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

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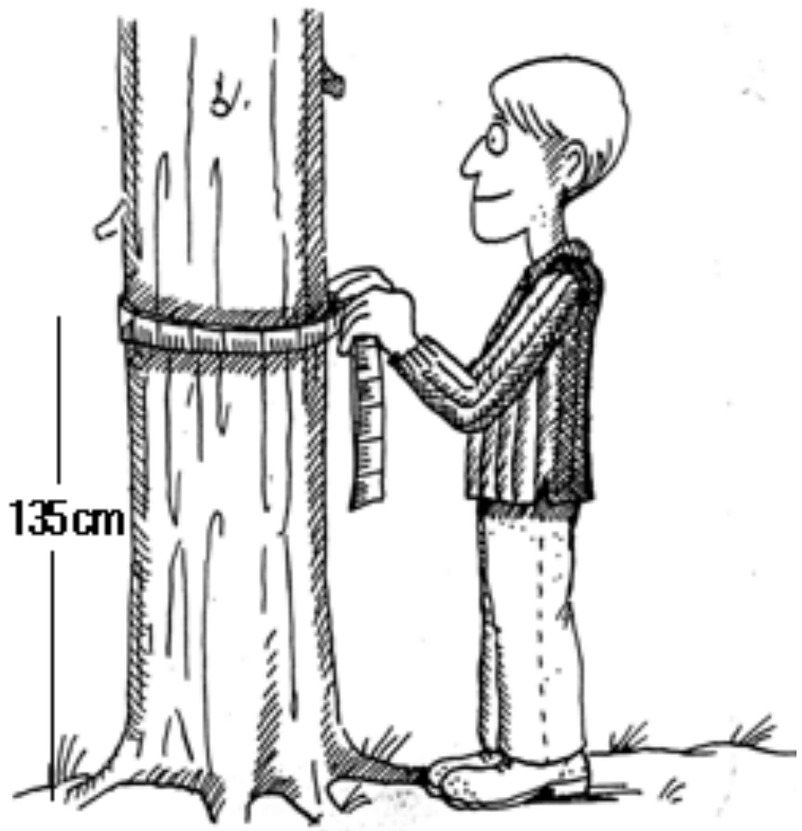
UMass Amherst Statistics Seminar Series

Friday, January 22, 2021

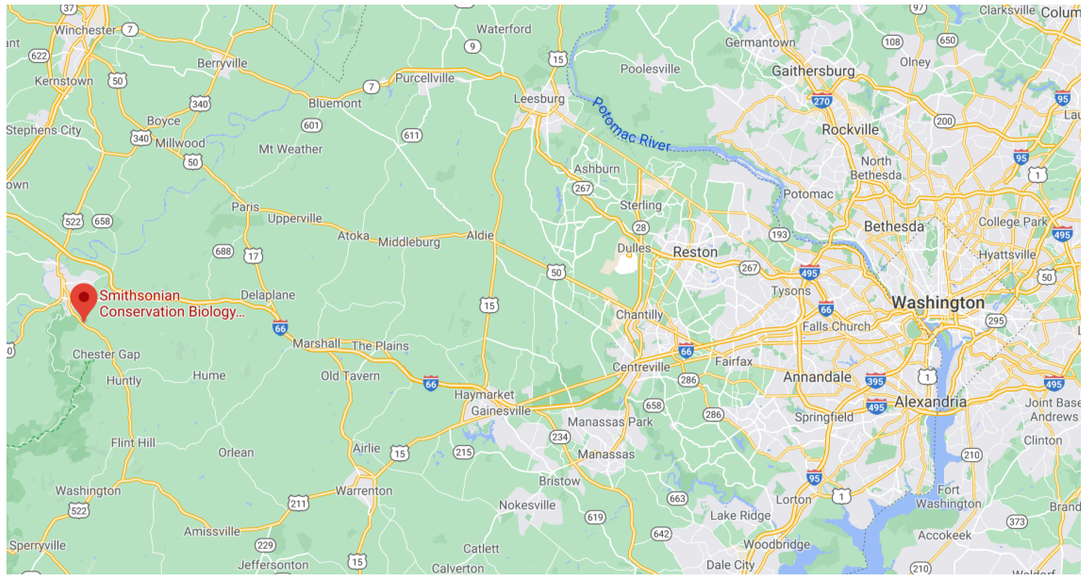
Context

Diameter at Breast Height (dbh)

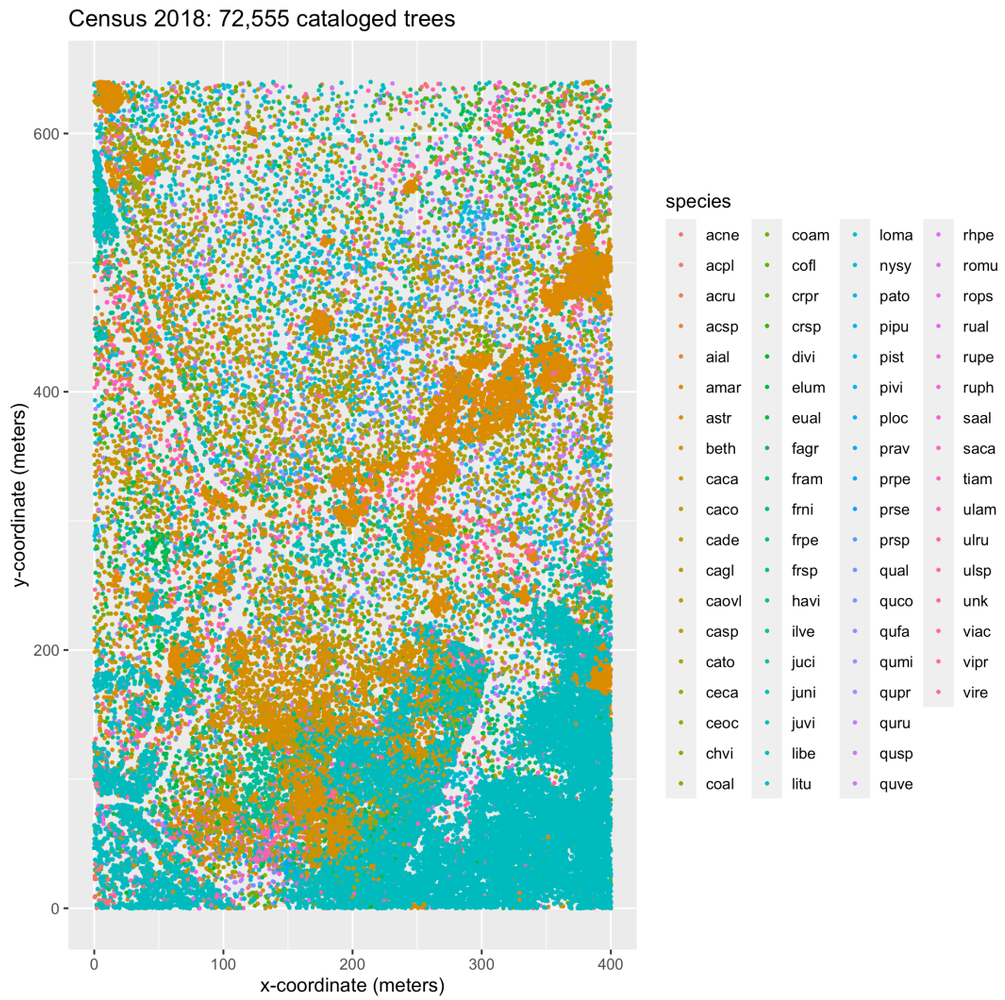
After species & location, one of the most informative variables about a tree is dbh



