Equilibrium- and transient- state dependencies of climate feedbacks: are they important for climate projections ?

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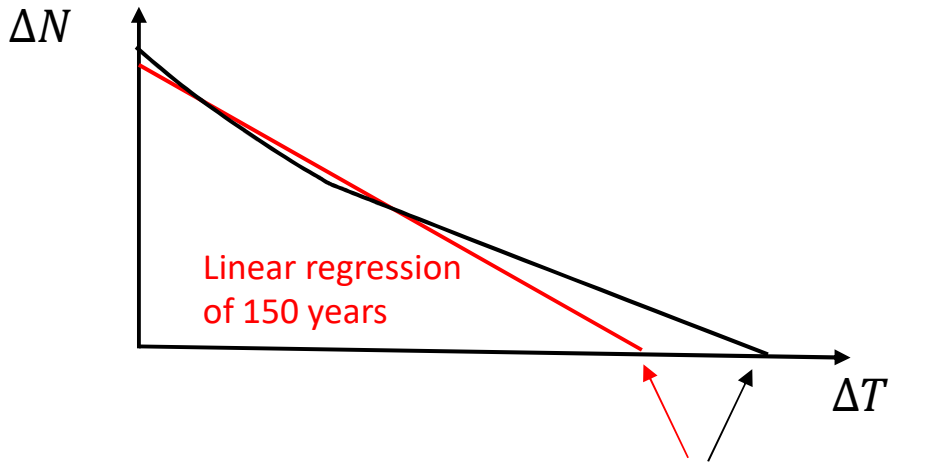
CFMIP, 2019

Some motivations

Abrupt2xCO2 in a Gregory plot :



- Need to use same type of estimations when comparing models and obs

- (Any estimate of) ECS not necessary the best metric for warming in 2100

- They are other effects than the pattern effect : equilibrium-state dependencies

→ Are changing feedbacks important for constraining climate projections ?

Outlines

- State dependencies of λ and CO2-forcing relationship in CMIP5 (+ CNRM-CM6.1)

- Importance for constraining climate projections ?

Linear 2-layer energy balance model

EBM *(Gregory et al., 2000 ; Held et al., 2010)*

Upper ocean + atmo + land $$C\frac{dT}{dt} = F - \lambda\Delta T - (\varepsilon - 1)H - H$$

Deep ocean $$C_d\frac{dT_d}{dt} = H = \gamma\,(\Delta T - \Delta T_d)$$

$\varepsilon \neq 1$ → pattern effect

(Winton et al., 2010; Held et al., 2010, Geoffroy et al., 2013b)

Linear 2-layer energy balance model

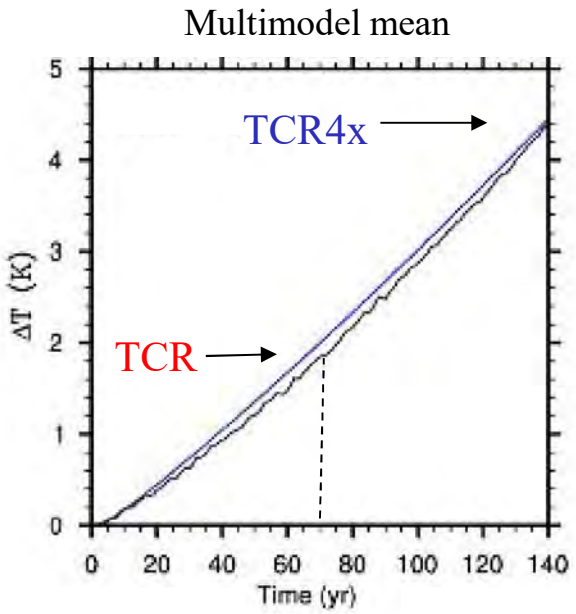
EBM *(Gregory et al., 2000 ; Held et al., 2010)*

