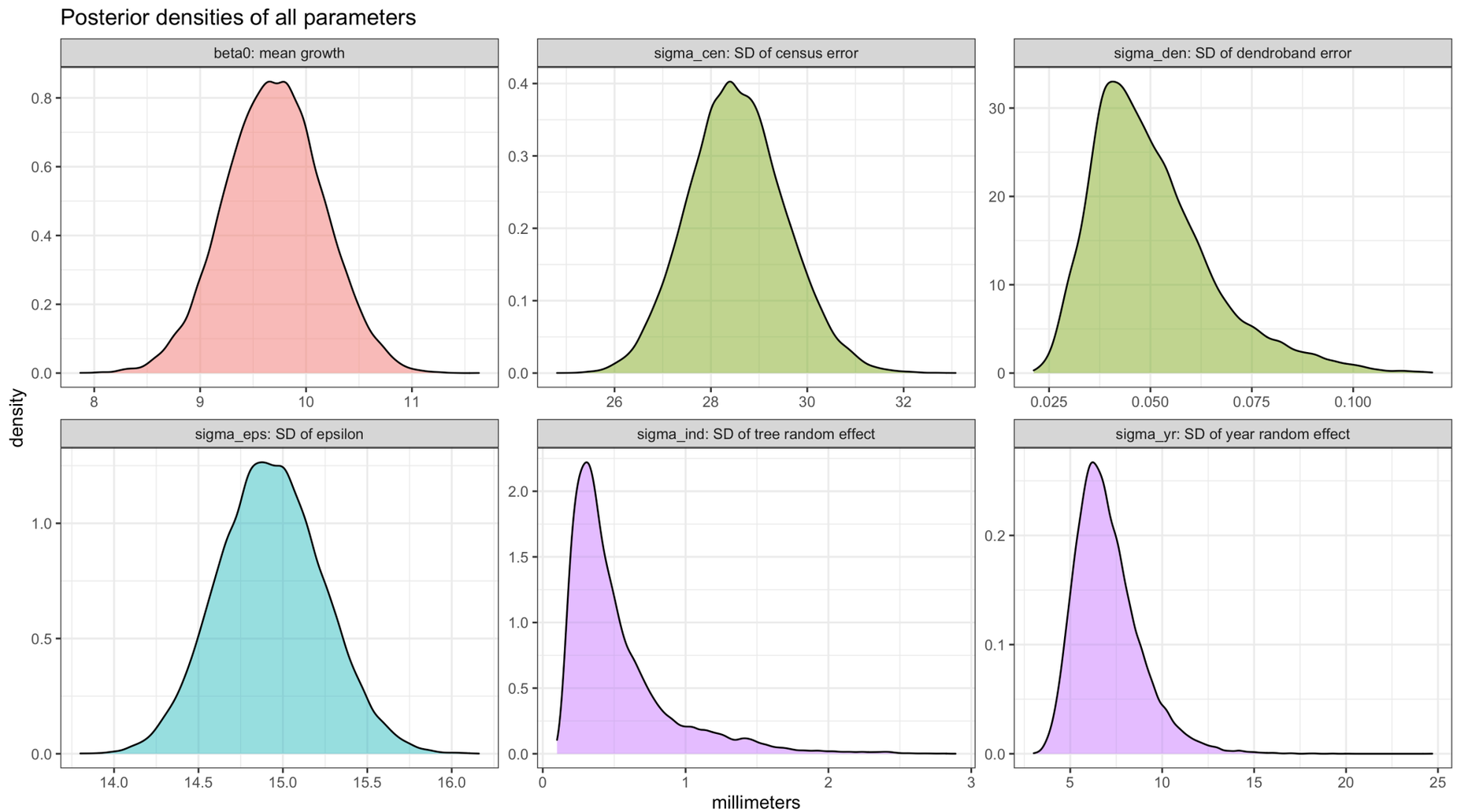