Smithsonian Conservation Biology Institute



25.6 ha = 35.85 soccer fields



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

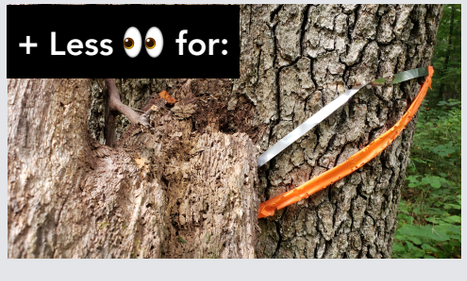
1. Measuring tape. Call this “census” data

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

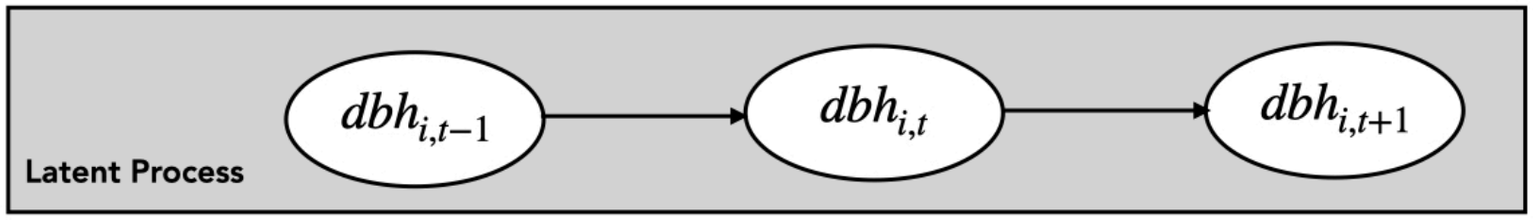
- Hidden: "Data fusion" via latent variables
  In our case: "true" dbh
- Markov: y_t depends on y_{t-1}
- Partition sources of error into those that
  - Are not of direct interest
  - Are "one and done" i.e. measurement error
  - Propagate when forecasting

Minimum Viable Product

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

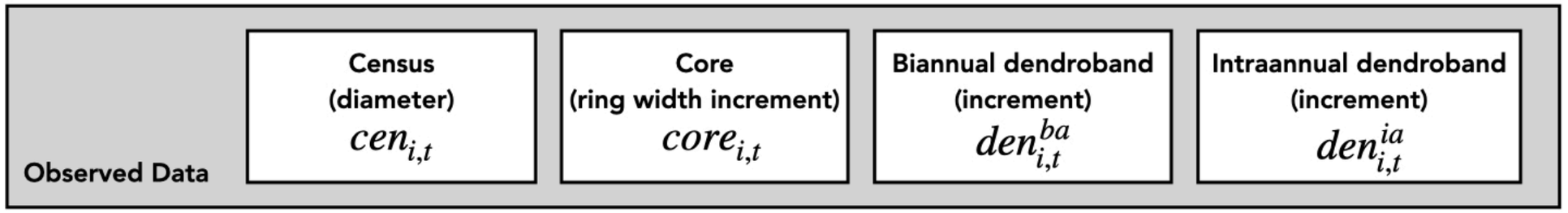
- $dbh_{i,t}$: "True" latent dbh for individual i at time t
- β_0 : Baseline growth
- β_i : Individual tree i random effect
- β_t : Time point t random effect
- $\epsilon \sim$ Normal $\left(0, \sigma_\epsilon^2\right)$