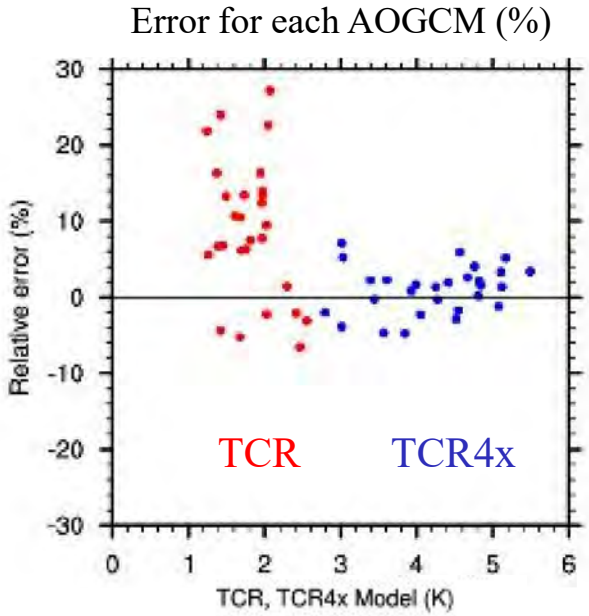
Upper ocean + atmo + land $$C\frac{dT}{dt} = F - \lambda\Delta T - (\varepsilon - 1)H - H$$

Deep ocean $$C_d\frac{dT_d}{dt} = H = \gamma\,(\Delta T - \Delta T_d)$$

Log CO2-ERF relationship *(Myhre et al., 1998)*

$$F(t) = F_4\, log_4\, c(t) \quad \text{with c} = \frac{[CO2]}{[CO2]_0}$$



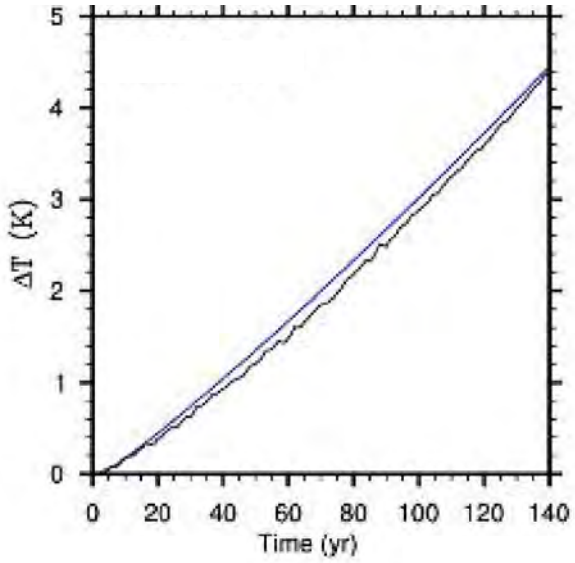


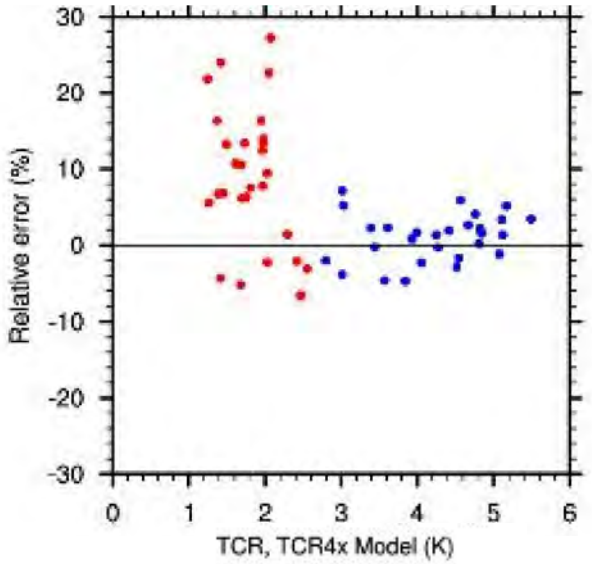
Calibration with abrupt4xCO2 → **Overestimation of TCR**

Large spread

Linear 2-layer energy balance model

Log CO2-ERF relationship :





Quadratic CO2-ERF relationship from line-by-line RT model (BG14) :

$$F(t) = F_4 \left[(1-f)\, log_4\, c(t) + f\, (log_4\, c(t))^2 \right] \qquad \text{with c} = \frac{[CO2]}{[CO2]_0}$$