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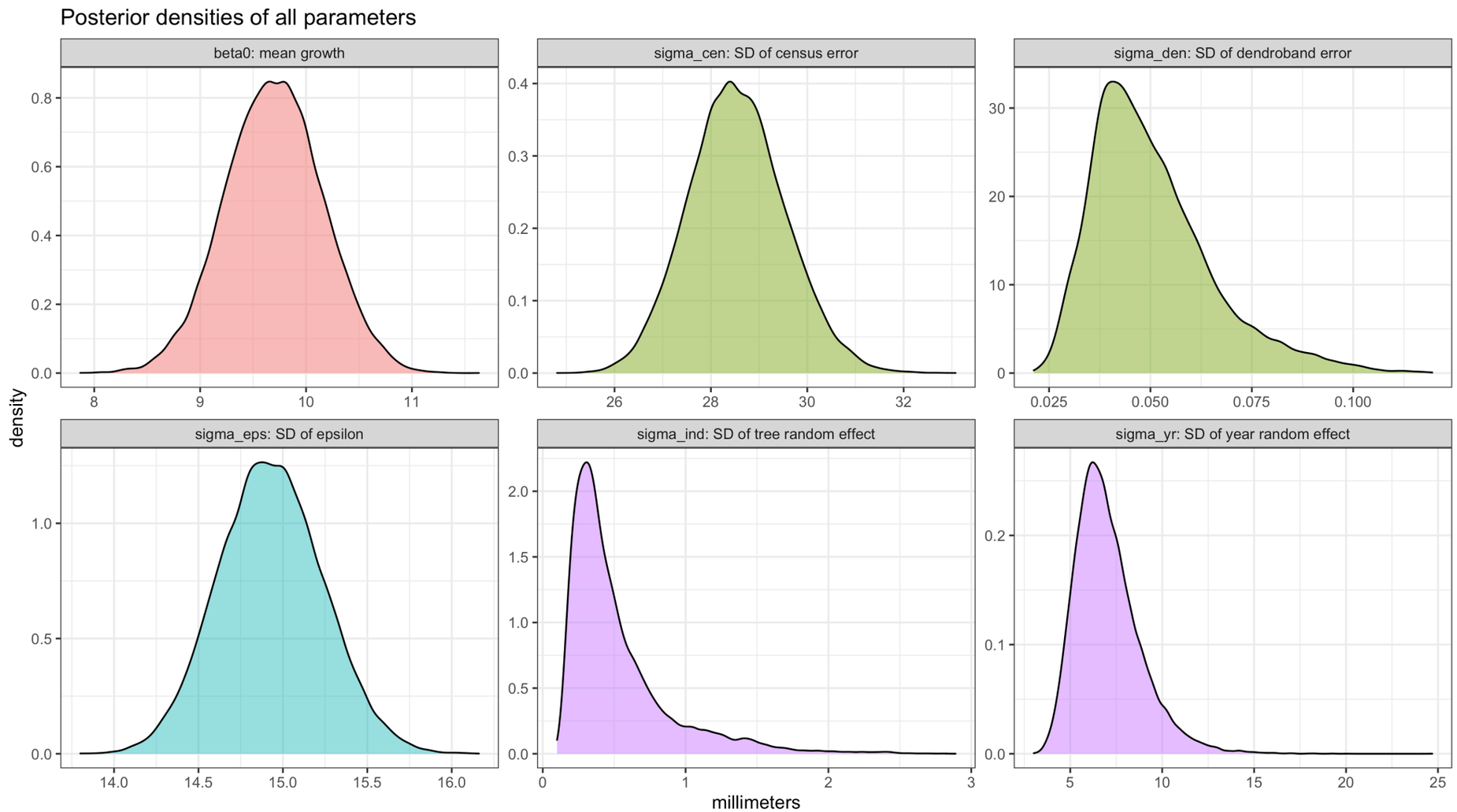