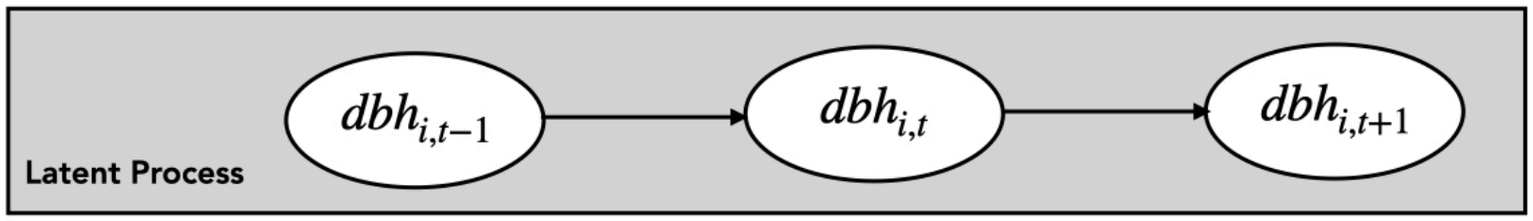
Model



Clark 2007

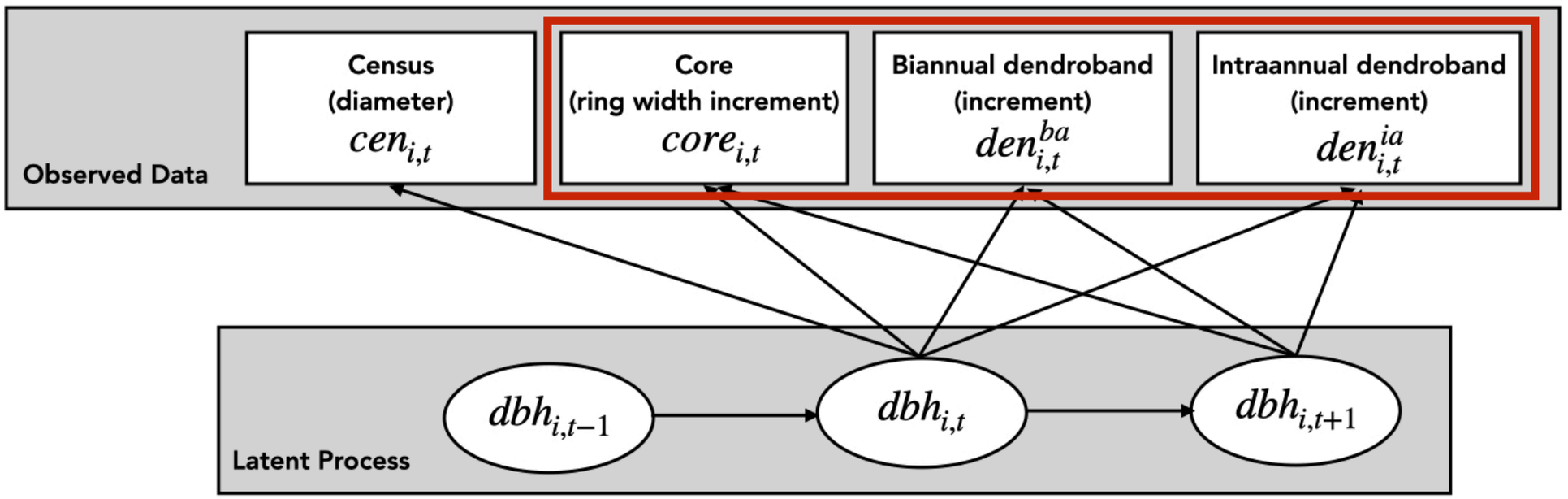
Model


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

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



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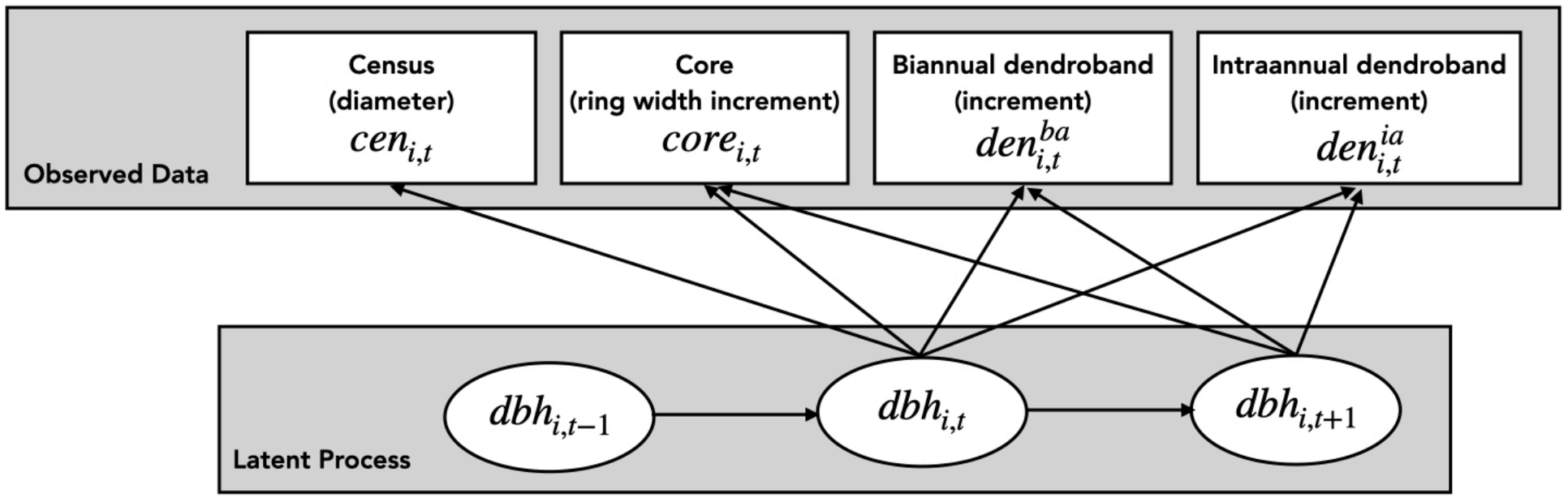
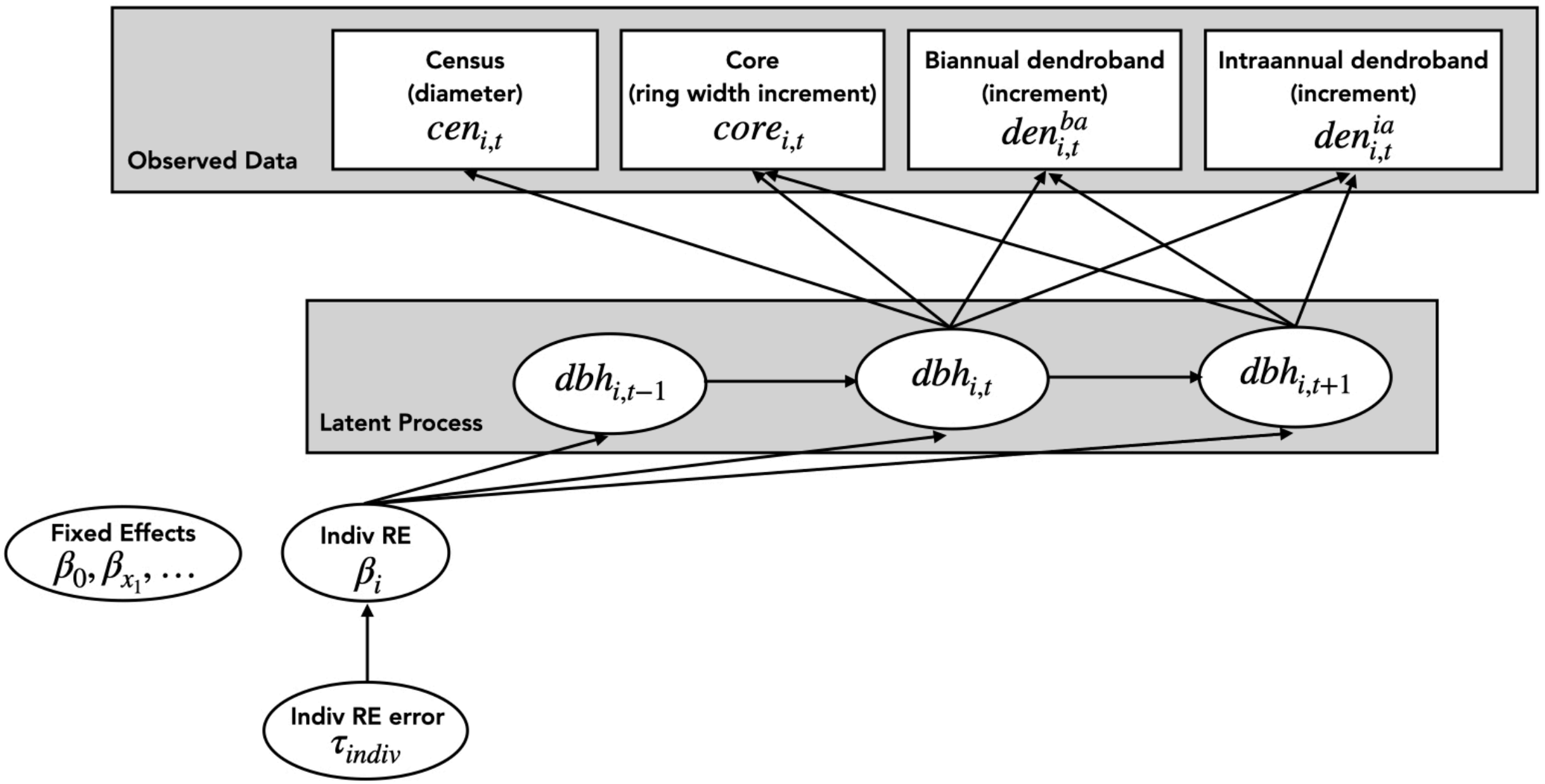