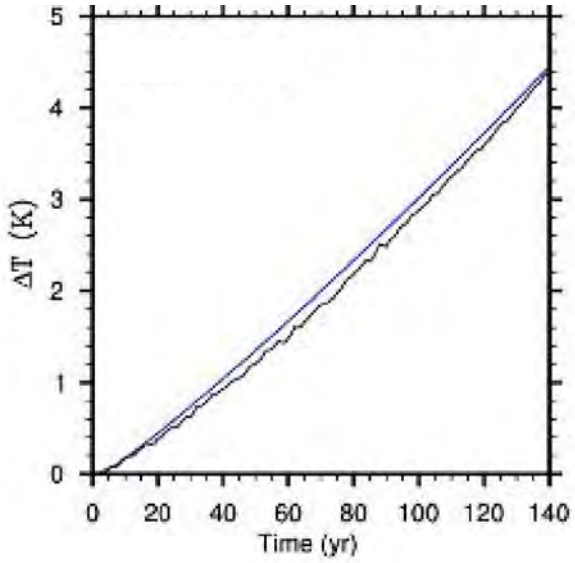
f ≈ 0.09

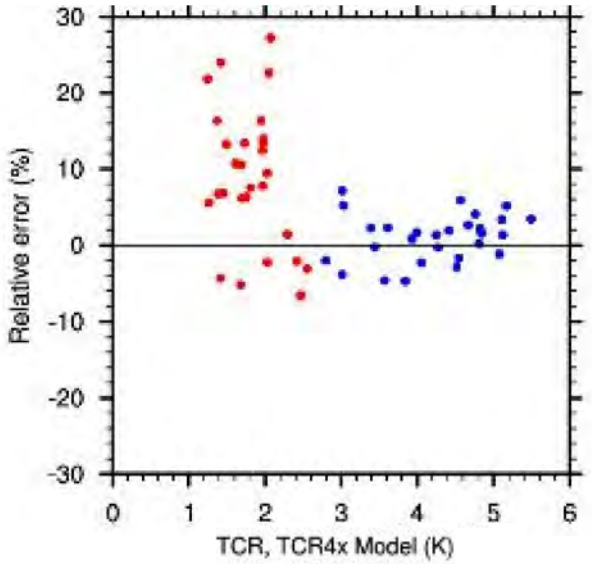
(Byrne and Goldblatt, 2014, Etminan et al., 2016, Gregory et al., 2015)

BG14

Linear 2-layer energy balance model

Log CO2-ERF relationship :





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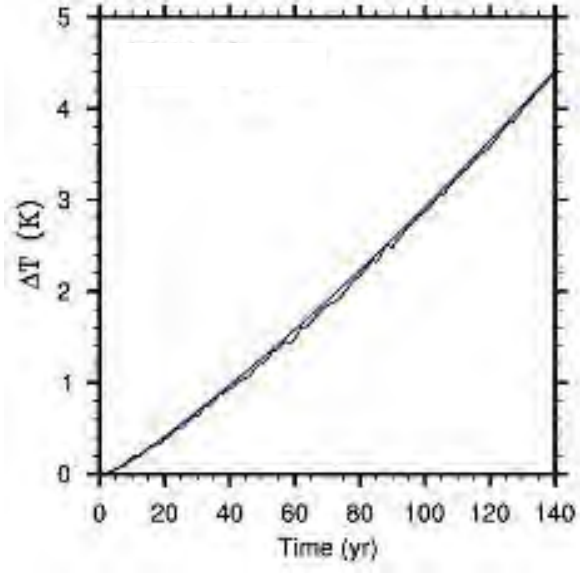
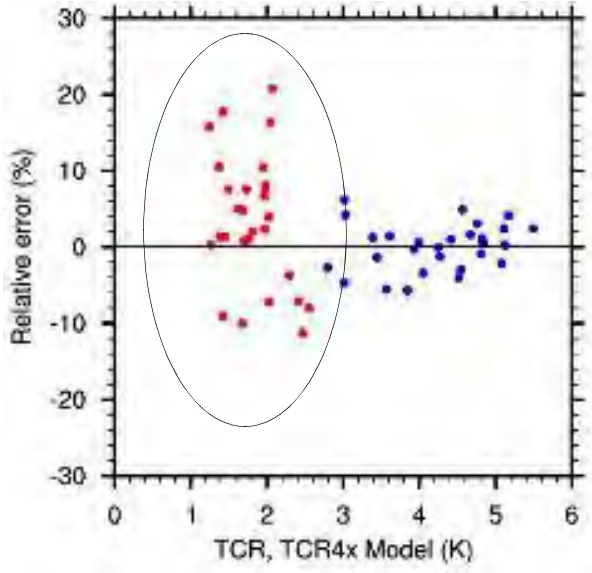




