Quantifying and Understanding the Earth System

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Toward Detection and Attribution of the Climate–Carbon Cycle Feedback

W. Knorr, P. Friedlingstein

QUEST-AIMES Conference

Edinburgh, 10-13 May 2010

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Questions

- Airborne CO_2 Fraction - the metric we need?
- Explanation for a near constant Airborne Fraction?
- When do we expect to detect a change?
- Uncertainties in land use emissions
- Uptake Efficiency (UE) – an alternative?
- The way forward…

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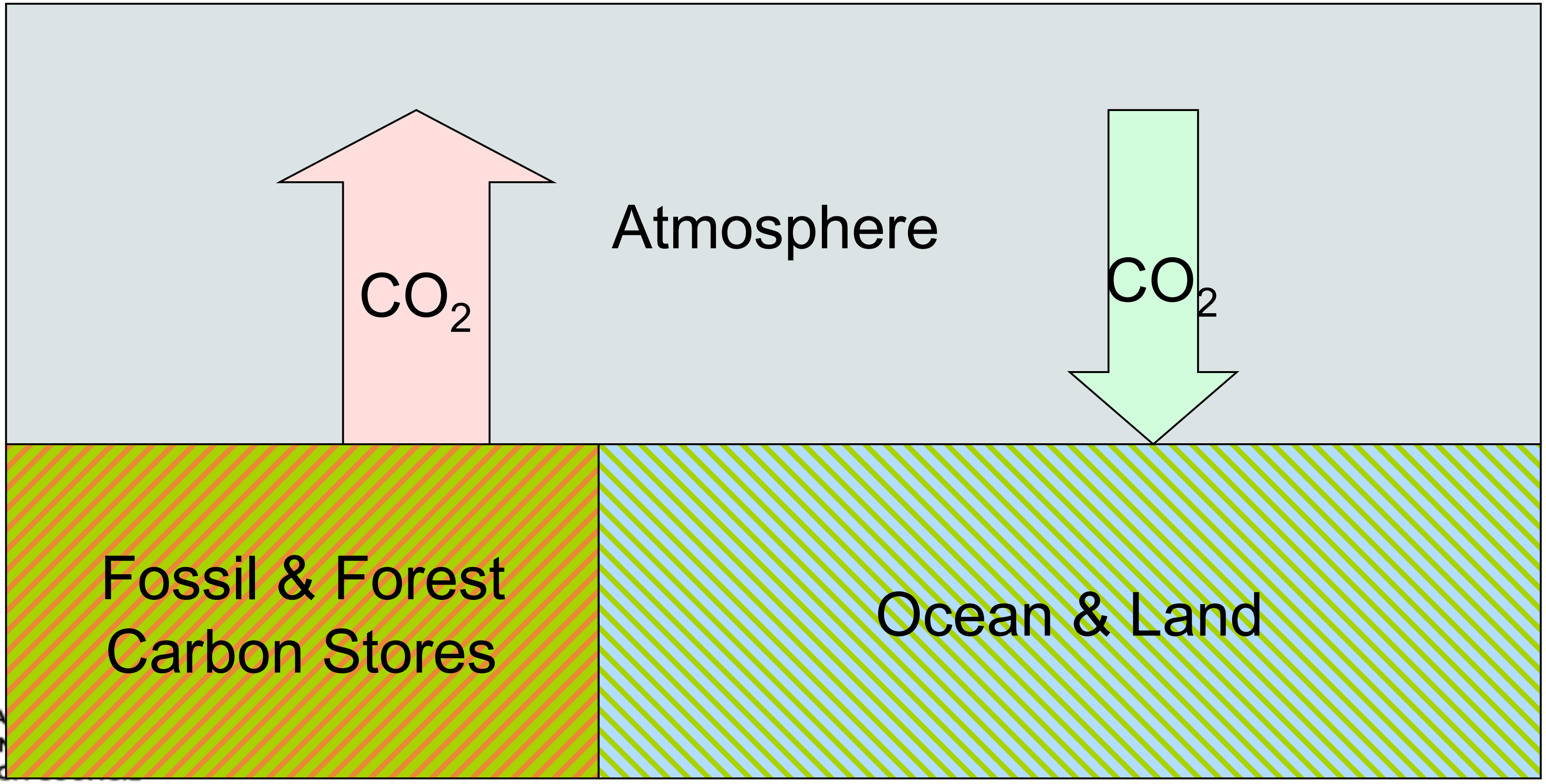
Definition of AF

- Airborne Fraction = (Flux in - Flux out) / Flux in
  = dC_A/dt / F (atm. CO_2 increase divided by emissions)



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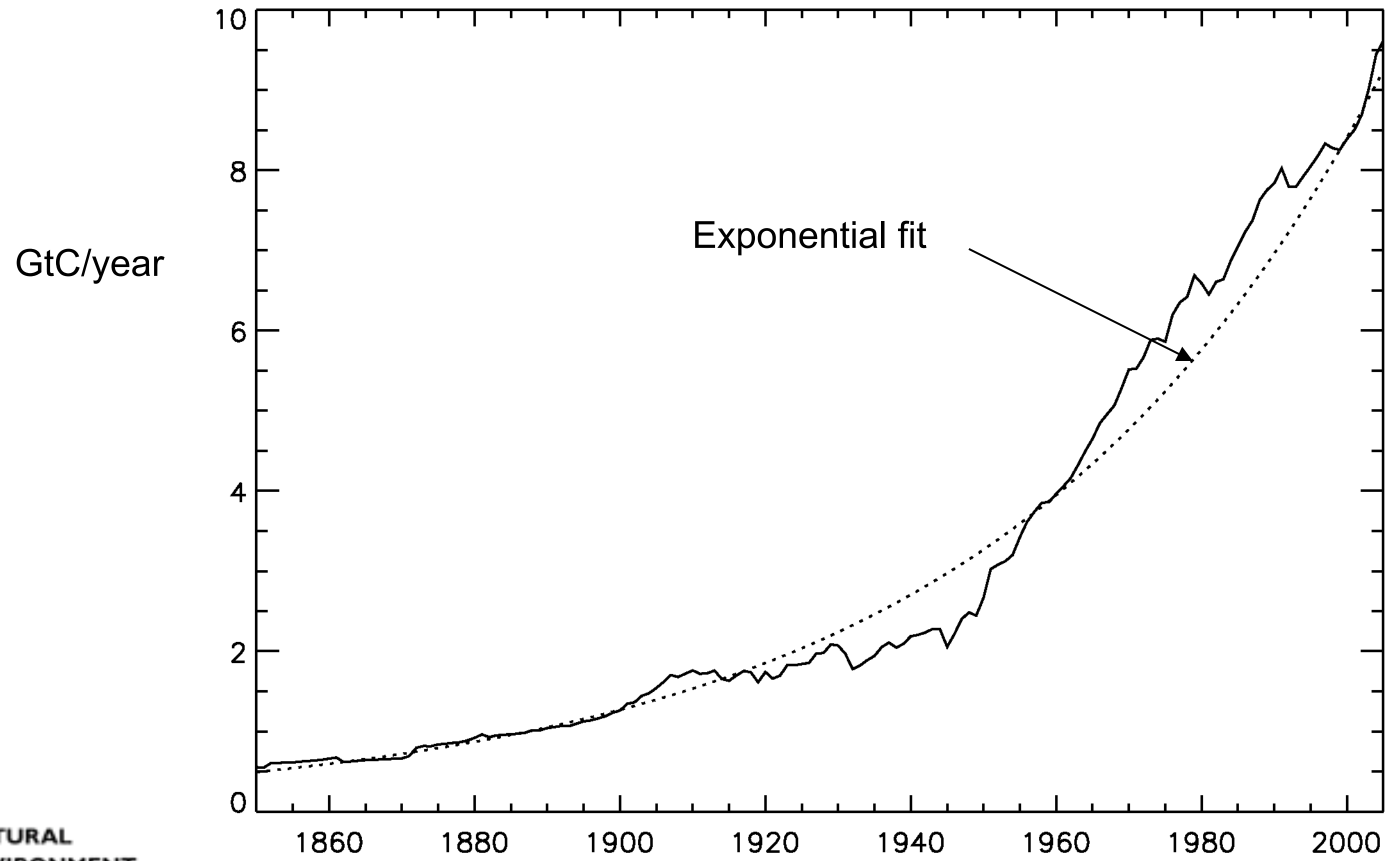
Total Emissions