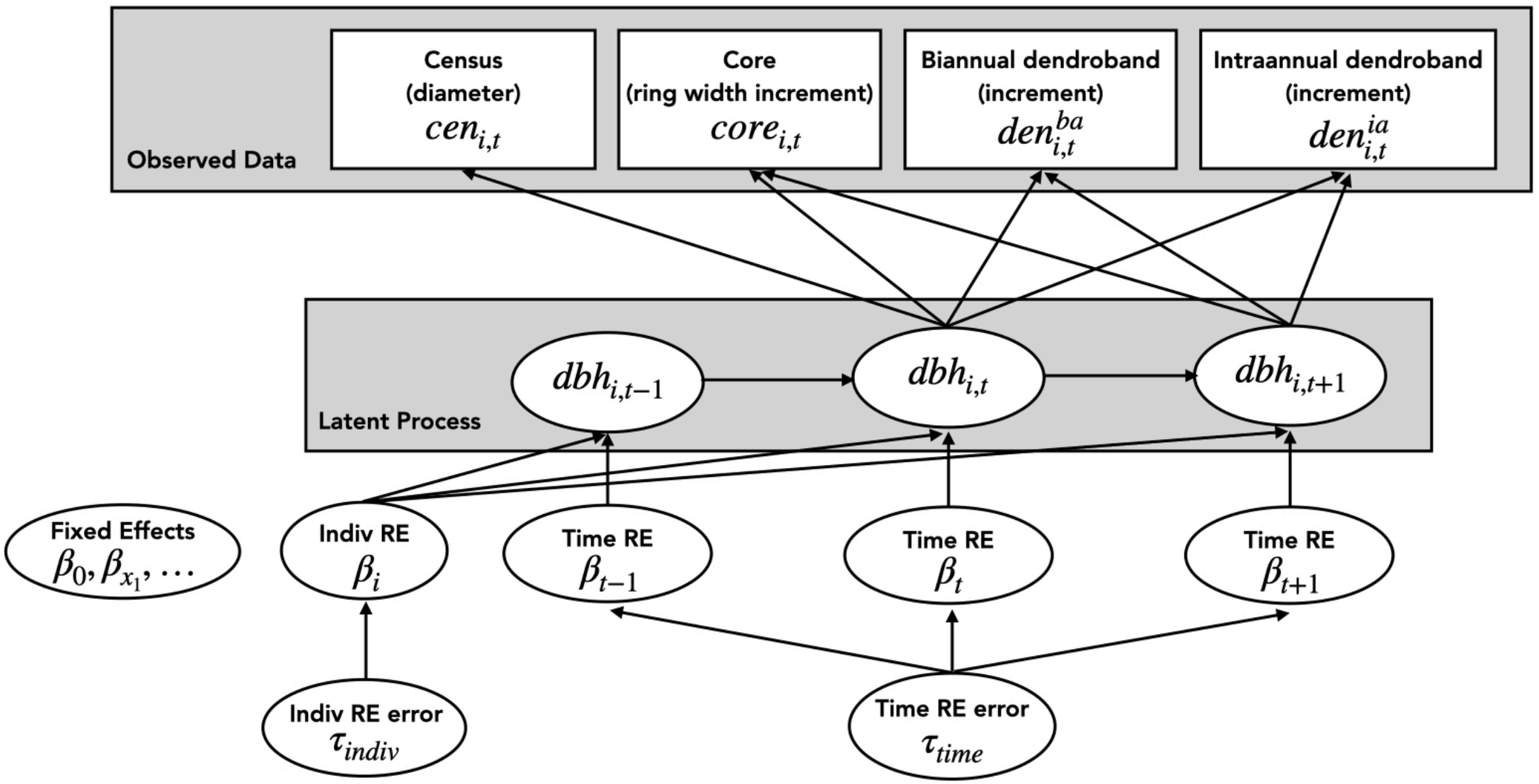
Fixed Effects
$\beta_0, \beta_{x_1}, \ldots$

Model



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

Model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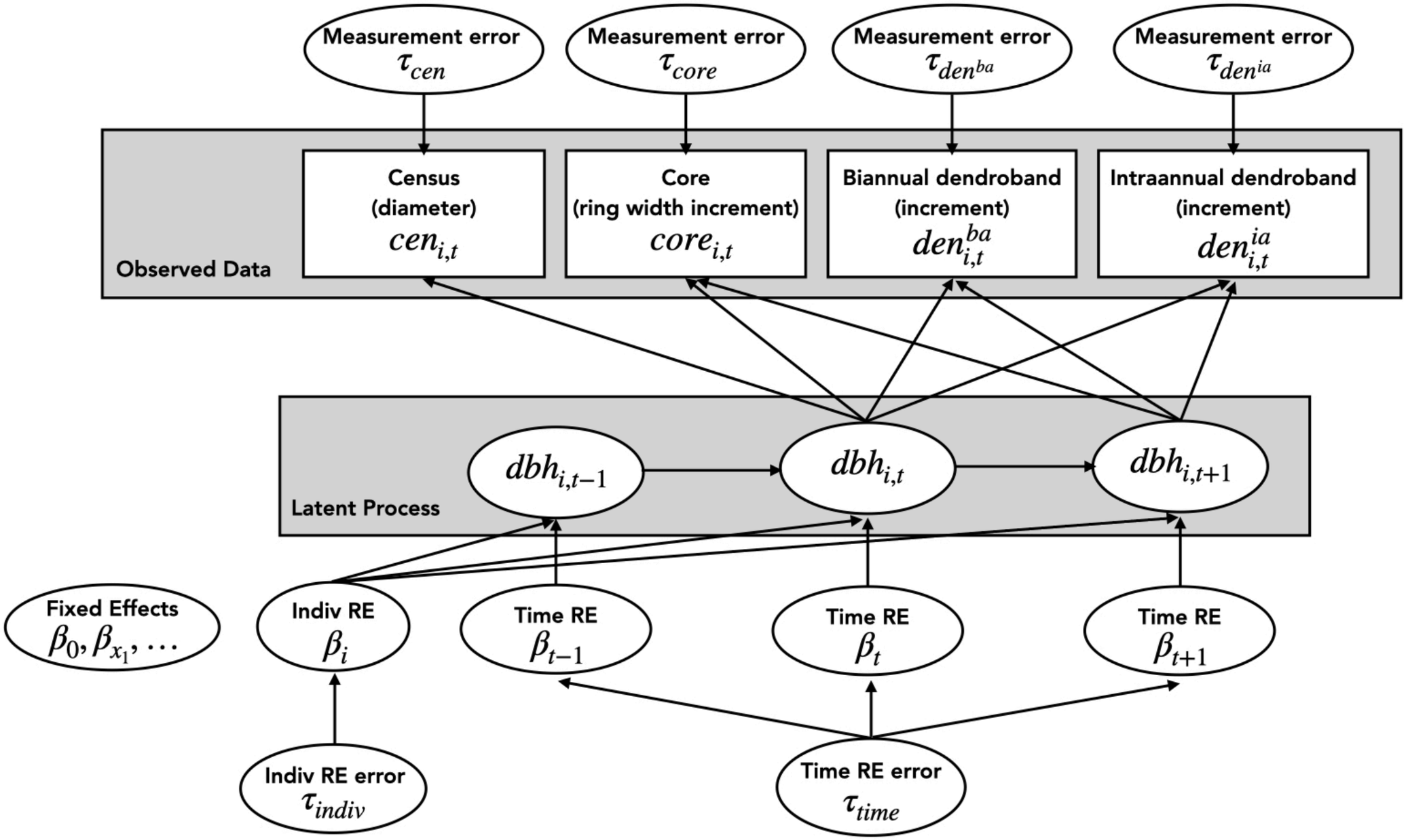
$\beta_0, \beta_{x_1}, \ldots$
Indiv RE
β_i
Time RE
β_{t-1}
Time RE
β_t
Time RE
β_{t+1}
Indiv RE error
τ_{indiv}
Time RE error
τ_{time}

