Towards Bayesian uncertainty quantification for forest models used in the U.K. GHG inventory for LULUCF

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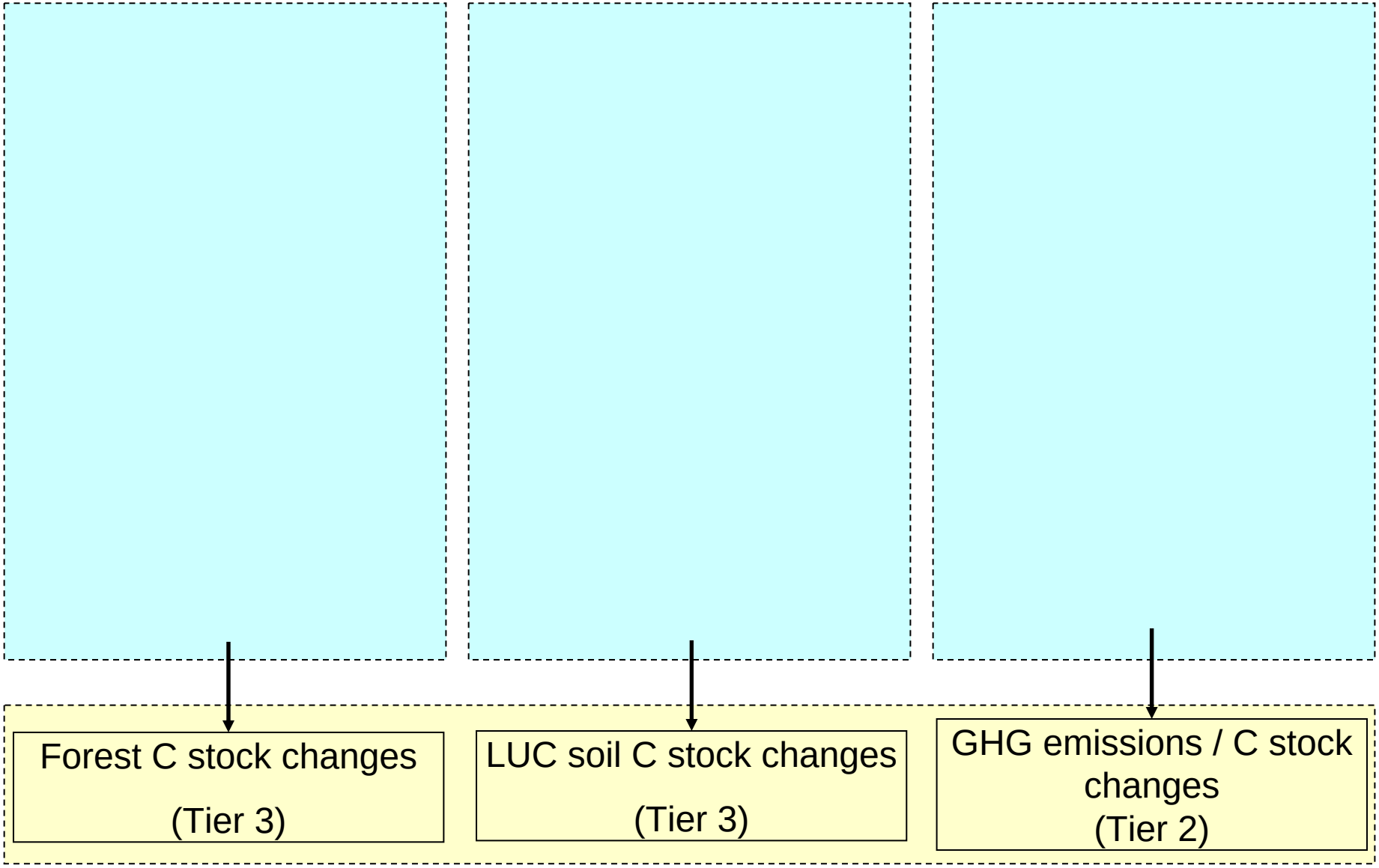
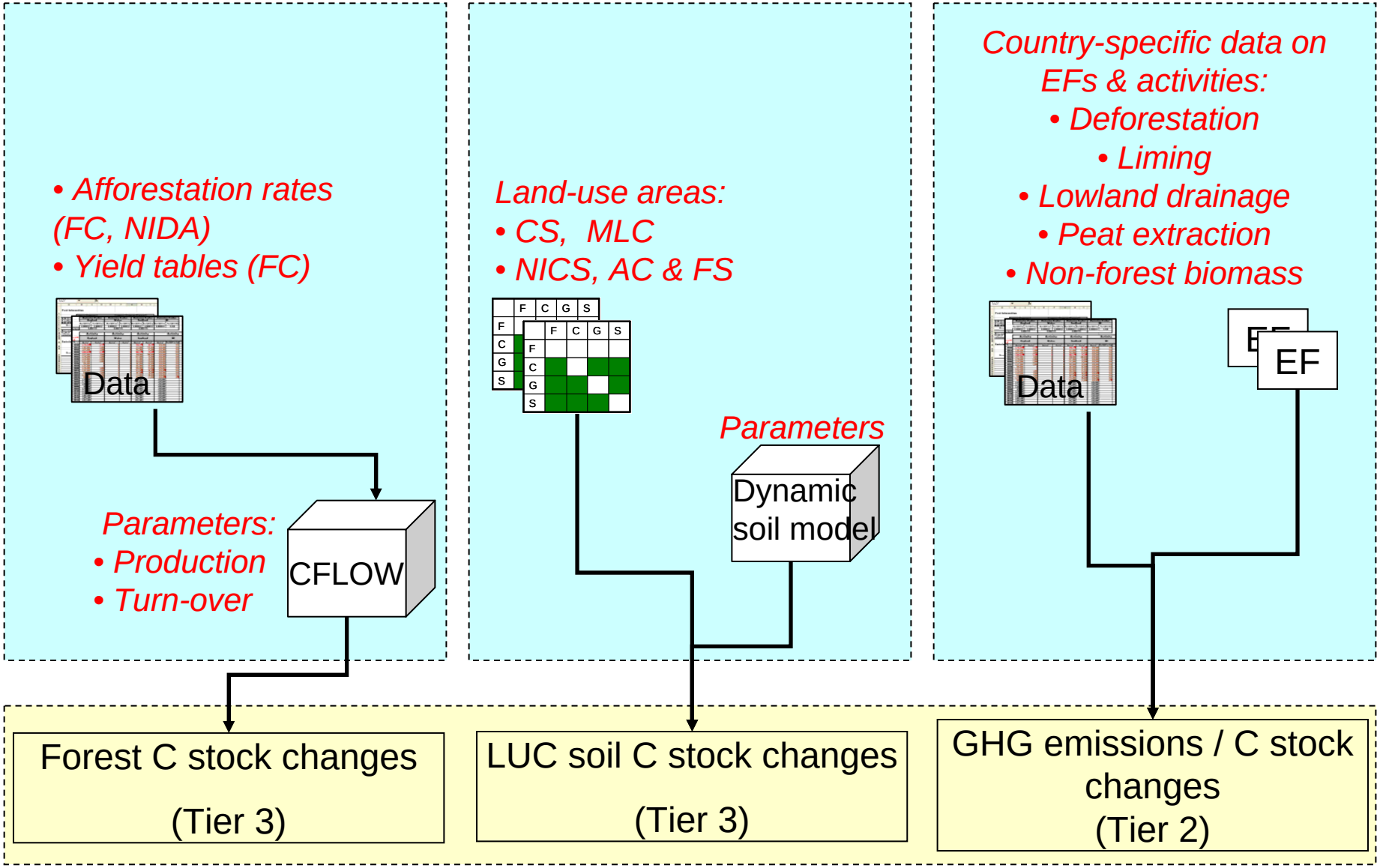
Contents