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[Emissions: Marland et al., Houghton]

Linear Carbon Cycle

Vector of pool sizes *away from equilibr.*

$$\frac{d}{dt}\mathbf{C} + \mathbf{AC} = 0$$

δ-peak input into Pool C_1

Green's Function:

$$\mathbf{G}(t) = \sum_{i=1}^{n} \mathbf{E}_i e^{-k_i t}$$

Eigenvalue of **A**

Eigenvector of **A** with $\sum_{i=1}^{n} \mathbf{E}_i = \{1,0,...,0\}$

Assume a flux of $F(t)=F_0\ exp(kt)$ into pool C_1

Airborne Fraction: $\dfrac{\frac{d}{dt}C_1(t)}{F(t)} = \sum_{i=1}^{n} \dfrac{[E_i]_1}{1+k_i/k} = \text{const.}$

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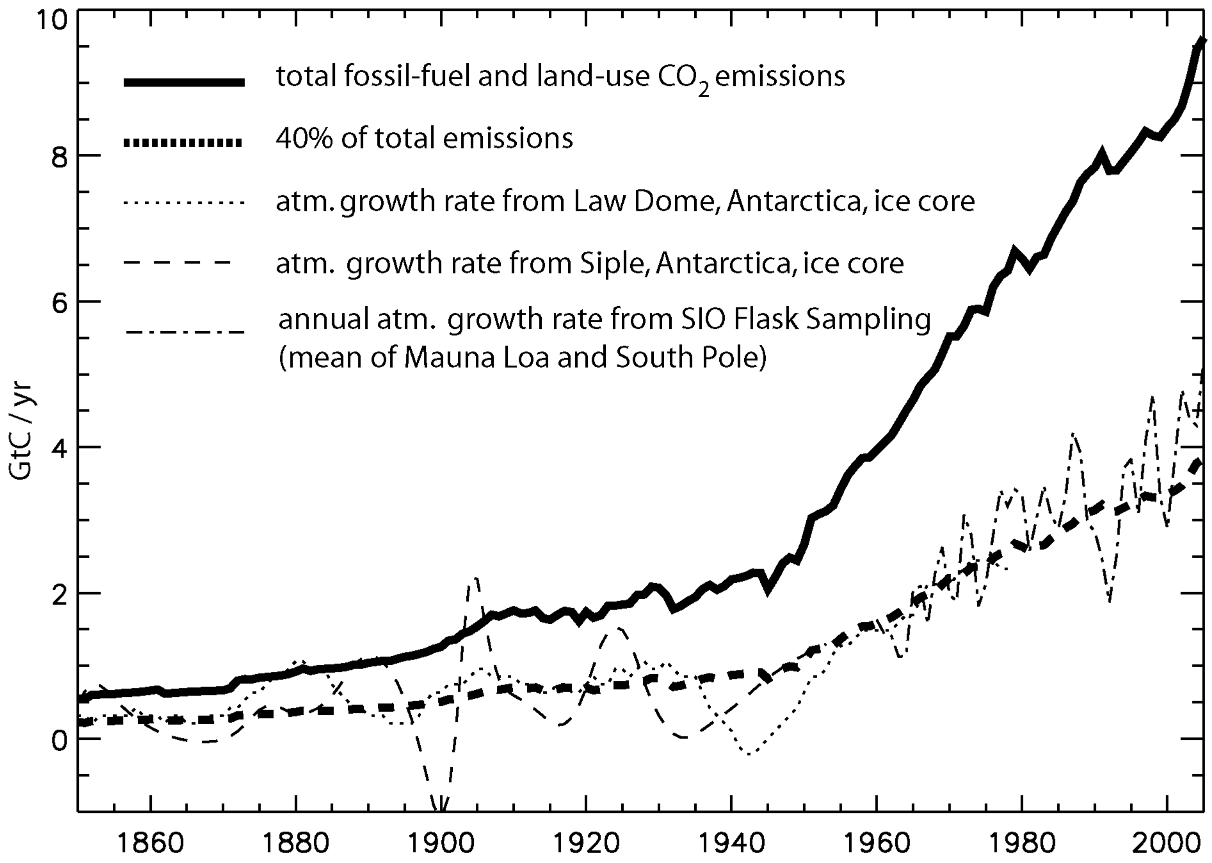
Observations



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[Emissions: Marland et al., Houghton]

Understanding the AF

What would happen if emissions stopped?

- $F \rightarrow 0$
- Land/ocean sinks would continue (depend on atm. CO_2 rather than emissions)
- Atm. CO_2 would decrease ($dC_A/dt<0$)
- $AF \rightarrow -\infty$

$AF = [dC_A/dt] / F$

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Uptake Efficiency

What would happen if emissions stopped?