Model


Measurement error
τ_{cen}
Measurement error
τ_{core}
Measurement error
$\tau_{den^{ba}}$
Measurement error
$\tau_{den^{ia}}$
Observed Data
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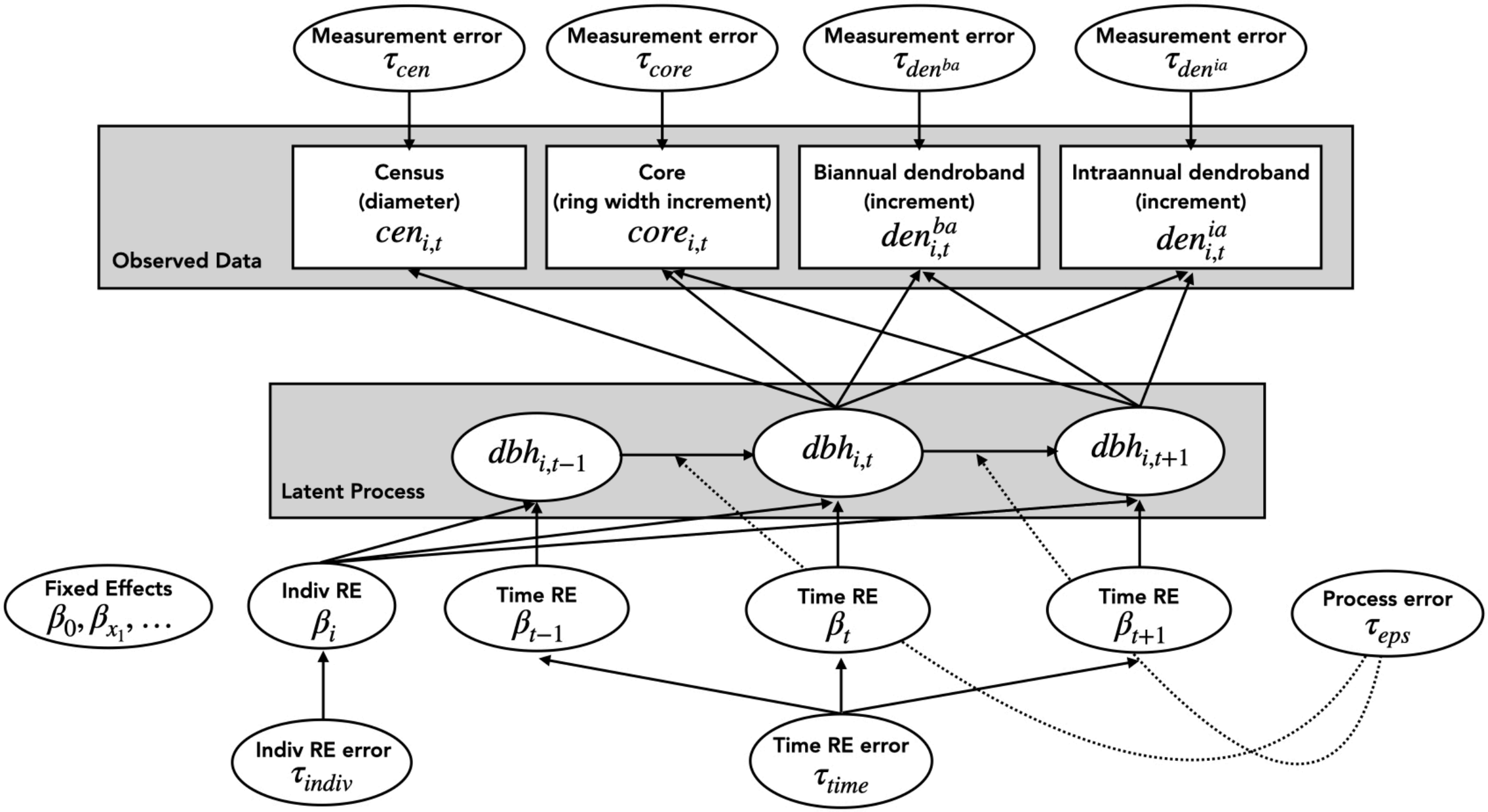
Indiv RE
β_i
Time RE
β_{t-1}
Time RE
β_t
Time RE
β_{t+1}
Indiv RE error
τ_{indiv}
Time RE error
τ_{time}