1. **Current methodology used to make the LULUCF inventory**
2. **Research on alternatives:**
   - **Forest models that include the effects of climate & soil conditions**
   - **Bayesian uncertainty quantification**
3. **Conclusions & outlook**

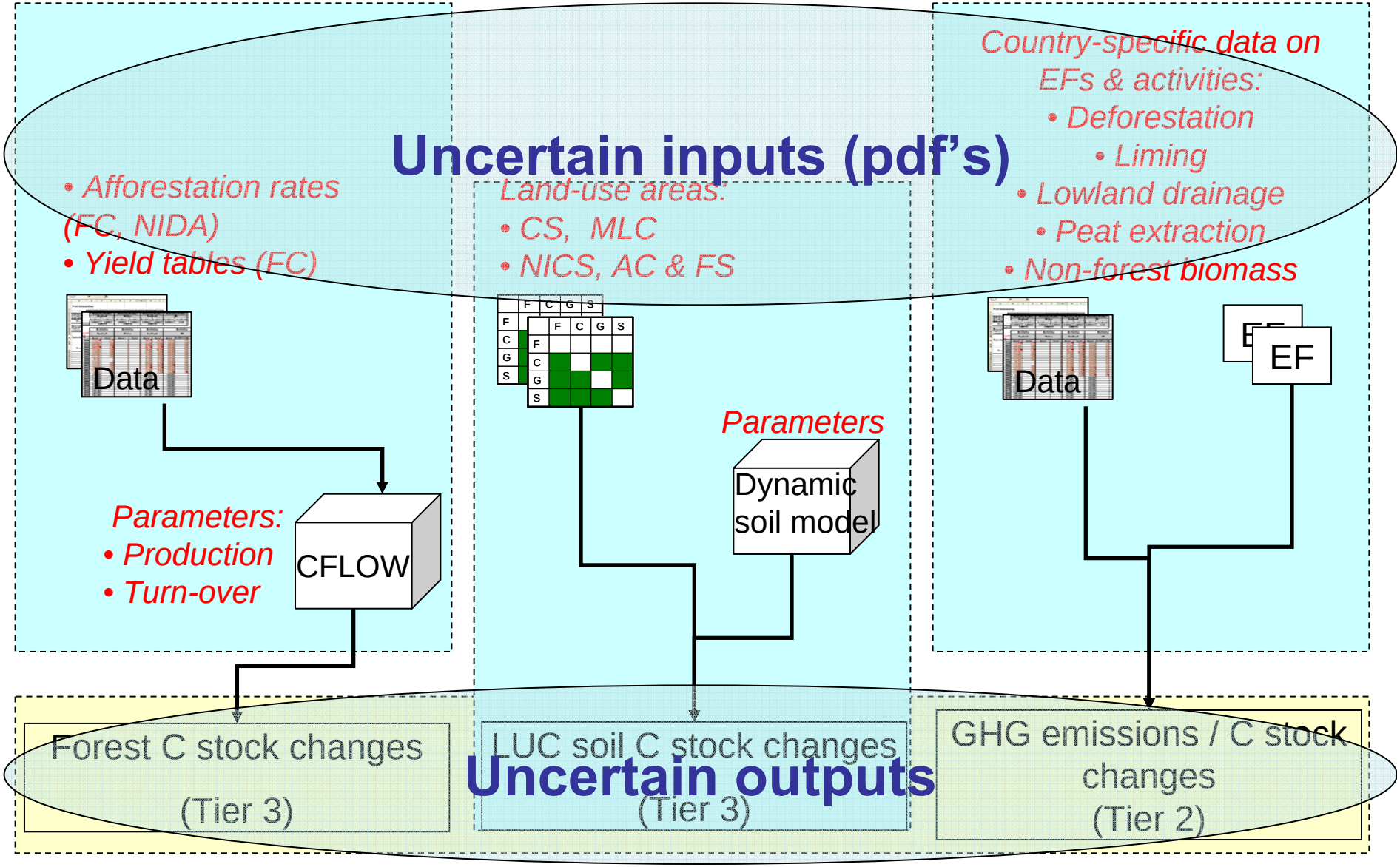
Primary information flows



Primary information flows



Uncertainty propagation

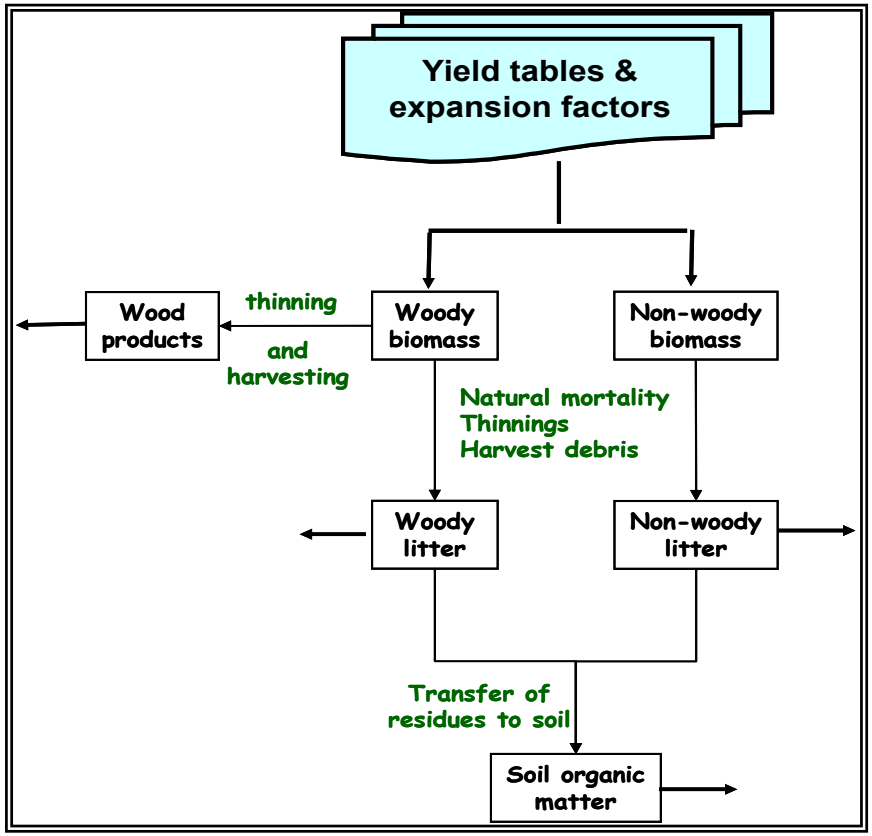


CFLOW

- *Afforestation rates (FC, NIDA)*
- *Yield tables (FC)*

Parameters:
- *Production*
- *Turn-over*