Better agreement, large spread

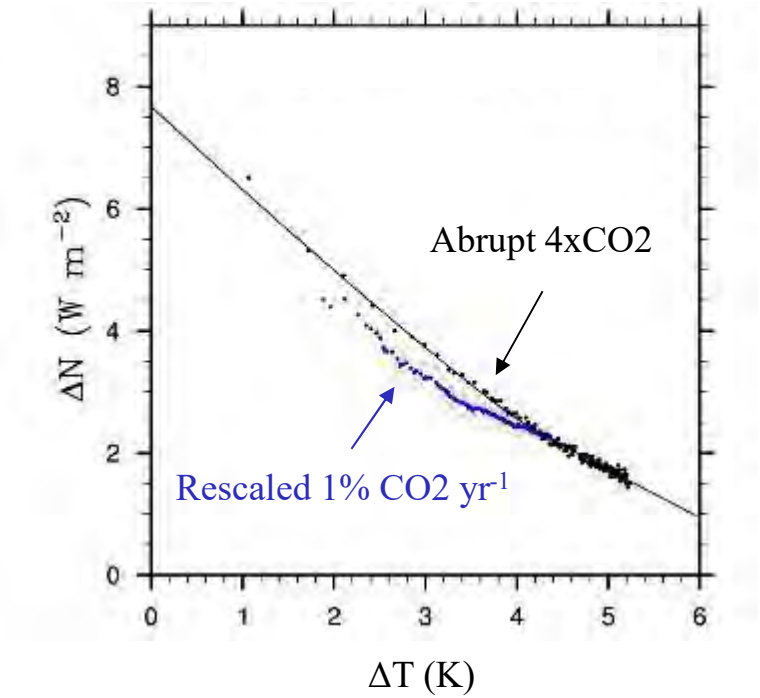
In agreement with Gregory et al. (2015)

Rescaled 1% CO2 yr^{-1} in order to match the abrupt4xCO2

$$\Delta N = F(t) - \lambda \Delta T \longrightarrow \frac{F_{4\times}}{F(t)} \Delta N = F_{4\times} - \lambda \frac{F_{4\times}}{F(t)} \Delta T$$

$$\times \frac{F_{4\times}}{F(t)}$$

Log forcing



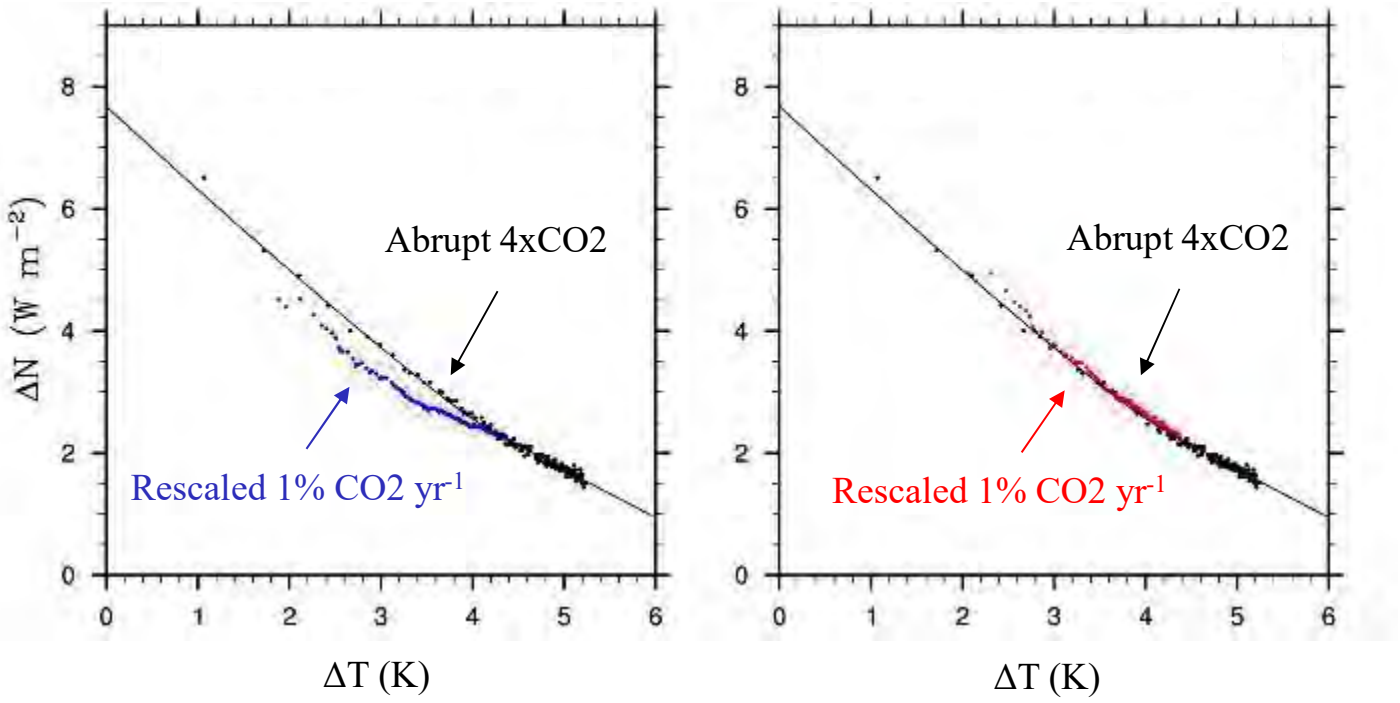
Rescaled 1% CO2 yr^{-1} in order to match the abrupt4xCO2