- UE := (F - dC_A/dt) / (C_A - 280ppm)
- $F \rightarrow 0$ but dC_A/dt would be reduced by F approximately
- no immediate change in UE because it reacts to concentrations, not emissions
- UE $\rightarrow$ 0 eventually

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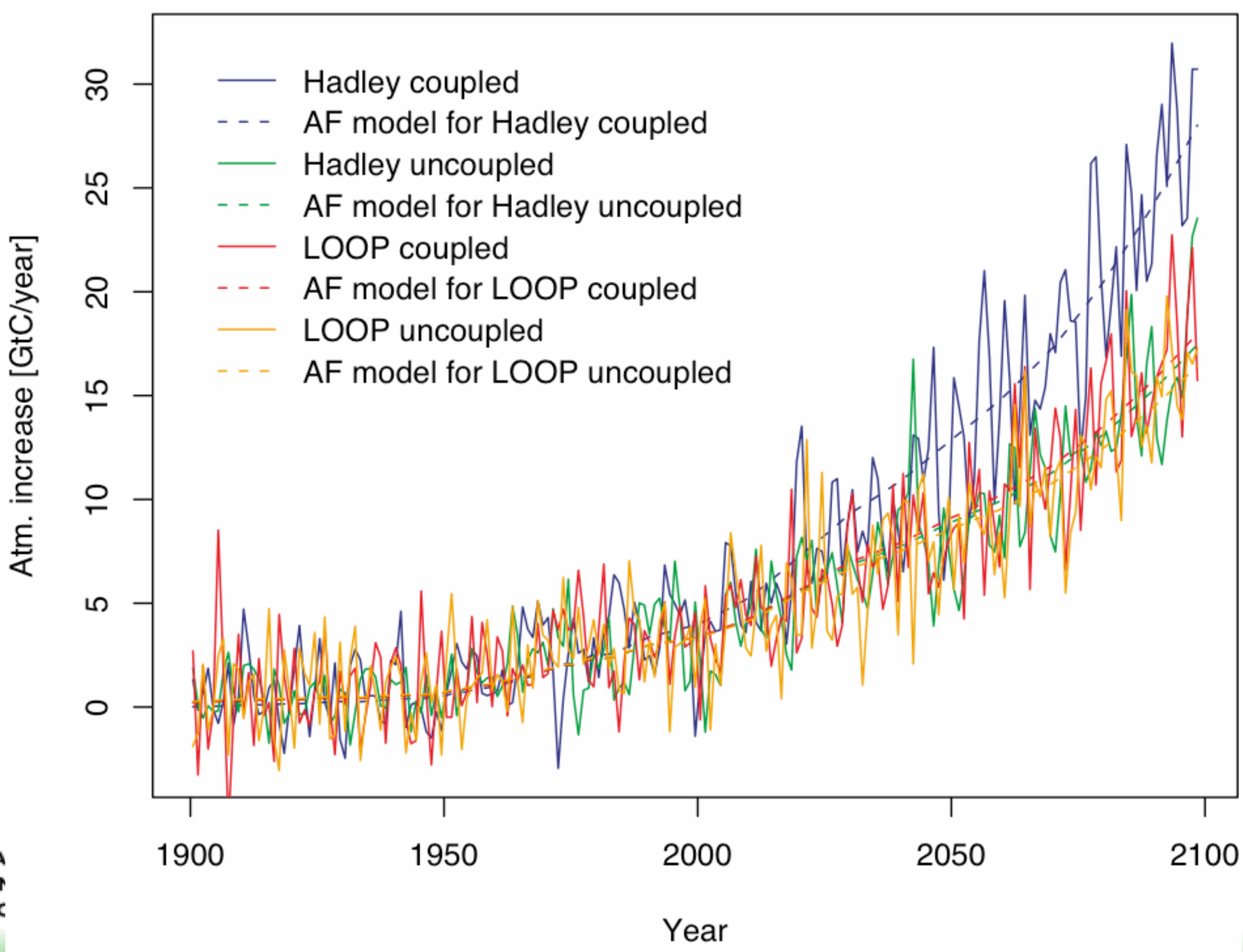
Detection of Change

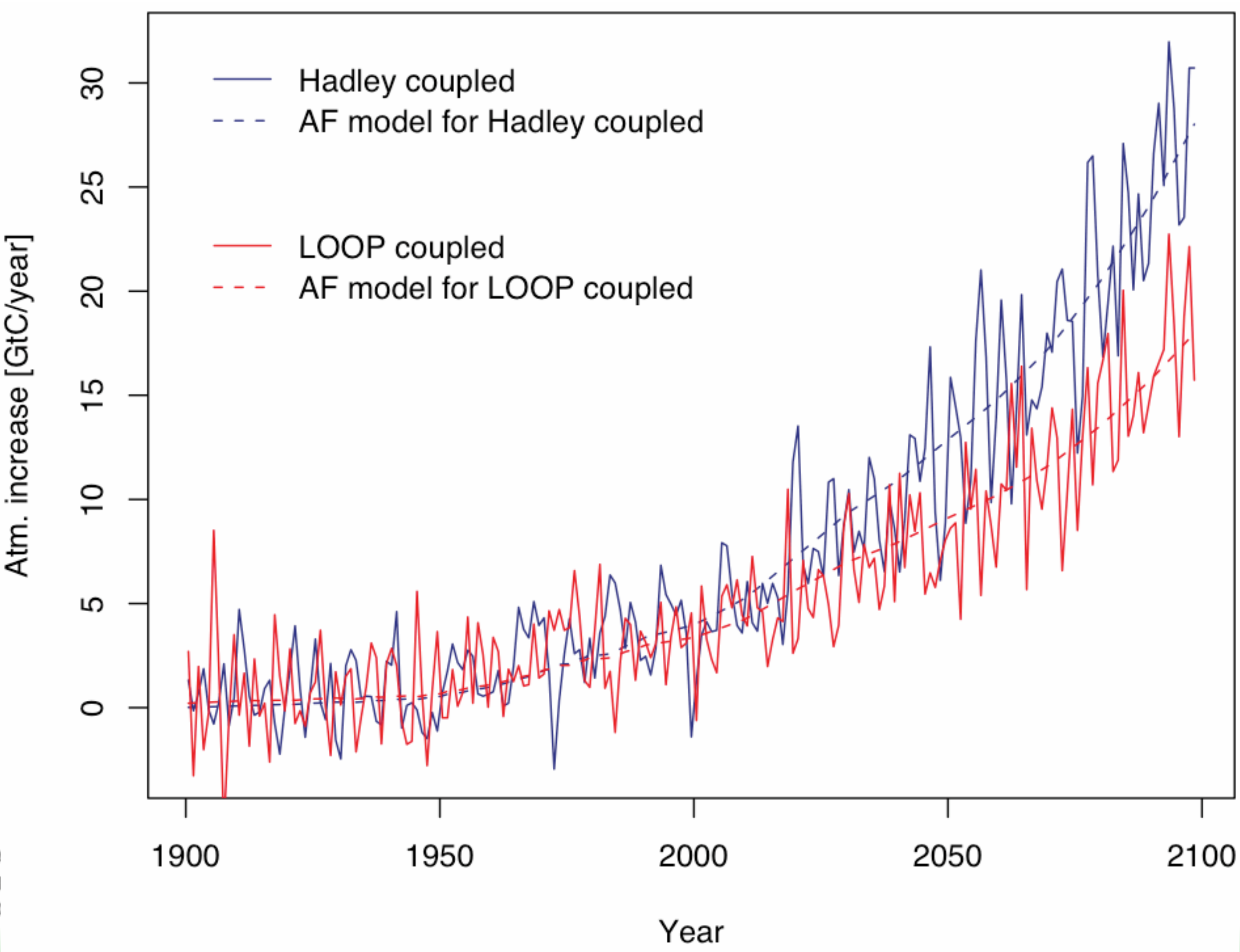
- Take Coupled Climate-Carbon Cycle Model Intercomparison Project simulations (C4MIP)
- 2 extreme cases: HadCM3 & IPSL-LOOP models
- Fit statistical model: $\mathrm{d}C_A/\mathrm{d}t=(\mathrm{AF}_0+\mathrm{AF}_s\, t)F$
- Observed and SRES A2 emissions with 60% systematic uncertainty in land use flux
- Simulated annual C_A with 0.5 ppm uncertainty (as with observations)
- Trend analysis starting 1900 to 1901, 1902, …, 2100
- Take 2σ of AF_s (the trend in AF) as ~95% confidence limit