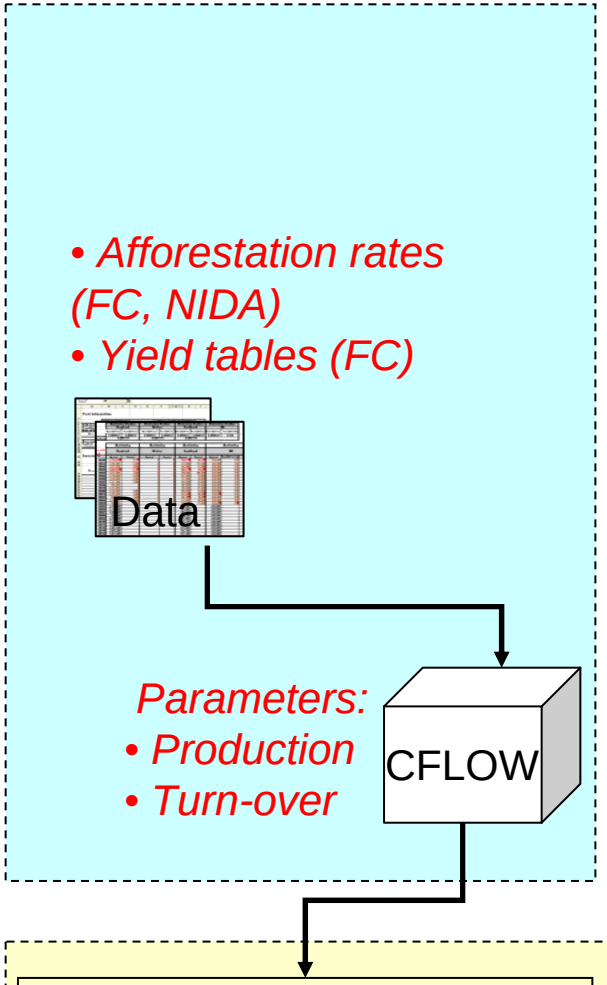
CFLOW



Forest C stock changes

(Tier 3)

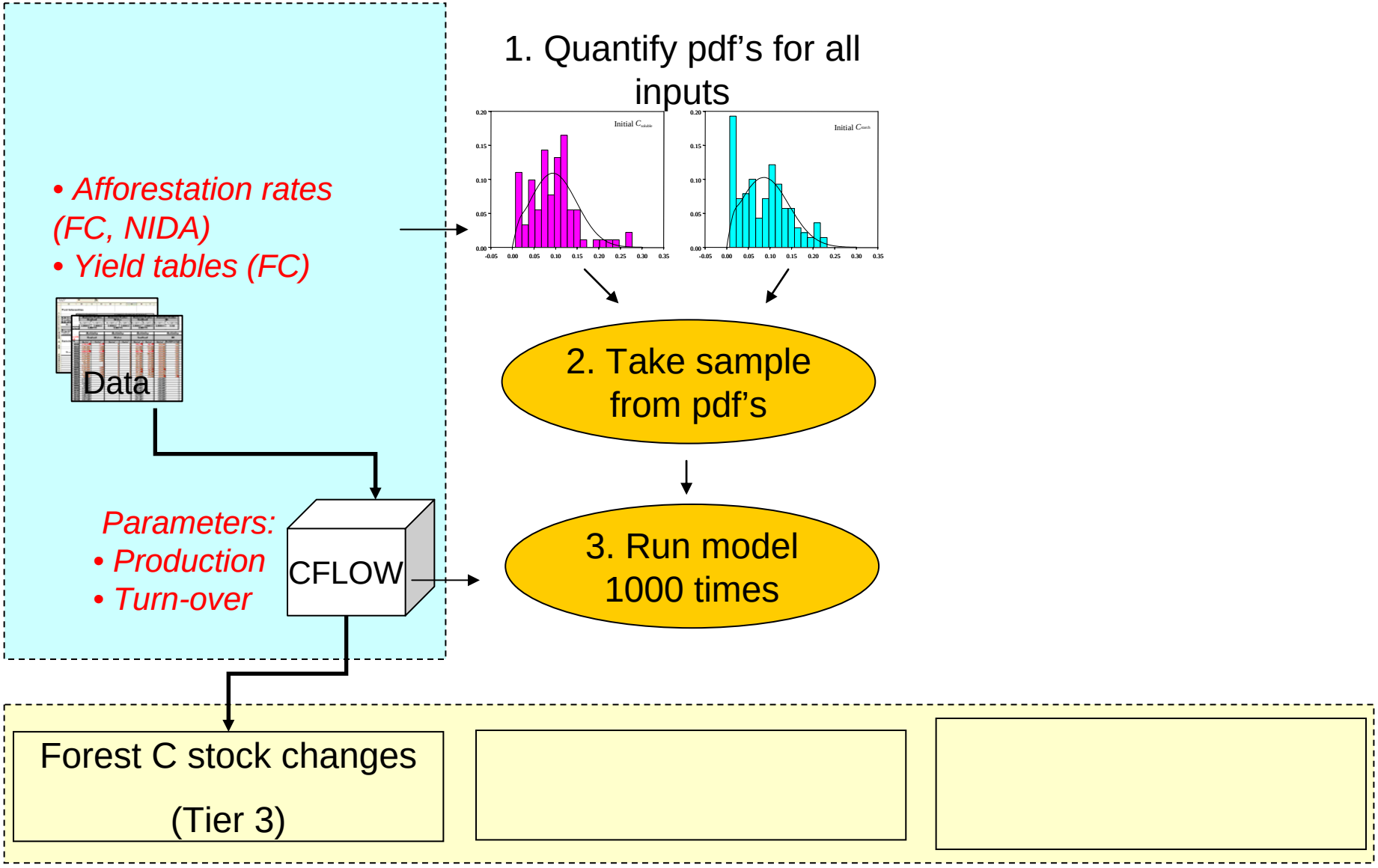
CFLOW



CFLOW forest model :

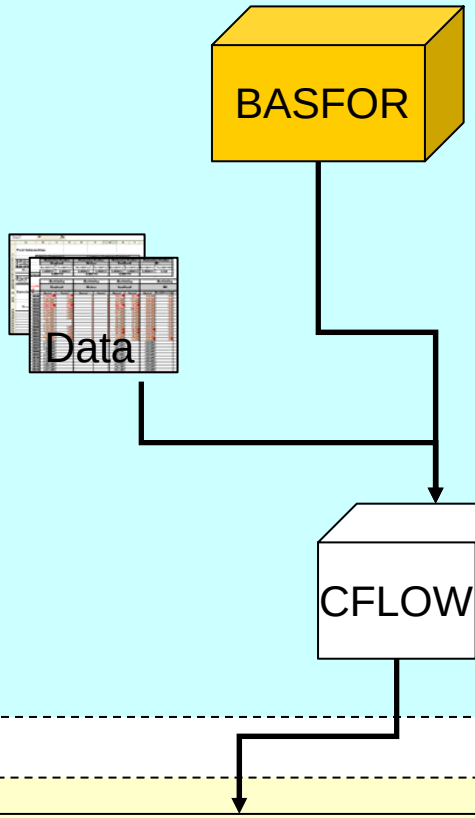
- Simple C-pools model with first order flows
- Robust
- Coarse (no effects climate & soil conditions)
- Uncertainty quantification …

CFLOW: Uncertainty quantification by MC



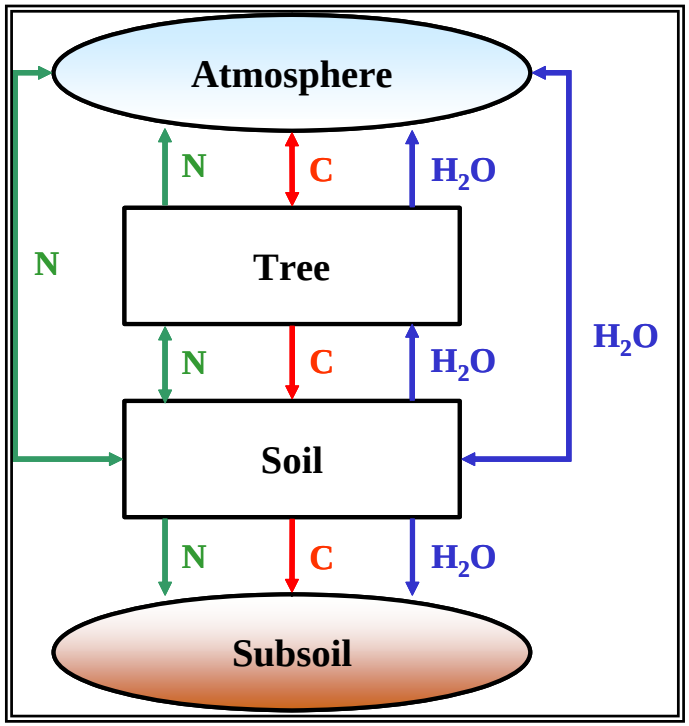
BASFOR: process-based forest model

- *Parameters (many!)*
- *Input variables (many!)*



BASFOR
inputs:

N-deposition
CO_2
Radiation
Temperature
Rain
Humidity
Wind speed



Forest C stock changes

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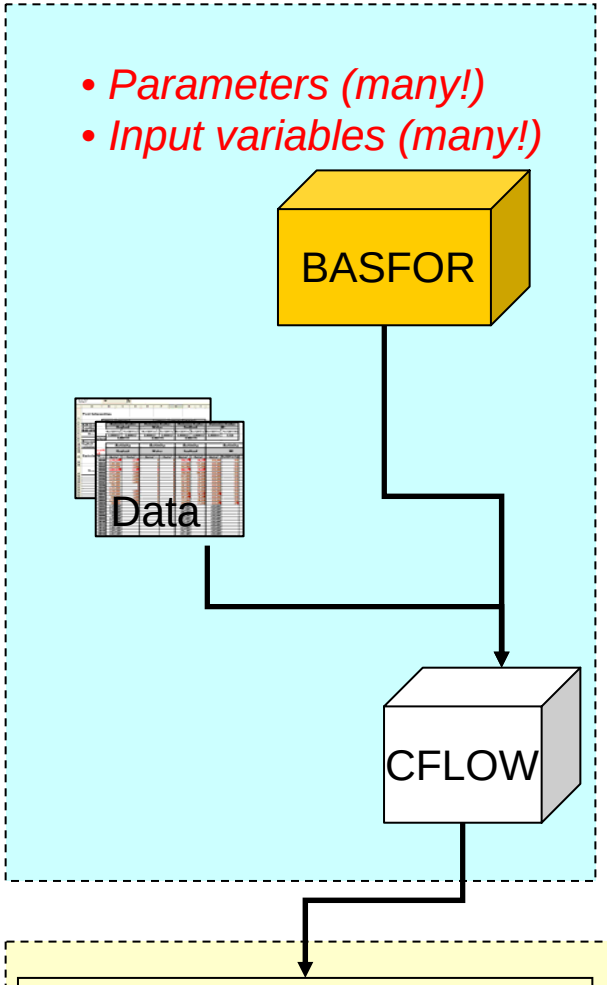
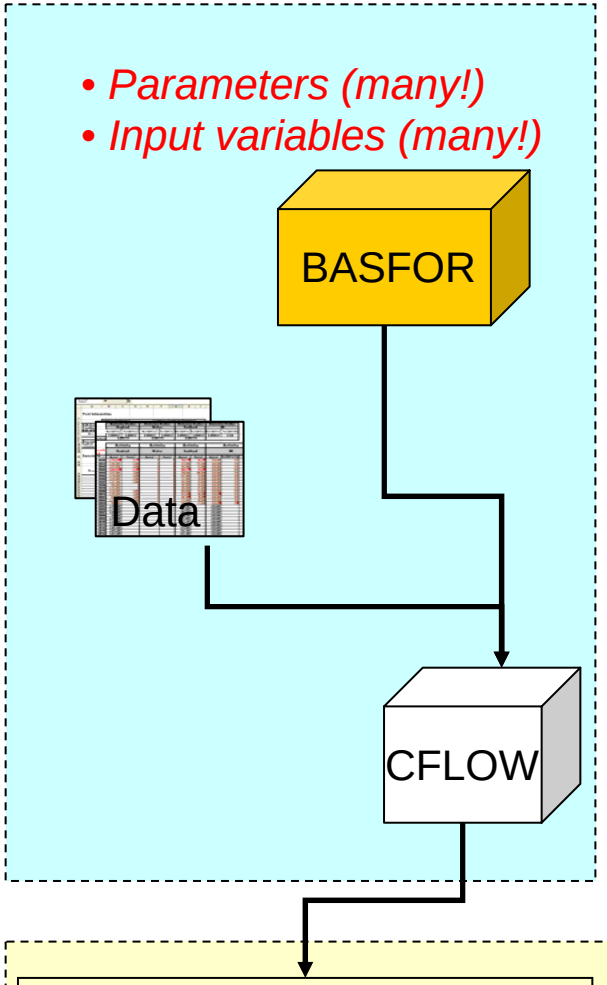


BASFOR forest model :

- Preprocessor for CFLOW (effects of climate, N-deposition, [CO2])
- … or replacement of CFLOW?
- But is BASFOR robust enough ?
- More inputs & parameters => more demanding uncertainty quantification

Process-based models



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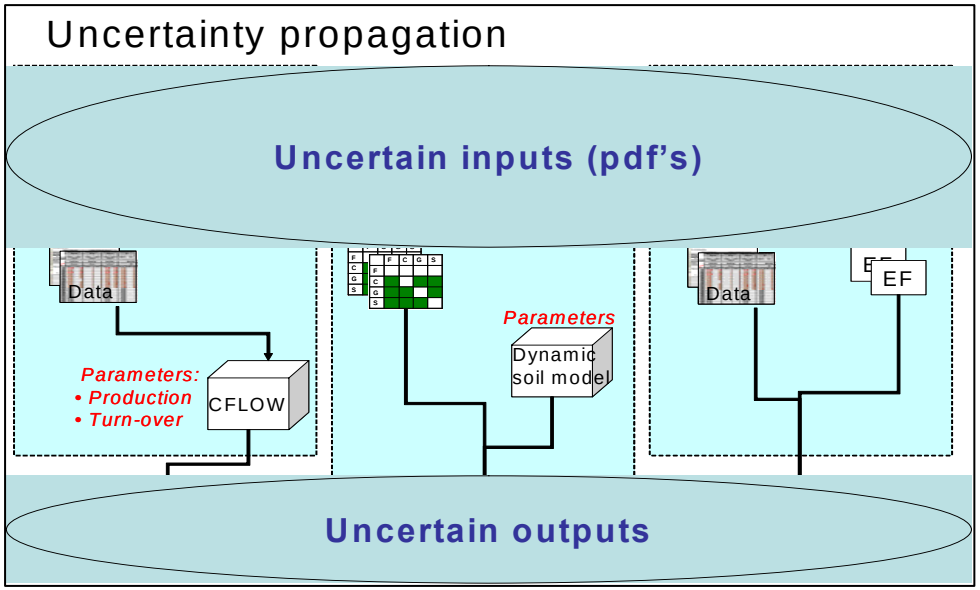
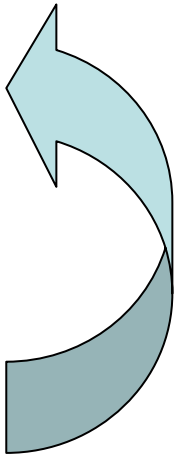
Bayesian calibration & uncertainty quantification