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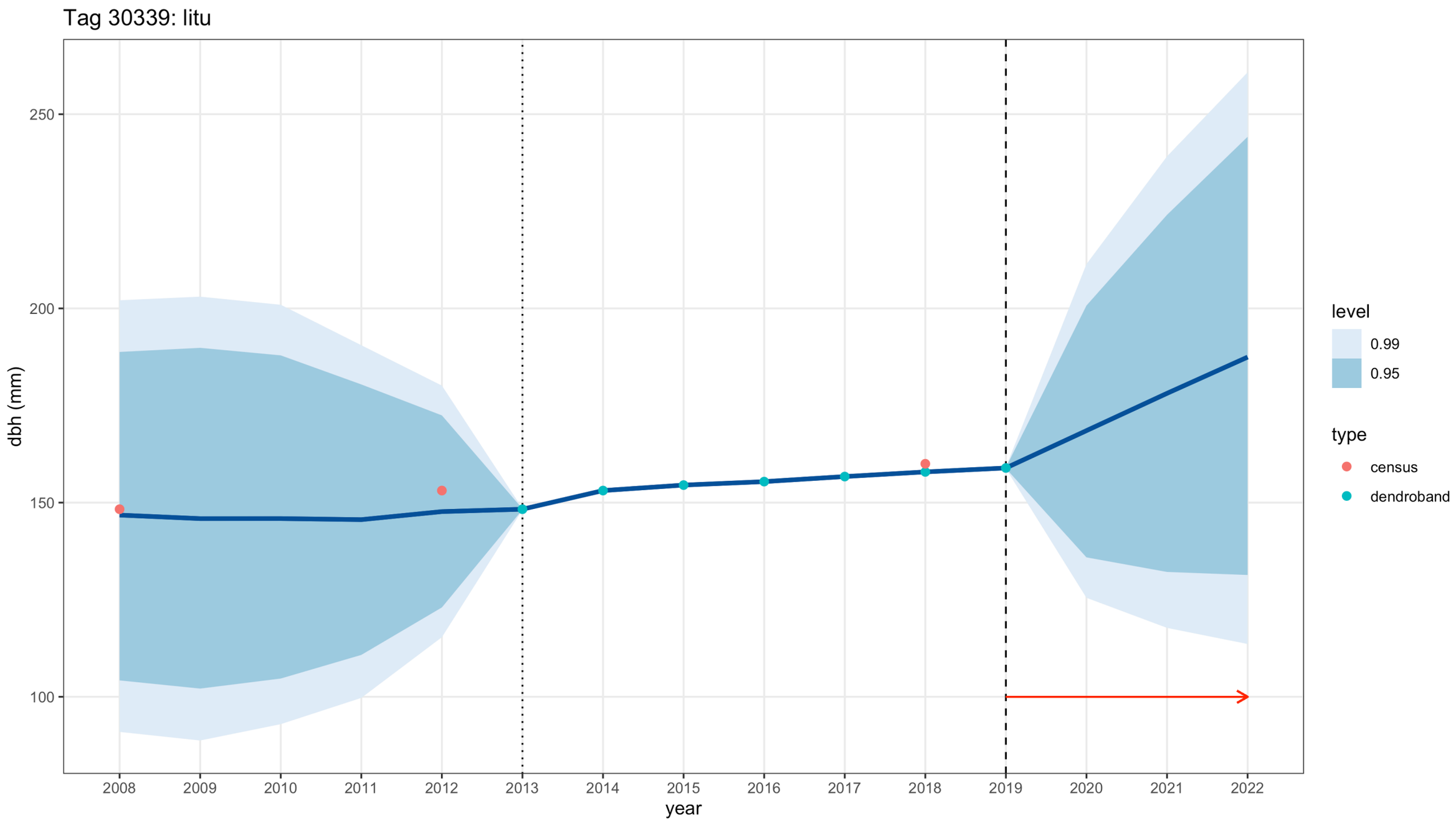
- $\sigma_{cen} >> \sigma_{den}$
- Year-to-year variation in growth > Between individuals variation
- σ_ϵ = remaining process error that propagates in forecasts across time

One particular tulip poplar

tag_stem	type	sp	`2007`	`2008`	`2009`	`2010`	`2011`	`2012`	`2013`	`2014`	`2015`	`2016`	`2017`	`2018`	`2019`
<chr>	*<chr>*	*<chr>*	*<dbl>*	*<dbl>*	*<dbl>*	*<dbl>*	*<dbl>*	*<dbl>*	*<dbl>*	*<dbl>*	*<dbl>*	*<dbl>*	*<dbl>*	*<dbl>*	*<dbl>*
30339_3	census	litu	NA	148.	NA	NA	NA	153.	NA	NA	NA	NA	NA	160	NA
30339_3	dendroband	litu	NA	NA	NA	NA	NA	NA	149.	155.	156.	157.	157.	159.	160.