[Methodology of Knorr GRL 2009]

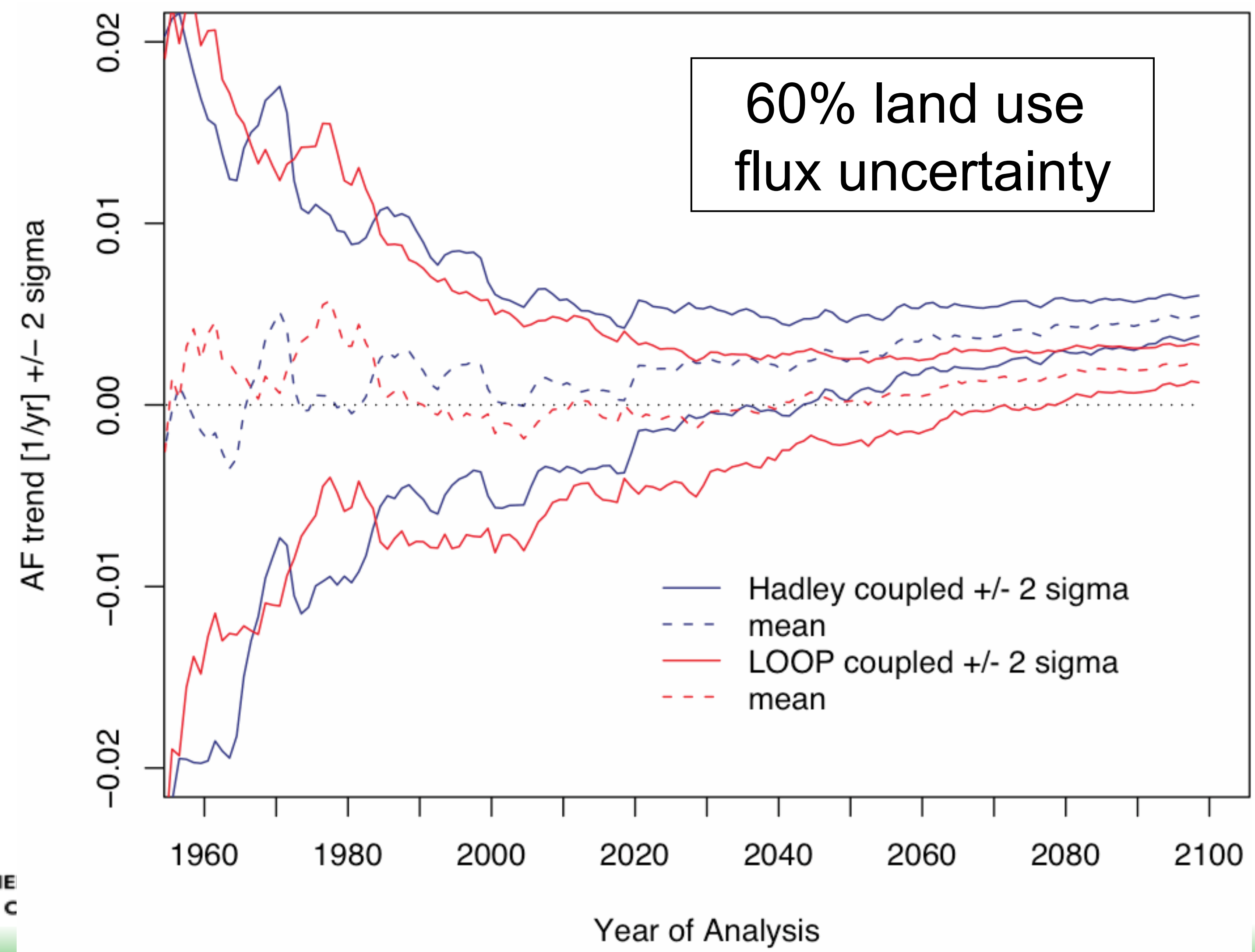
Fit of Linear AF Model



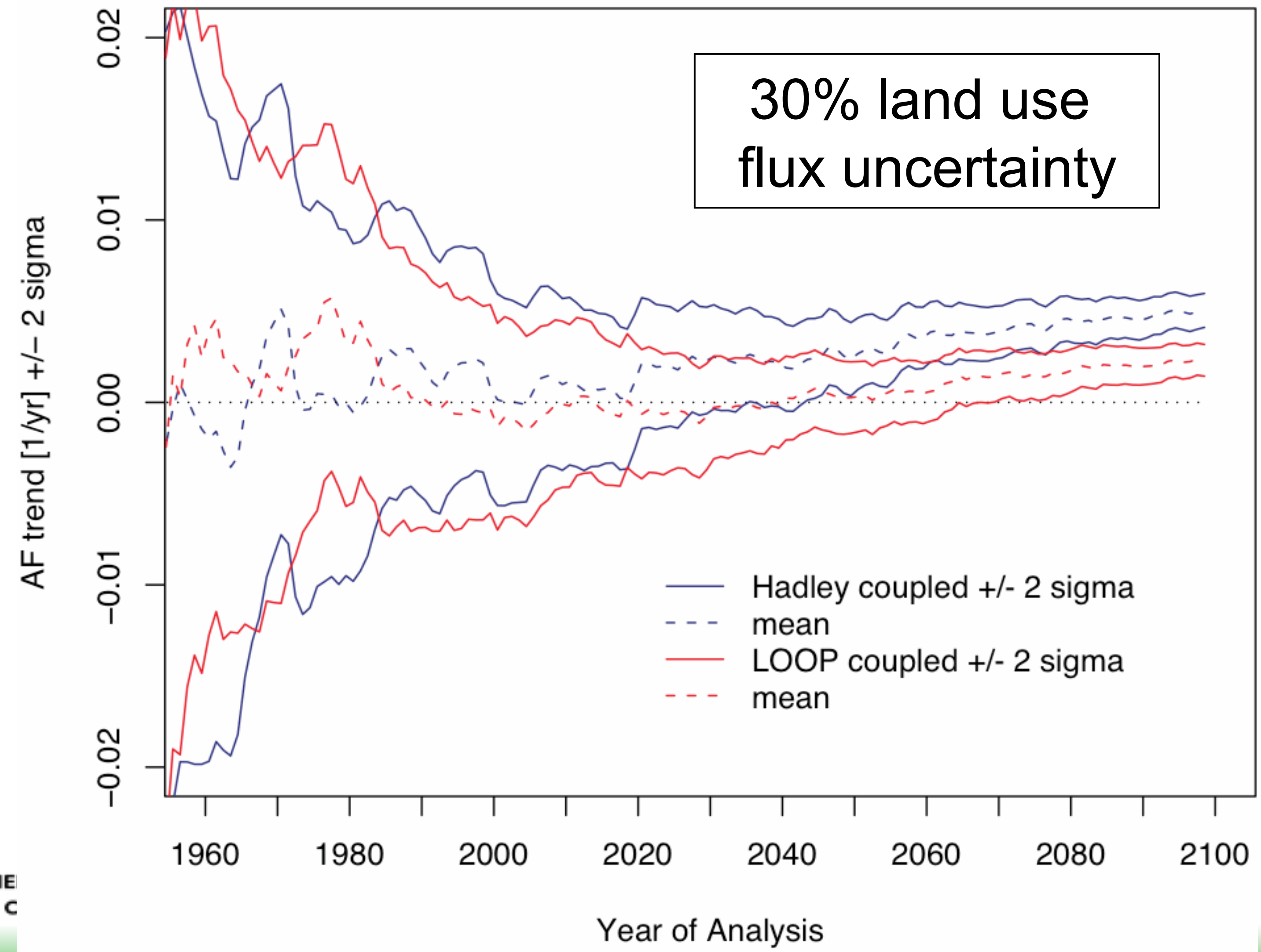
Fit of Linear AF Model