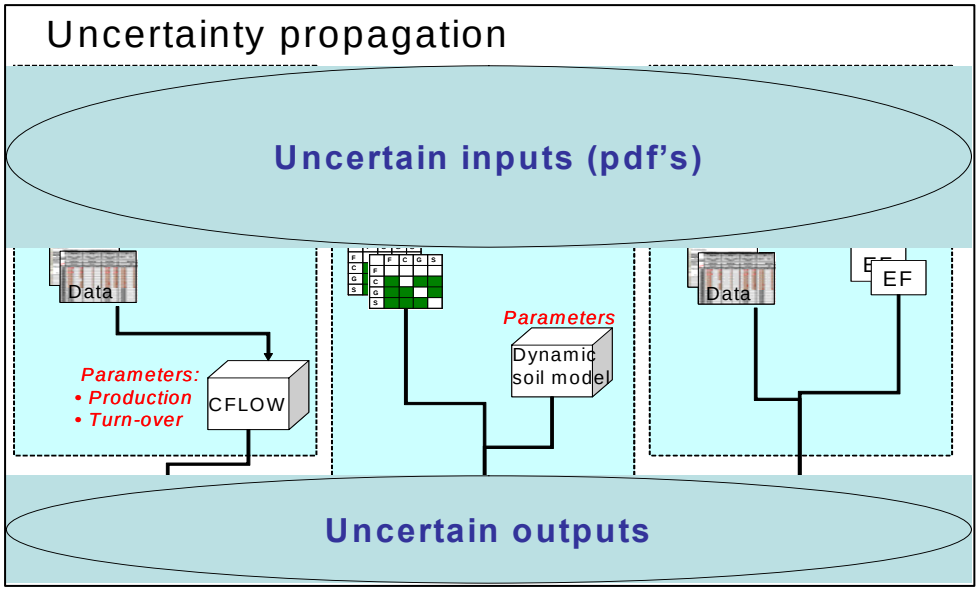
The Bayesian approach





Bayesian calibration

The Bayesian approach



Bayesian calibration

Prior pdf for the parameters

Likelihood of the data

$$P(\vartheta|D) = P(\vartheta)\, P(D|\vartheta) / P(D)$$

Posterior pdf for the parameters

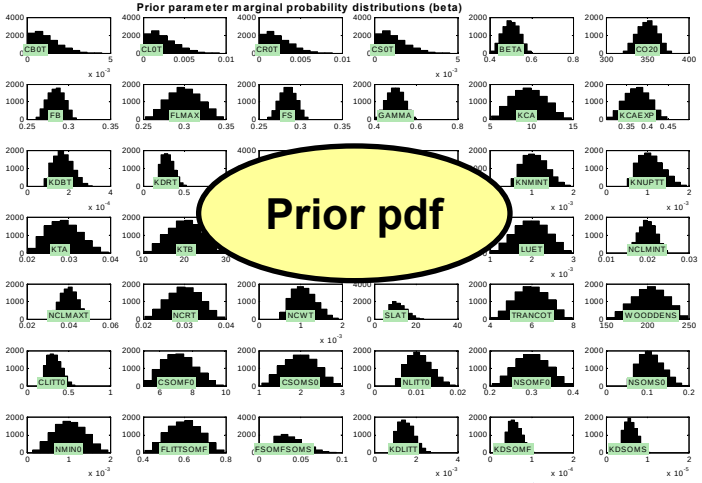
Scaling constant
(= $\int P(\vartheta)\, P(D|\vartheta)\, d\vartheta$)

The Bayesian approach

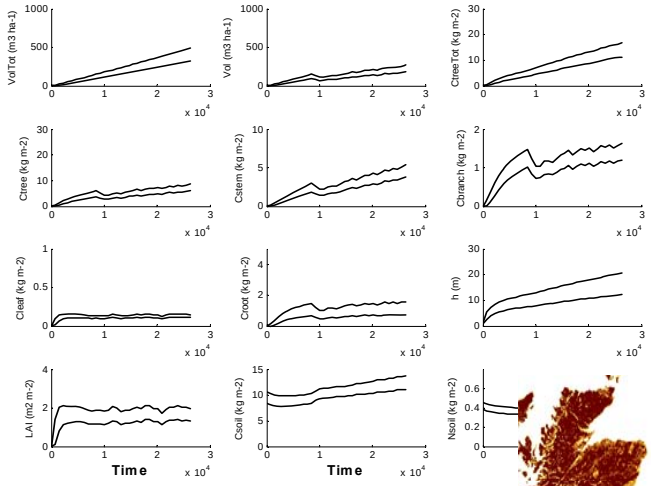
$$P(\vartheta|D) = P(\vartheta)\, P(D|\vartheta) / P(D)$$

Bayes' Theorem implemented using
MCMC (Metropolis algorithm)