One particular tulip poplar diameter

y = modeled true latent $dbh_{i,t}$



Dendroband installed in 2013

Future Work

TODO

TODO

- Add remaining data:

TODO

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  - All, not just first yearly observation, intra-annual dendroband

TODO

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  - All, not just first yearly observation, intra-annual dendroband
  - All biannual dendroband

TODO

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  - All biannual dendroband
  - Tree coring data

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- Merge dendroband after comparing τ_{den}^{ba} versus τ_{den}^{ia}?

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  - $dbh_{i,t} = dbh_{i,t-1} + \beta_0 + \ldots + \epsilon$

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  - Covariates: In particular species & starting diameter

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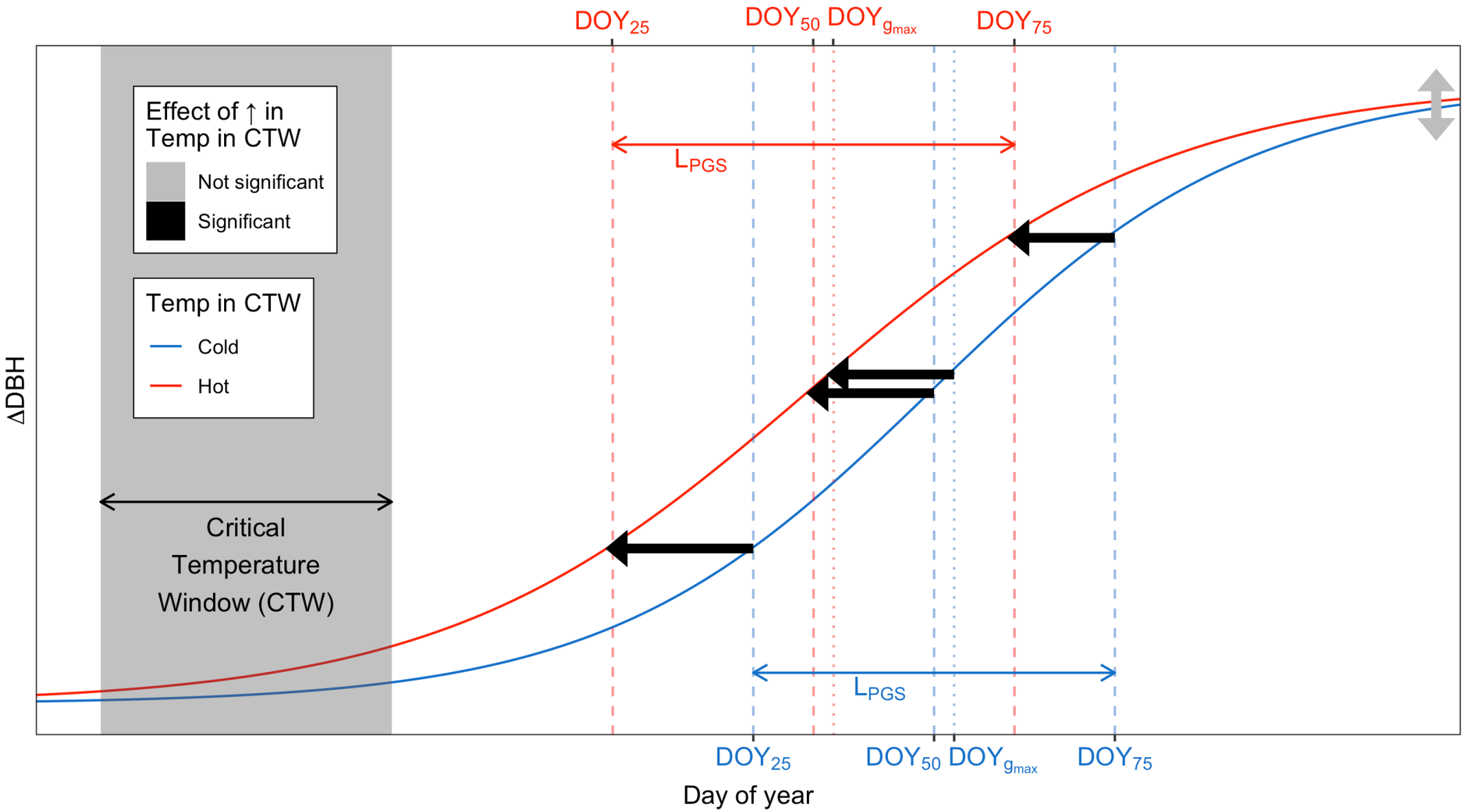
- Improve model for latent variable
  - $dbh_{i,t} = dbh_{i,t-1} + \beta_0 + \ldots + \epsilon$
  - Covariates: In particular species & starting diameter
- Choose appropriate time scale for t