Trend Detection



Trend Detection



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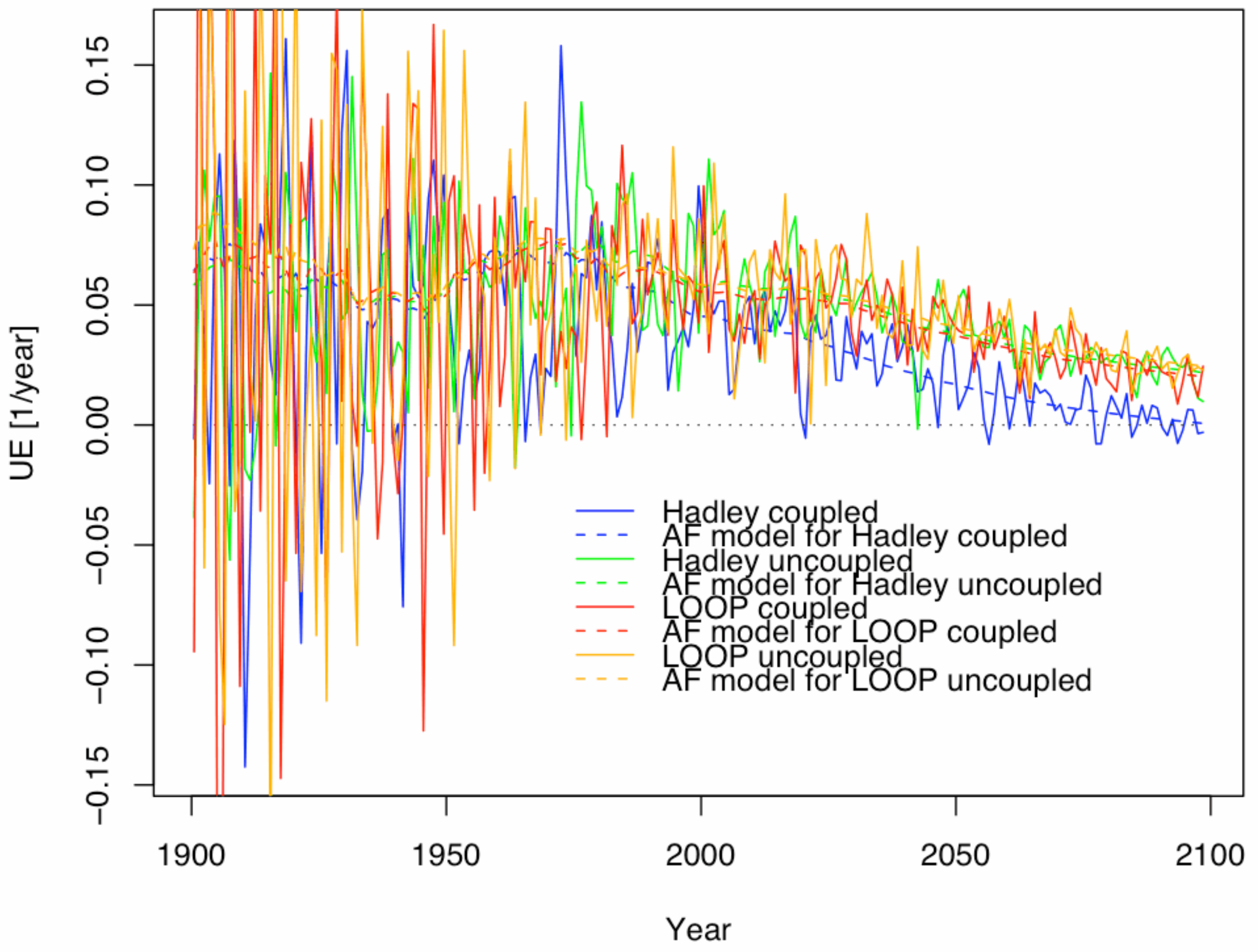
Uptake Efficiency