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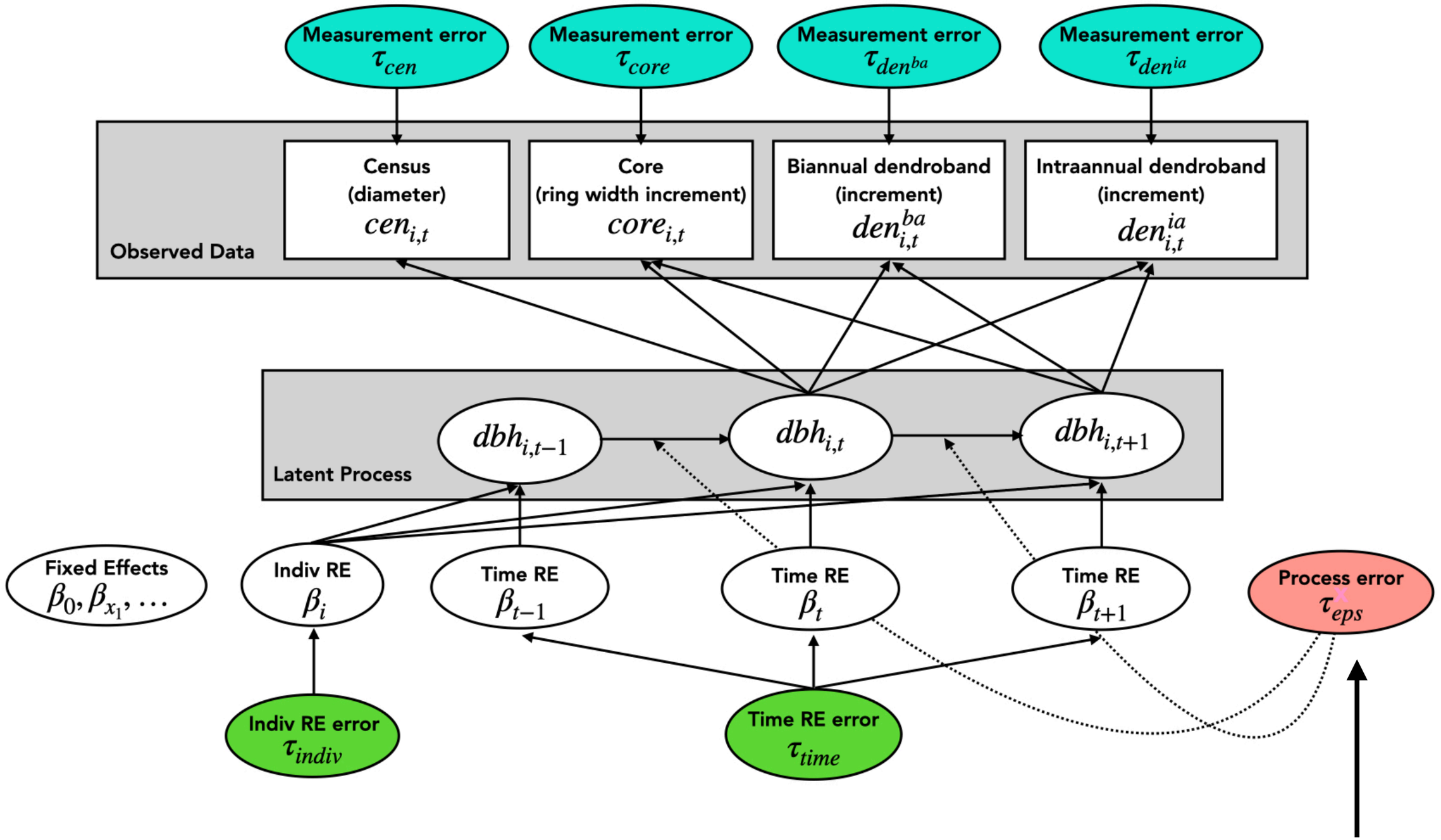
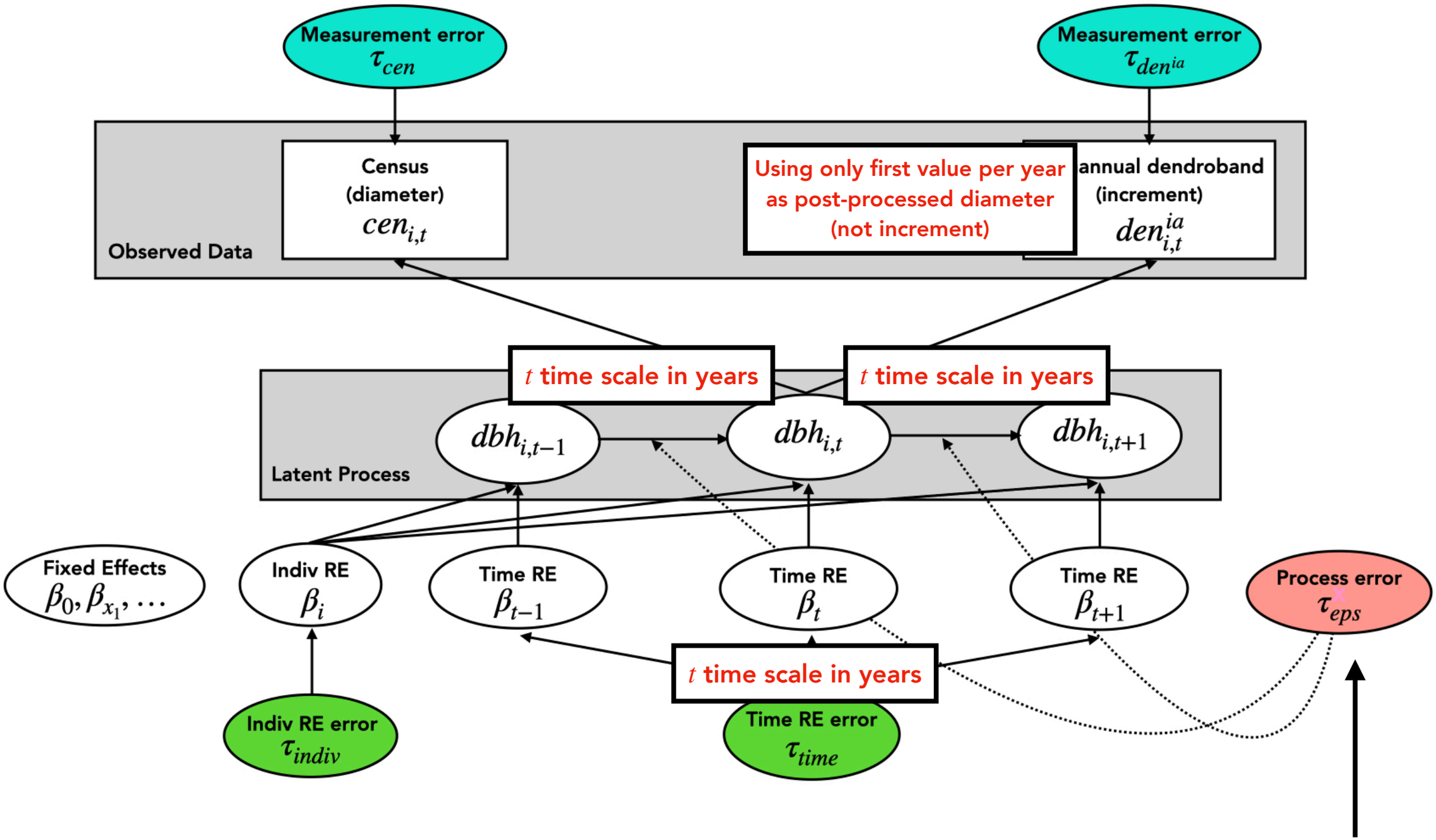
Indiv RE
β_i
Time RE
β_{t-1}
Time RE
β_t
Time RE
β_{t+1}
Process error
τ_{eps}
Indiv RE error
τ_{indiv}
Time RE error
τ_{time}

Model



Moral: only error this propagates across time in forecasts

Model as of 2021/1/22



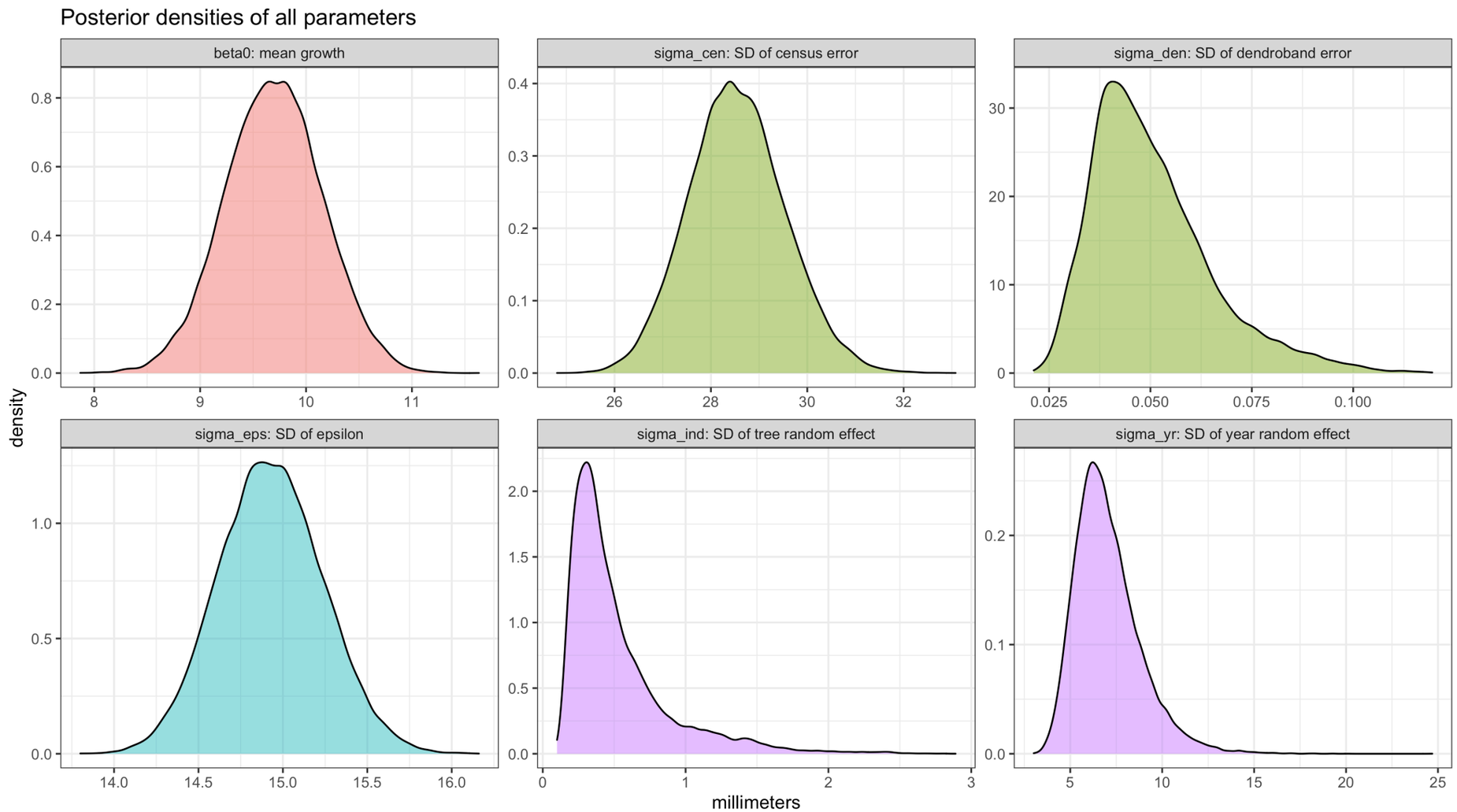
Moral: only error this propagates across time in forecasts