$$\Delta N = F(t) - \lambda \Delta T \longrightarrow \frac{F_{4\times}}{F(t)} \Delta N = F_{4\times} - \lambda \frac{F_{4\times}}{F(t)} \Delta T$$

$$\times \frac{F_{4\times}}{F(t)}$$

Log forcing

Quadratic forcing from BG14

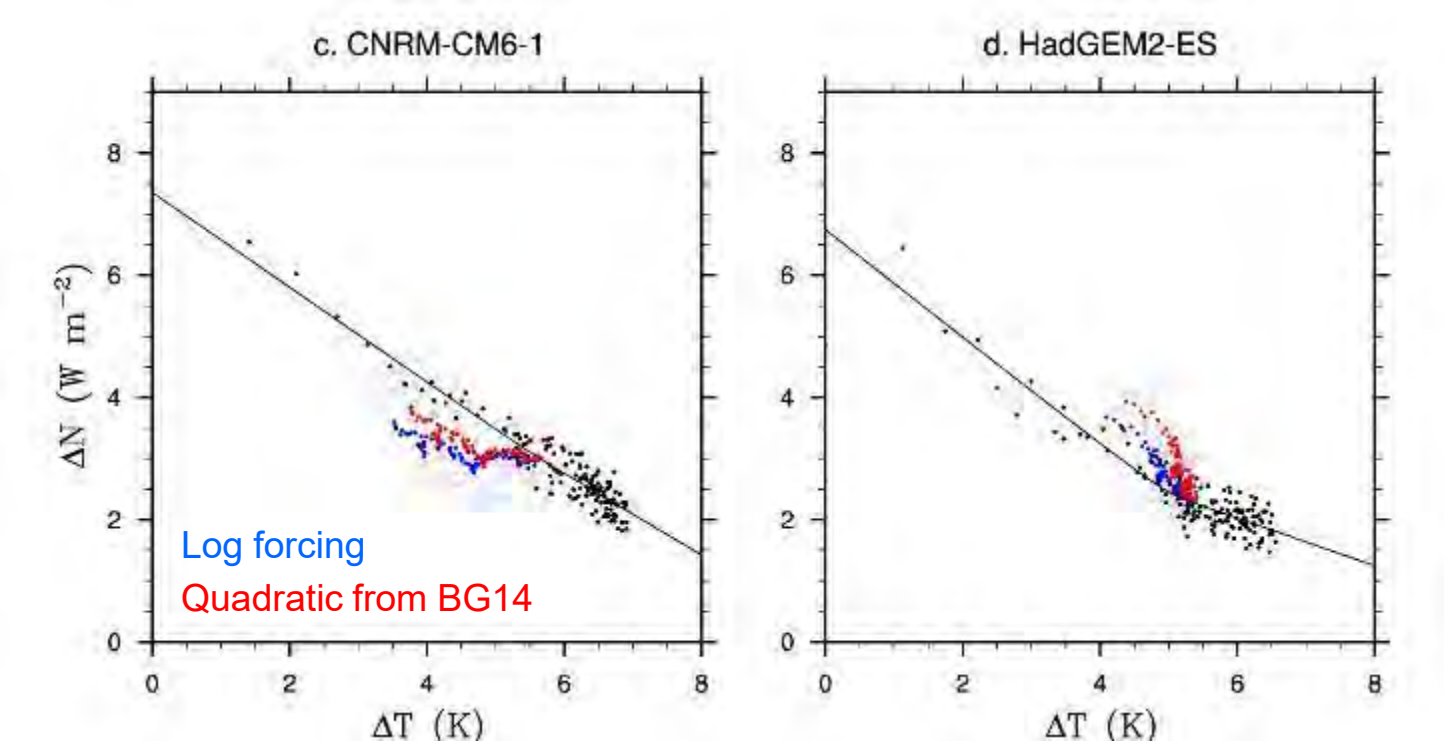


Good representation

In agreement with Gregory et al. (2015)