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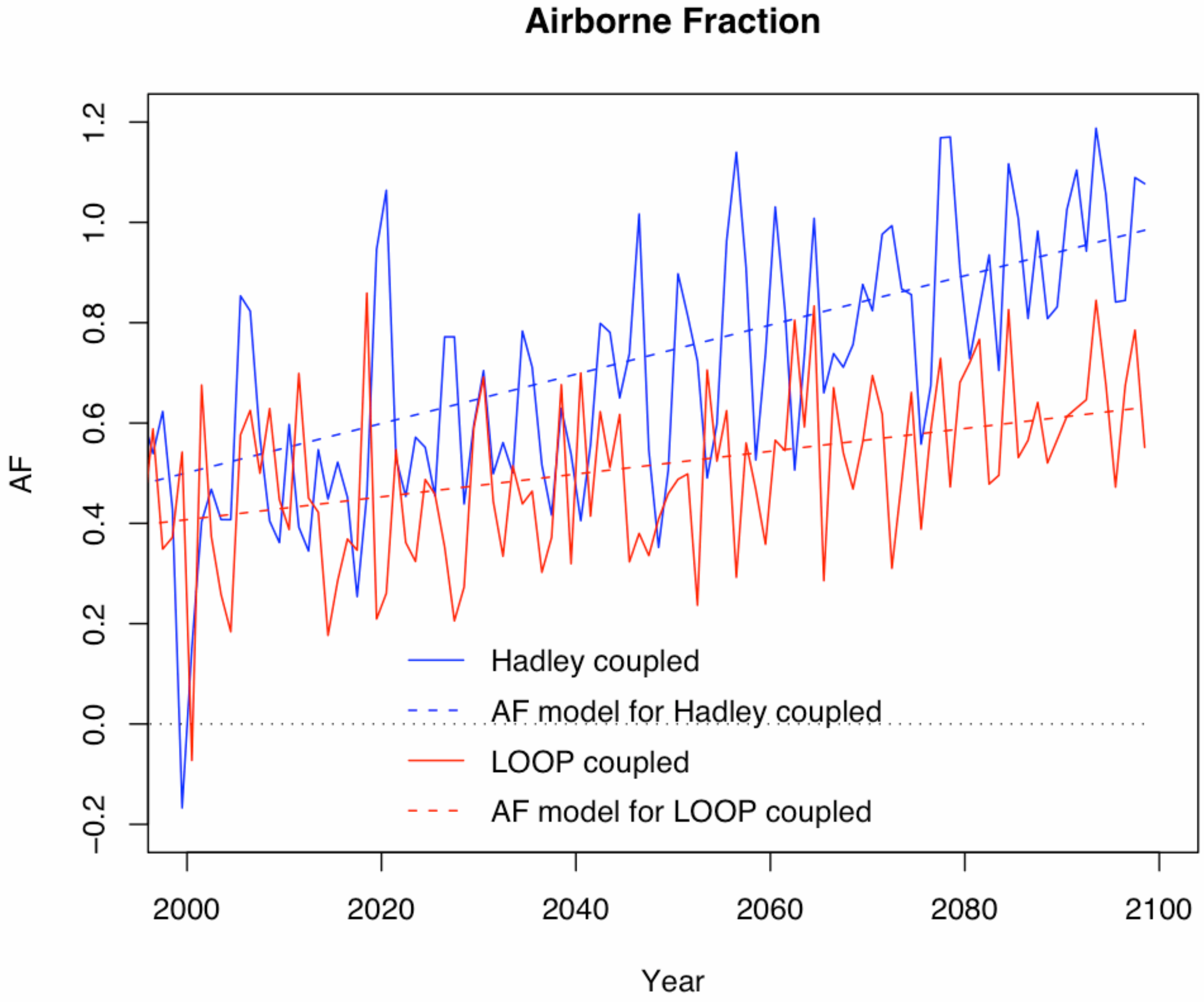
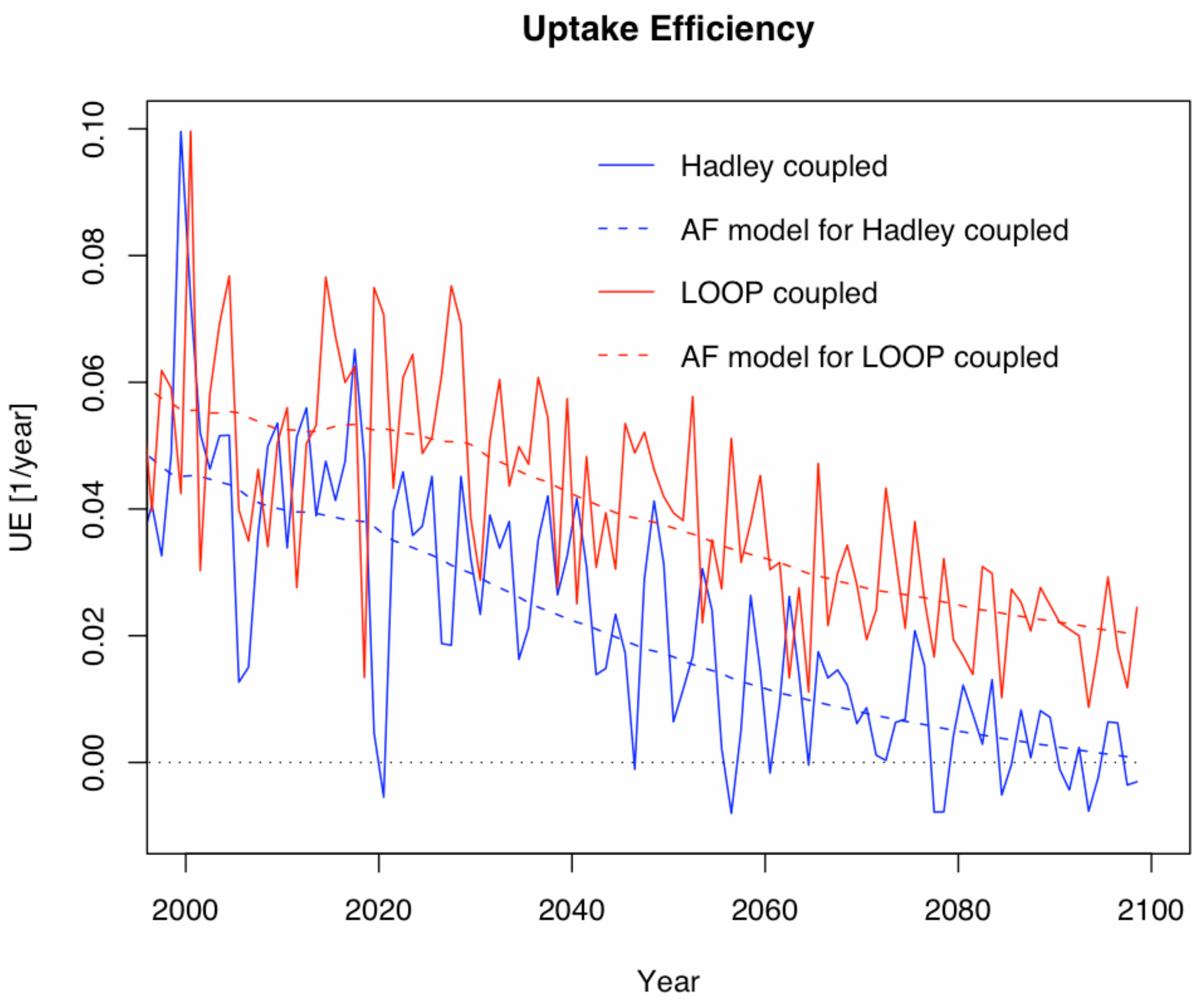
21st Century