Results

MCMC specifications

- n = 155 trees with intraannual dendrobands (tend to be larger canopy trees)
- Implemented in JAGS
- 30k draws from posterior minus 10% burn-in
- Empirical Bayes (data informed) prior parameters
- Forecast into 2020 - 2022 by treating these years as missing values

Posterior Distributions



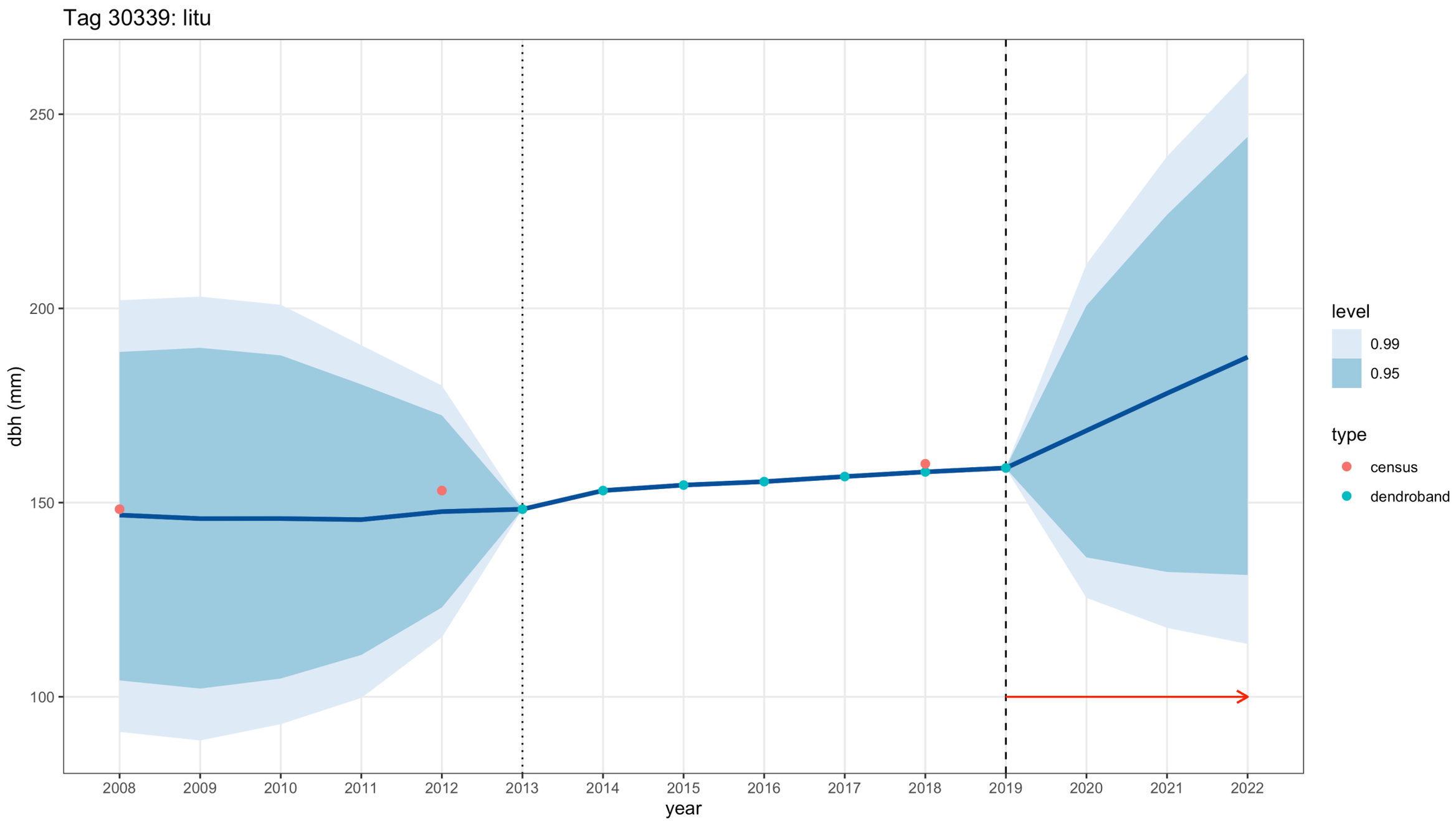
- mean β_0 ~ 1cm growth per year (needs sanity checking)
- $\sigma_{cen} >> \sigma_{den}$
- Year-to-year variation in growth > Between individuals variation
- σ_ϵ = remaining process error that propagates in forecasts across time