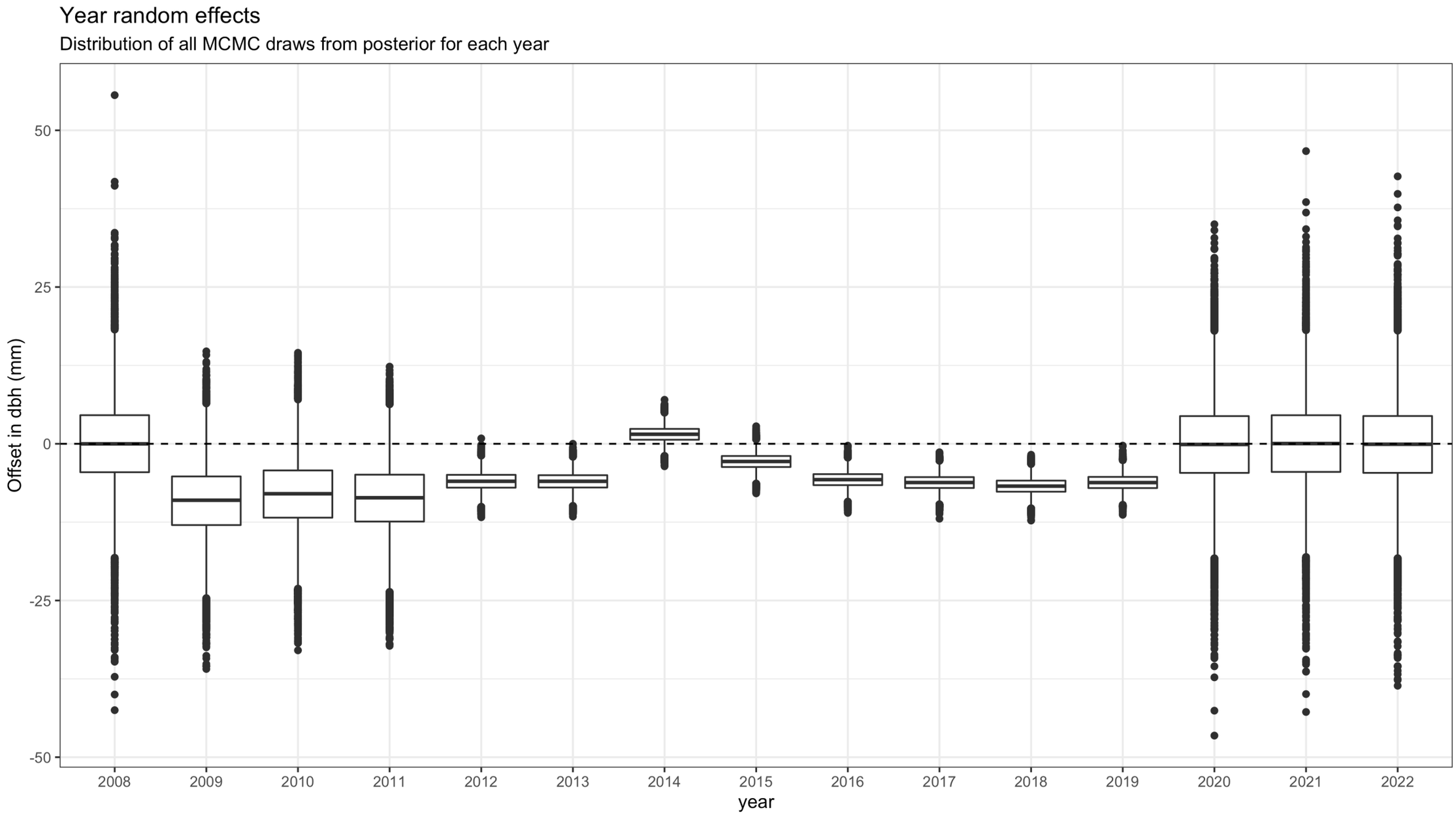
Thanks!

Slides on Twitter
@rudeboybert

Intra-annual effect of climate



Year Random Effects



Individual Random Effects