21st Century



Concluding Remarks

- Increase of AF and decrease of UE even without Climate–Carbon Cycle Feedback
- Attribution (*e.g. to emissions*) …
- Reduction in landuse flux uncertainty not enough for early detection
- Use of global integral of carbon sinks insufficient to detect carbon cycle feedback → use spatial patterns?
- Confidence in models…

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Media Response

Telegraph.co.uk

Climate change study shows Earth is still absorbing carbon dioxide

But Wolfgang Knorr, author of the new study, found that the amount of CO2 in the atmosphere has remained just over 50 per cent, with only tiny fluctuations being recorded despite the massive hike in output.

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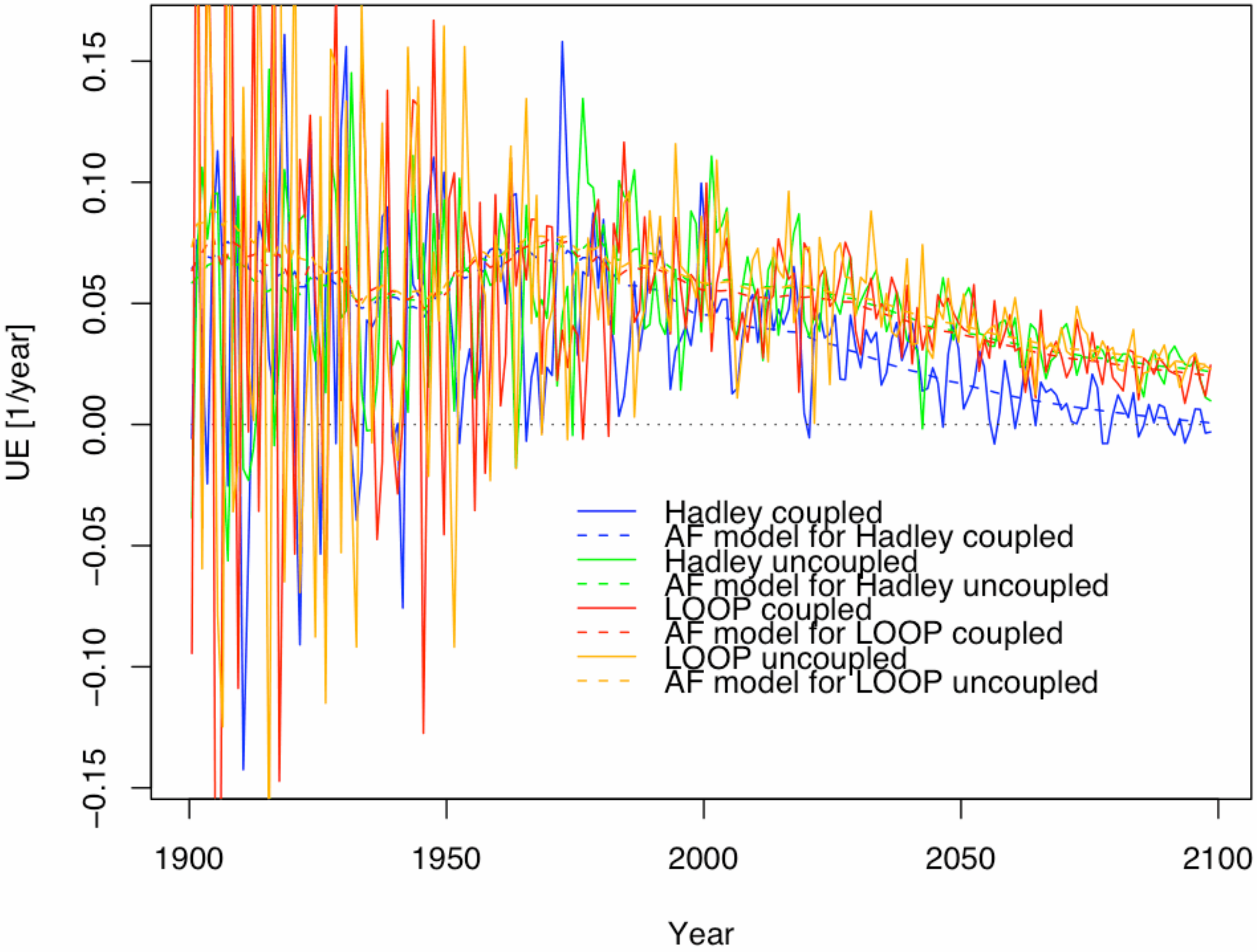
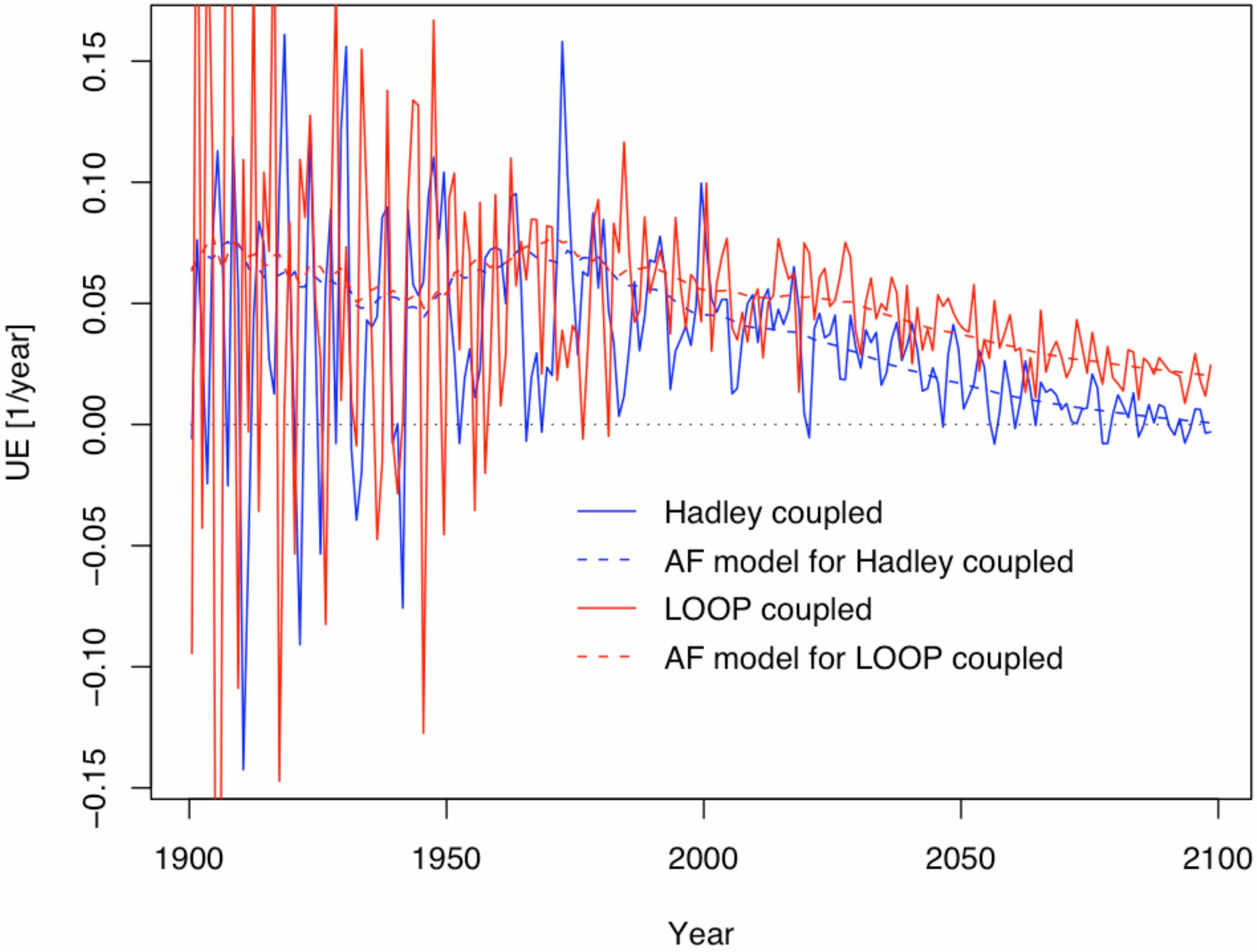
Final Remark