Using data in Bayesian calibration of BASFOR

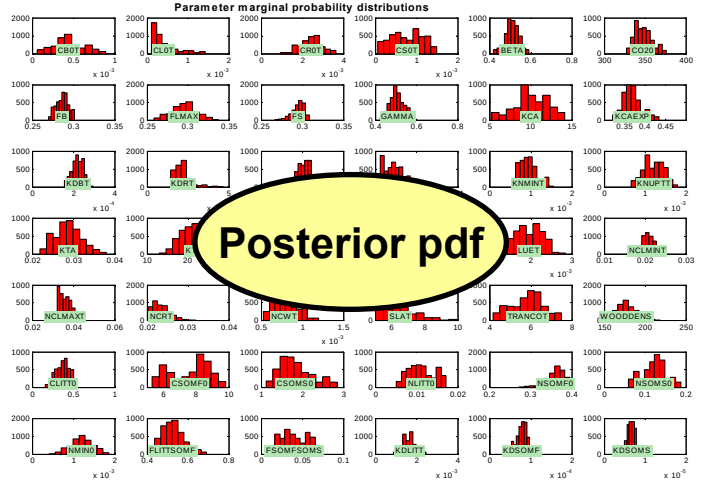


Prior pdf

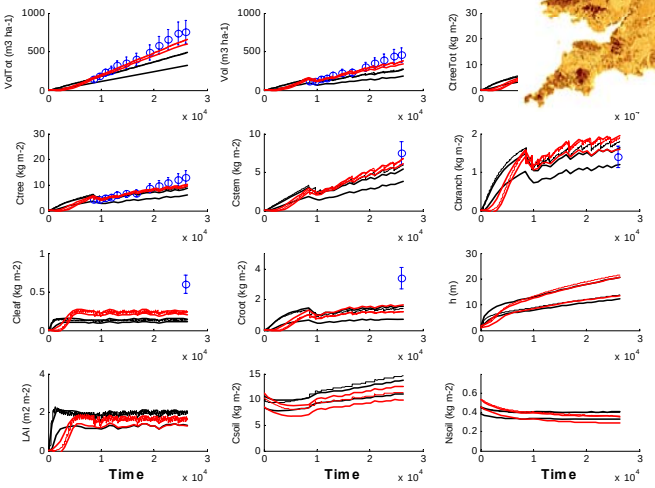


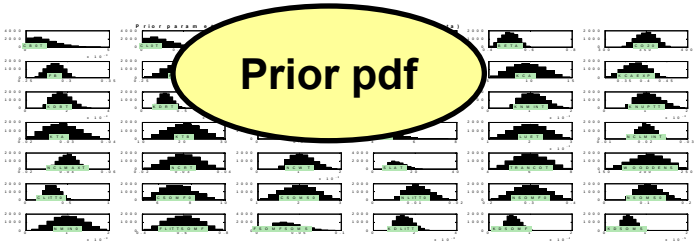
Bayesian calibration

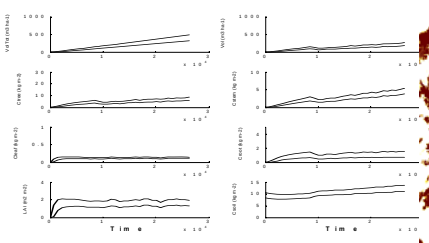
Data

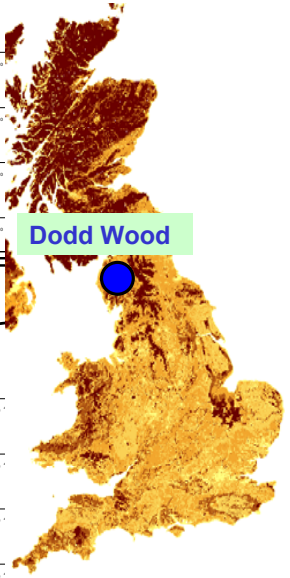


Posterior pdf



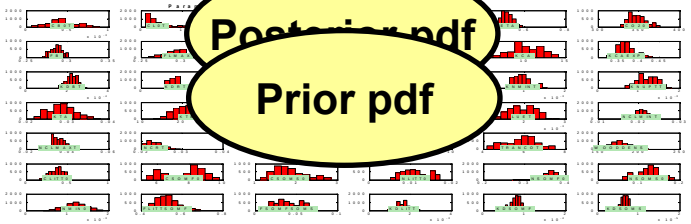


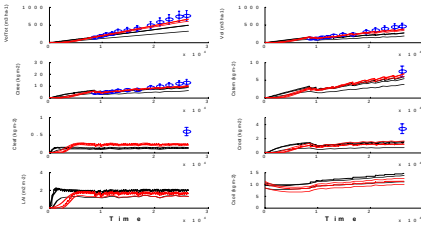




Bayesian calibration

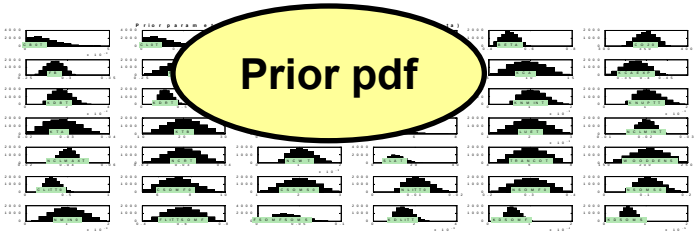
Data

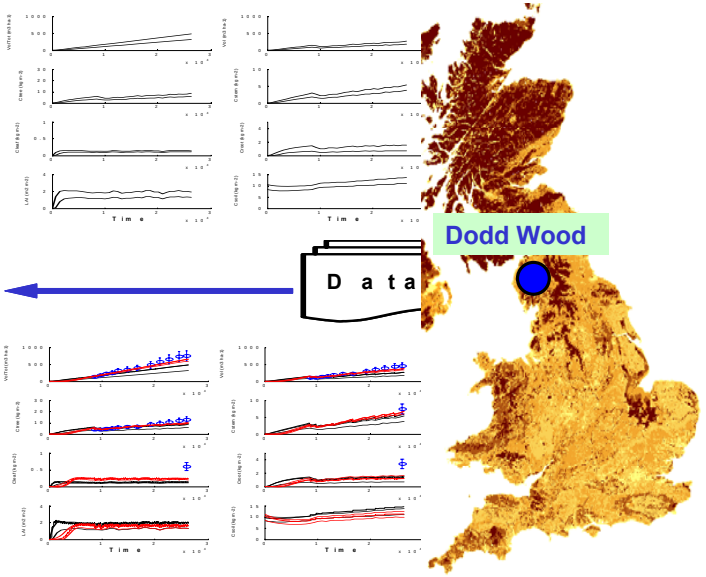




Bayesian calibration

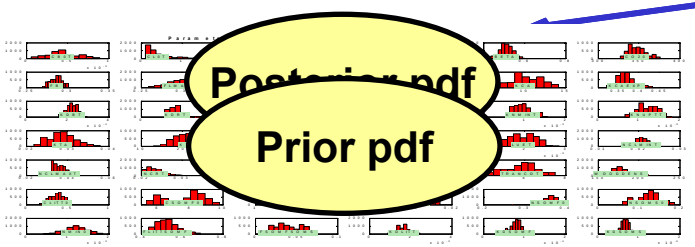
New data





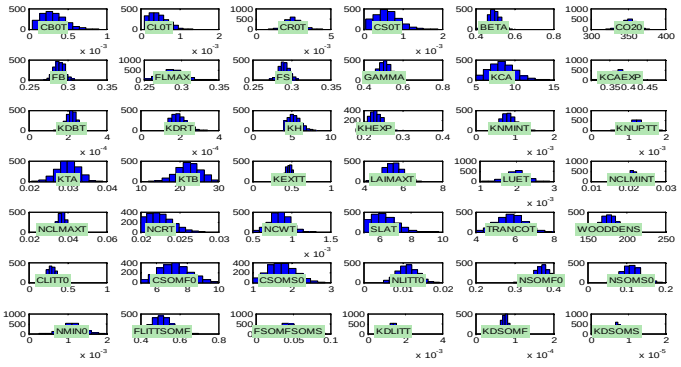
Bayesian calibration

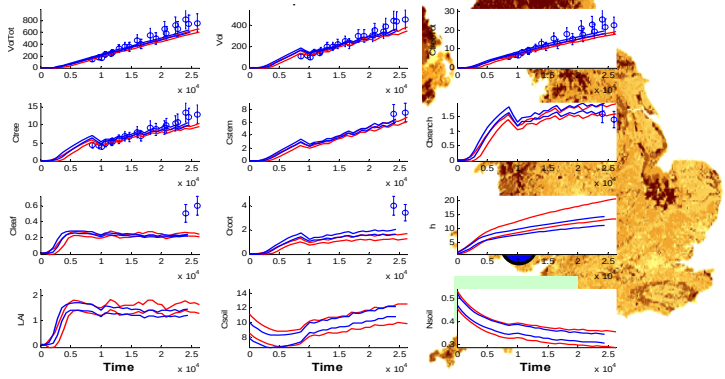
Data



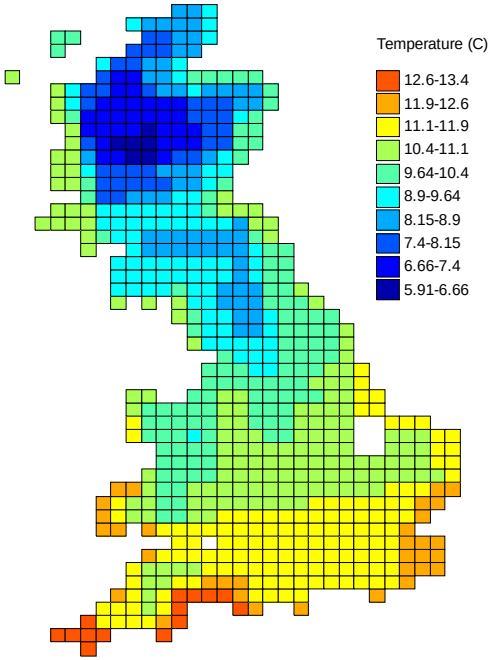
Bayesian calibration

New data