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

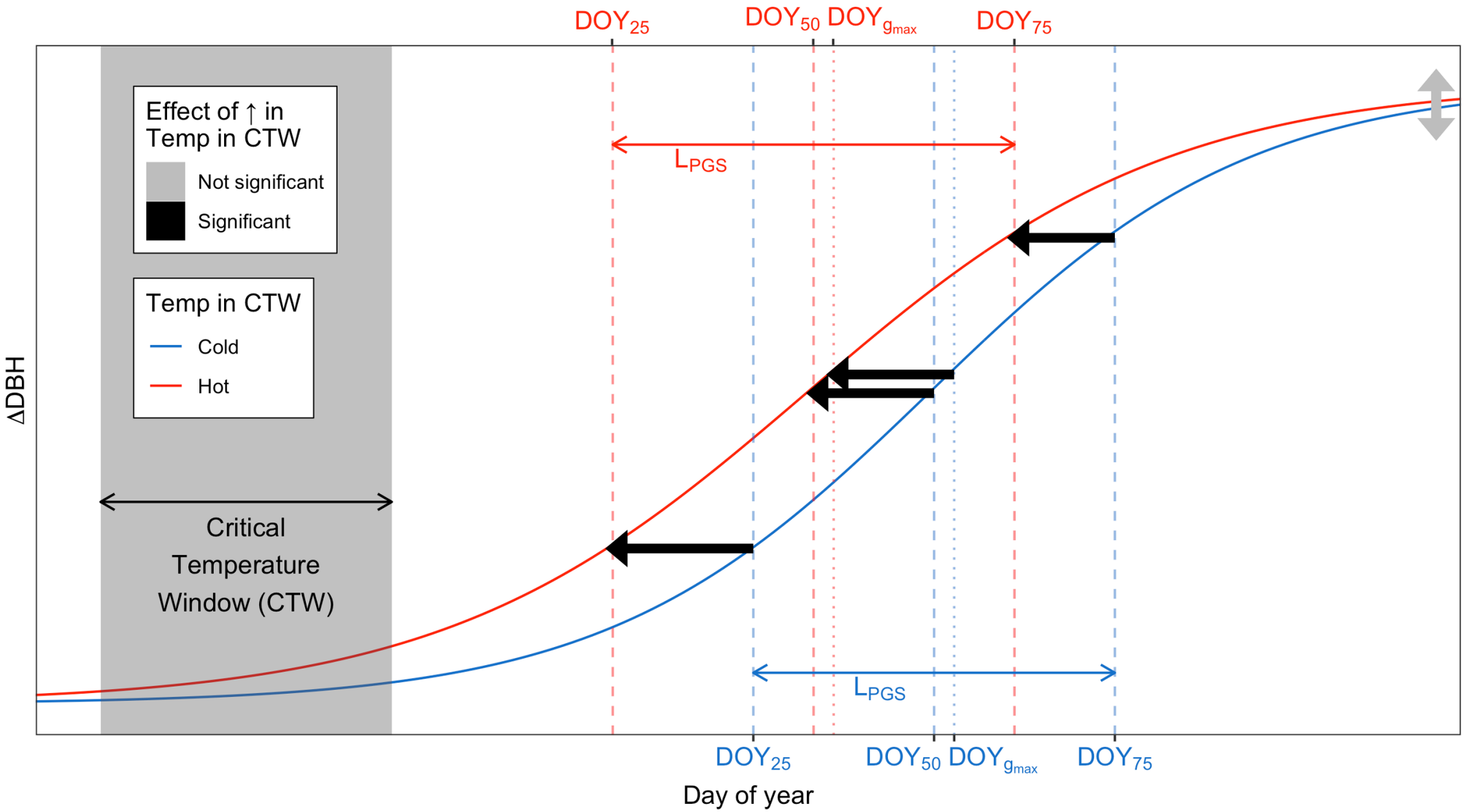
TODO

- Add remaining data:
  - All, not just first yearly observation, intra-annual dendroband
  - All biannual dendroband
  - Tree coring data
- Merge dendroband after comparing τ_{den}^{ba} versus τ_{den}^{ia}?
- 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

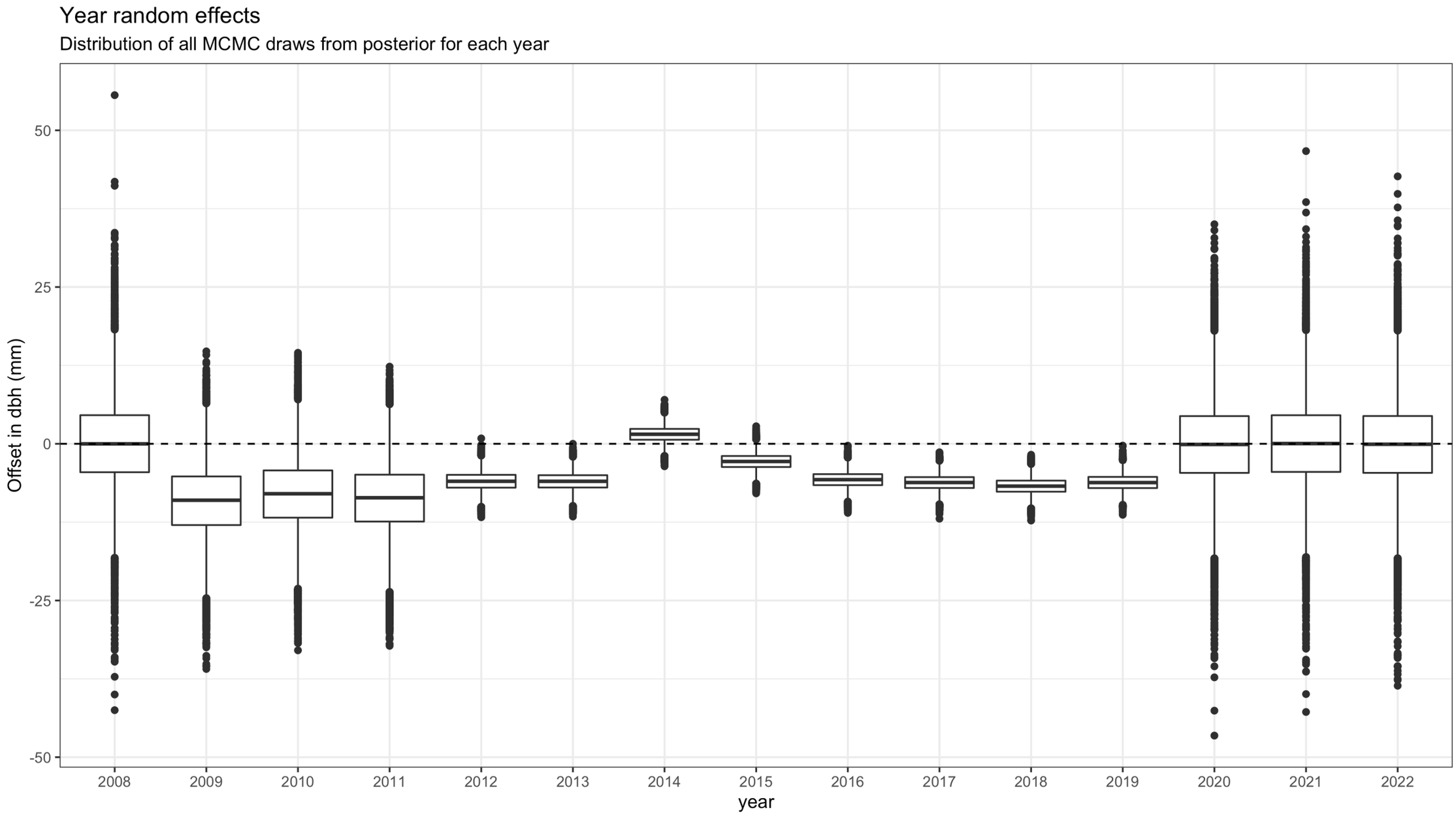
Thanks!

Slides on Twitter
@rudeboybert

Intra-annual effect of climate



Year Random Effects



Individual Random Effects