- We need to be clear about what we mean by a “change in the airborne fraction” of anthropogenic CO_2 emissions

Uptake Efficiency



Uptake Efficiency



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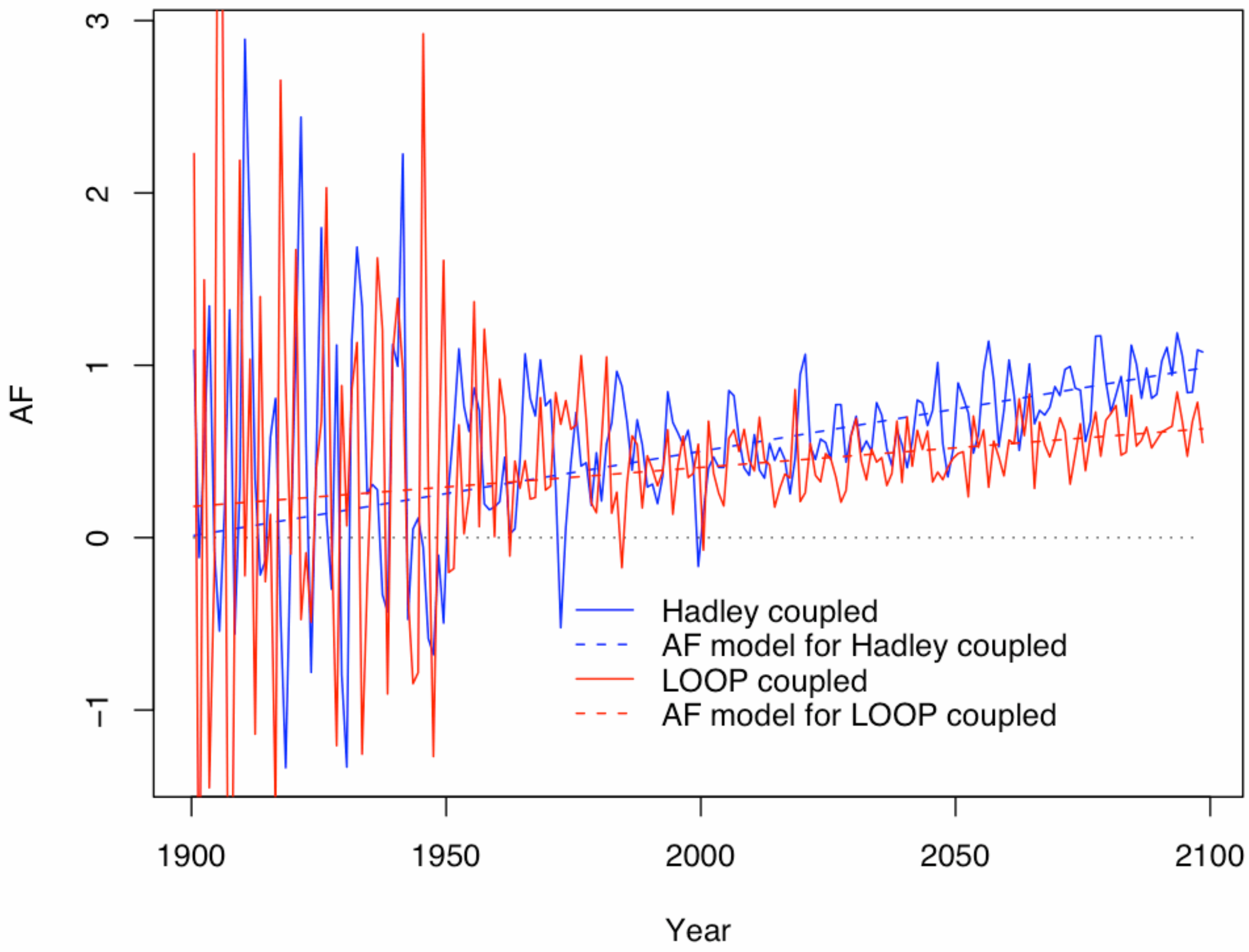
Airborne Fraction



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