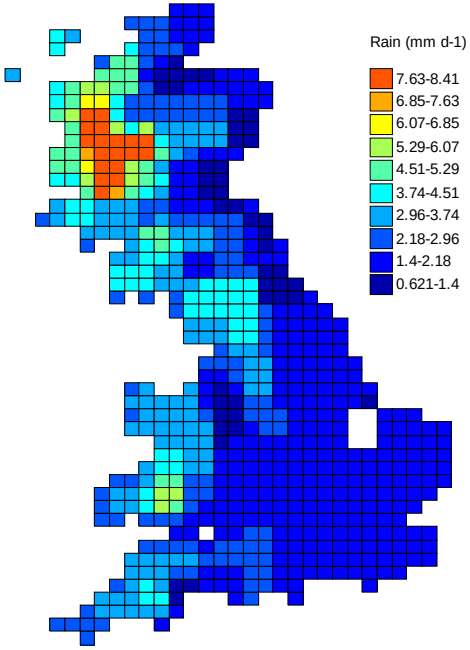




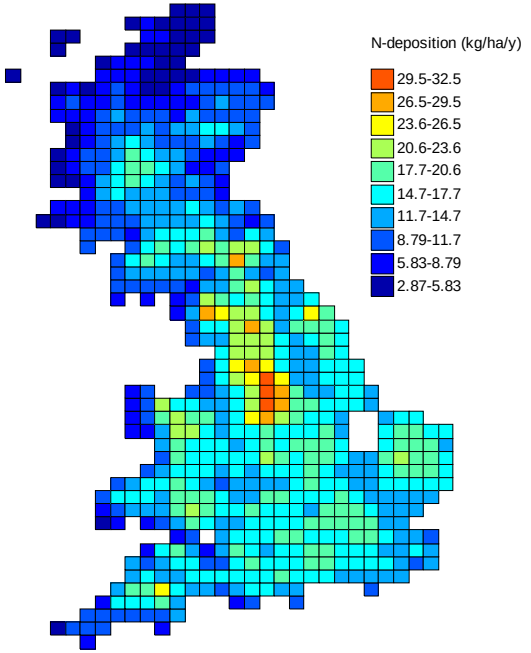
Input data: atmosphere (UKCIP & NEGTAP)



Mean temperature for 1920-2000. Data source: UKCIP

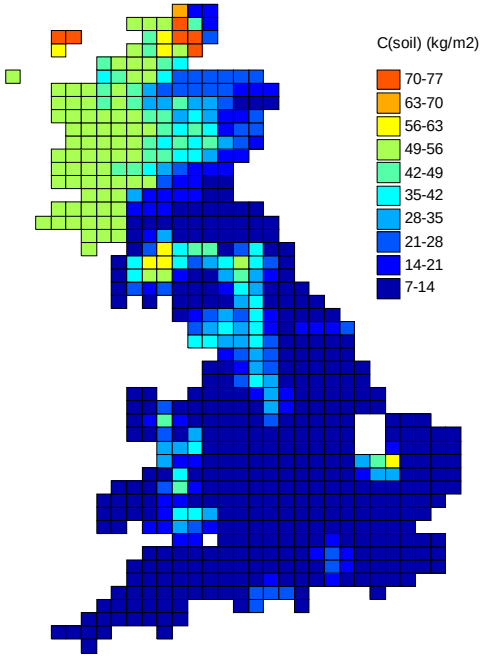


Mean precipitation for 1920-2000. Data source: UKCIP

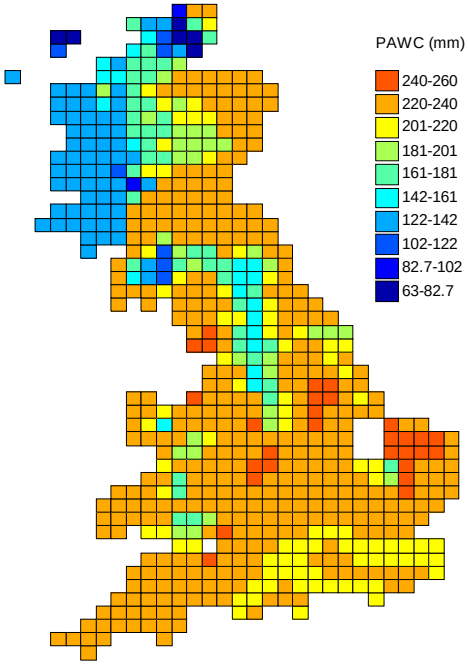


Atmospheric N-deposition in 2004. Data source: NEGTAP / R.I. Smith

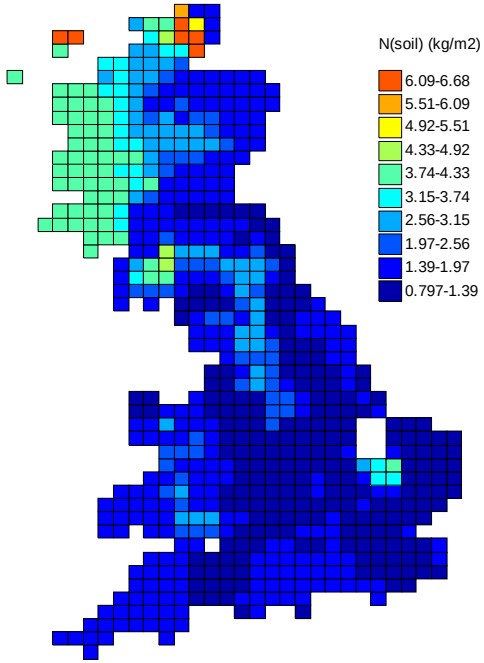
Input data: soil (IGBP-DIS)



Total carbon in top 100 cm soil. Data source: IGBP-DIS

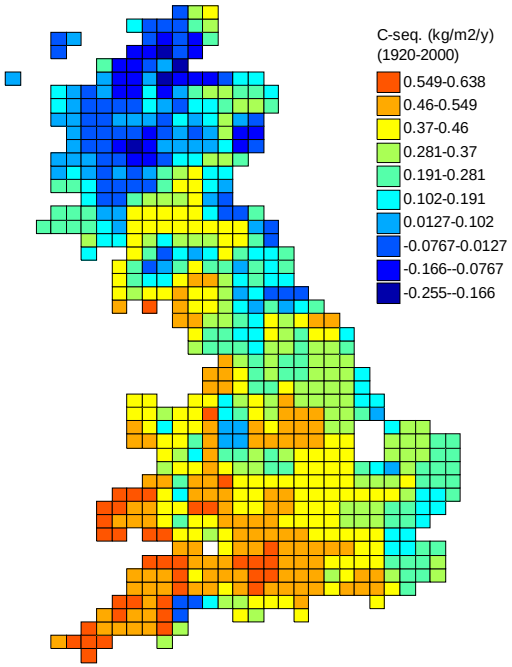


Maximum plant available water in top 100 cm soil. Data source: IGBP-DIS

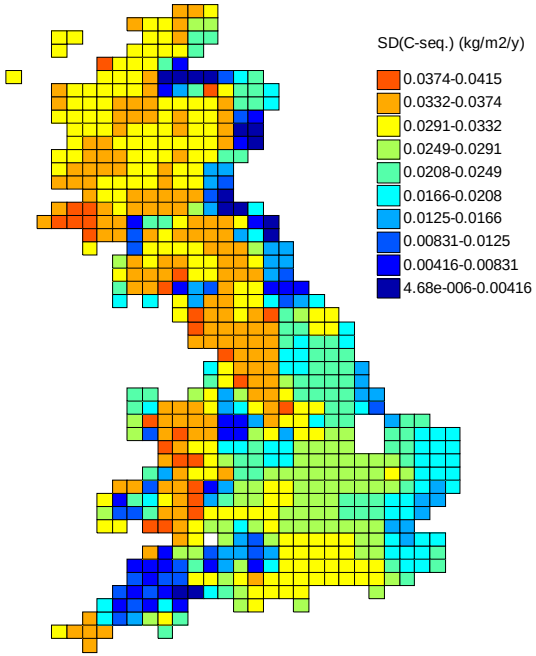


Total nitrogen in top 100 cm soil. Data source: IGBP-DIS

Model results, using env. input data & posterior parameter pdf's (Bayesian calibr.)

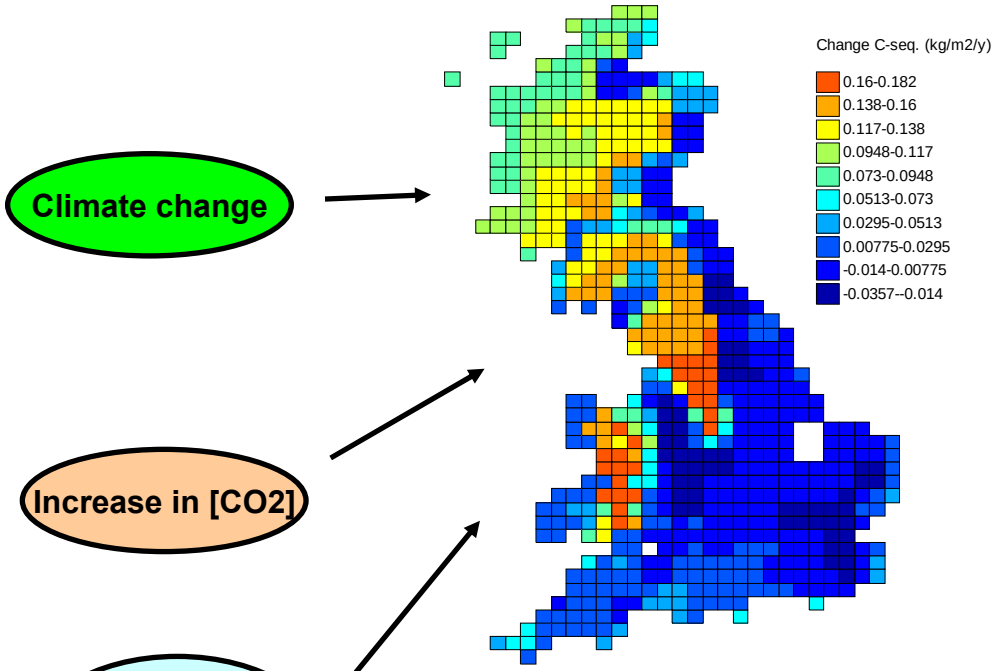


Simulated average annual C-sequestration (in soil, living trees and wood products) for 1920-2000. Results from model BASFOR



Uncertainty (standard deviation) in simulated average annual C-sequestration (in soil, living trees and wood products) for 1920-2000. Results from model BASFOR

Effect of env. change on C-sequestration



Simulated change in average annual C-sequestration (in soil, living trees and wood products) from 1920-2000 to 2000-2080. Results from model BASFOR

Environmental factor analysis

(Dodd Wood)

		Impact of environmental change		
Ecosystem variable	Dodd Wood value	Effect of temperature (per °C)	Effect of [CO_2] (per 100 ppm)	Effect of N-deposition (per 10 kg N ha^{-1} y^{-1})
Yield class (m^3 ha^{-1} y^{-1})	7.91 ± 1.11	0.18 ± 0.05	1.32 ± 0.38	0.74 ± 0.26
C-sequestration (t C ha^{-1} y^{-1})	3.99 ± 0.64	0.10 ± 0.03	0.76 ± 0.21	0.41 ± 0.14
C-sequestration, soil (t C ha^{-1} y^{-1})	1.58 ± 0.31	0.05 ± 0.01	0.36 ± 0.10	0.18 ± 0.07
C-sequestration, trees and products (t C ha^{-1} y^{-1})	2.41 ± 0.34	0.05 ± 0.02	0.40 ± 0.12	0.23 ± 0.07

Conclusions from factor analysis:

- **Uncertainties (standard deviations) of factor effects: 20-40%**

`But …:

- **Actual uncertainty is larger, as only parameter uncertainty was quantified (not uncertainty about inputs or model structure)**
- **Sensitivities are nonlinear, so site-specific, and thus need to be calculated UK-wide**

Possible use of yield class modifiers with uncertainties (Bayesian): input to CFLOW

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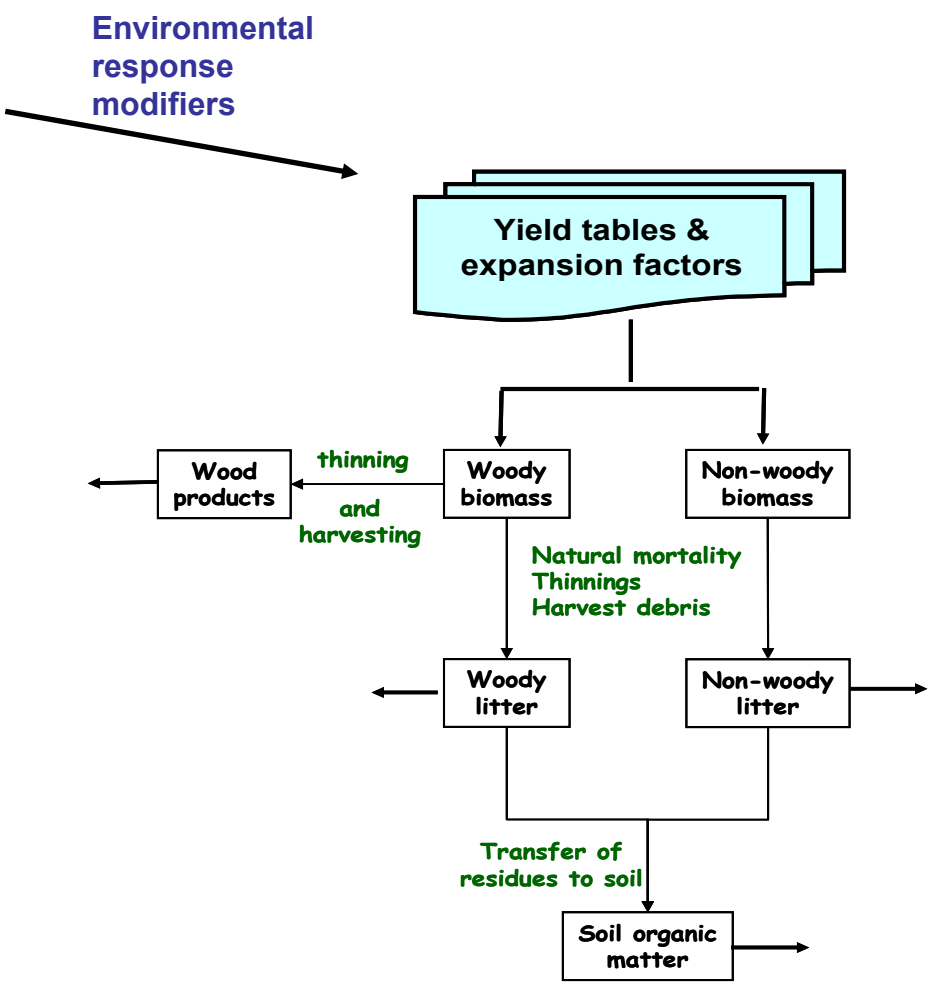

Conclusions

1. Method of sequential data assimilation & uncertainty quantification by Bayesian calibration works well
2. Tree data for calibration and environmental data of model drivers still limited. Key issue: soil nitrogen
3. Environmental factor analysis for Dodd Wood showed importance of elevated CO_2, but …
   - needs to be repeated after better tree & soil information has become available for further Bayesian calibration
   - needs to be repeated UK-wide because the same change in an environmental factor has different effects on different sites
4. Because of the above, methodology not yet ripe for the official inventory

Outlook

Bayesian methods used in other European collaborations:

- **NitroEurope**: European Union IP aimed at quantifying nitrogenous GHG budget for Europe
  - Protocol for Uncertainty Quantification & Uncertainty Analysis
  - At least 2 models for each vegetation type (4 for forests)
  - Bayesian methods also used to assess structural uncertainty ("how plausible are the different models?"
- **CarboEurope**: (just starting, for crop models)
- **Forest Focus** (forests & env. change)
- **WINSUR** (grasslands & env. change)