Rescaled 1% CO2 yr^{-1} in order to match the abrupt4xCO2

Large spread :



Difference due to CO_2-ERF relationship and/or equilibrium state dependency of λ

CO_2-ERF relationship and equilibrium state dependency of λ in an EBM

Quadratic ERF $F_4\,[\,(1-f)\,log_4\,c + f\,(log_4\,c)^2\,]$	EBM 1	EBM 2	EBM 3
	f model dependent	f from BG14 (f ≈ 0.09)	f from BG14 (f ≈ 0.09)
λ	Constant	f([CO_2])	f(ΔT)

$$\lambda = \lambda_4\,[\,(1-g_c) + g_c\,log_4\,c\,]$$

$$\lambda = \lambda_0^T\,[\,(1-g_T) + g_T\,\frac{\Delta T}{ECS_0}\,]$$

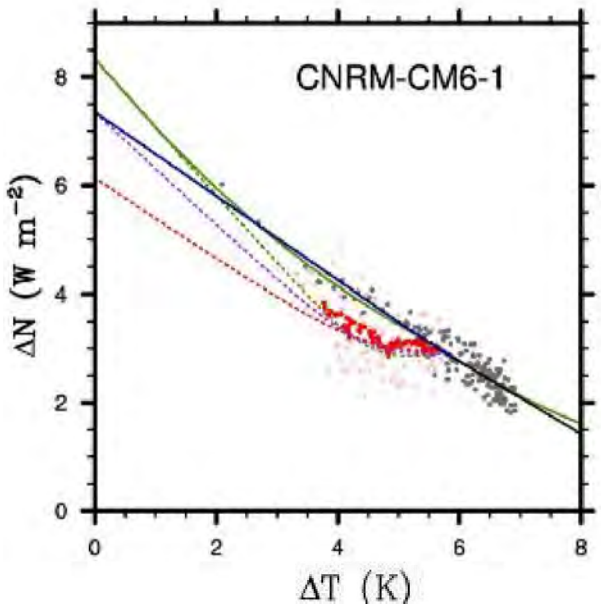
Equilibrium state dependencies of λ

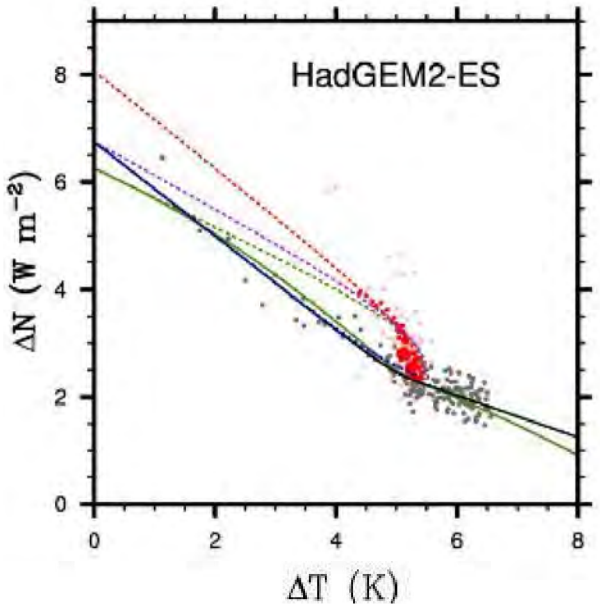
(Colman et al., 1997; Jonko et al. 2012, Block and Mauritsen, 2013; Bloch-Johnson et al., 2015)

CO_2-ERF relationship and equilibrium state dependency of λ in an EBM

	EBM 1	EBM 2	EBM 3
Quadratic ERF $F_4\ [\ (1-f)\ log_4\ c + f\ (log_4\ c)^2\ ]$	f model dependent	f from BG14 (f ≈ 0.09)	f from BG14 (f ≈ 0.09)
λ	Constant	f([CO_2])	f(ΔT)

Effects can not be dissociated → Assume one single effect fully explain the nonlinear behaviour



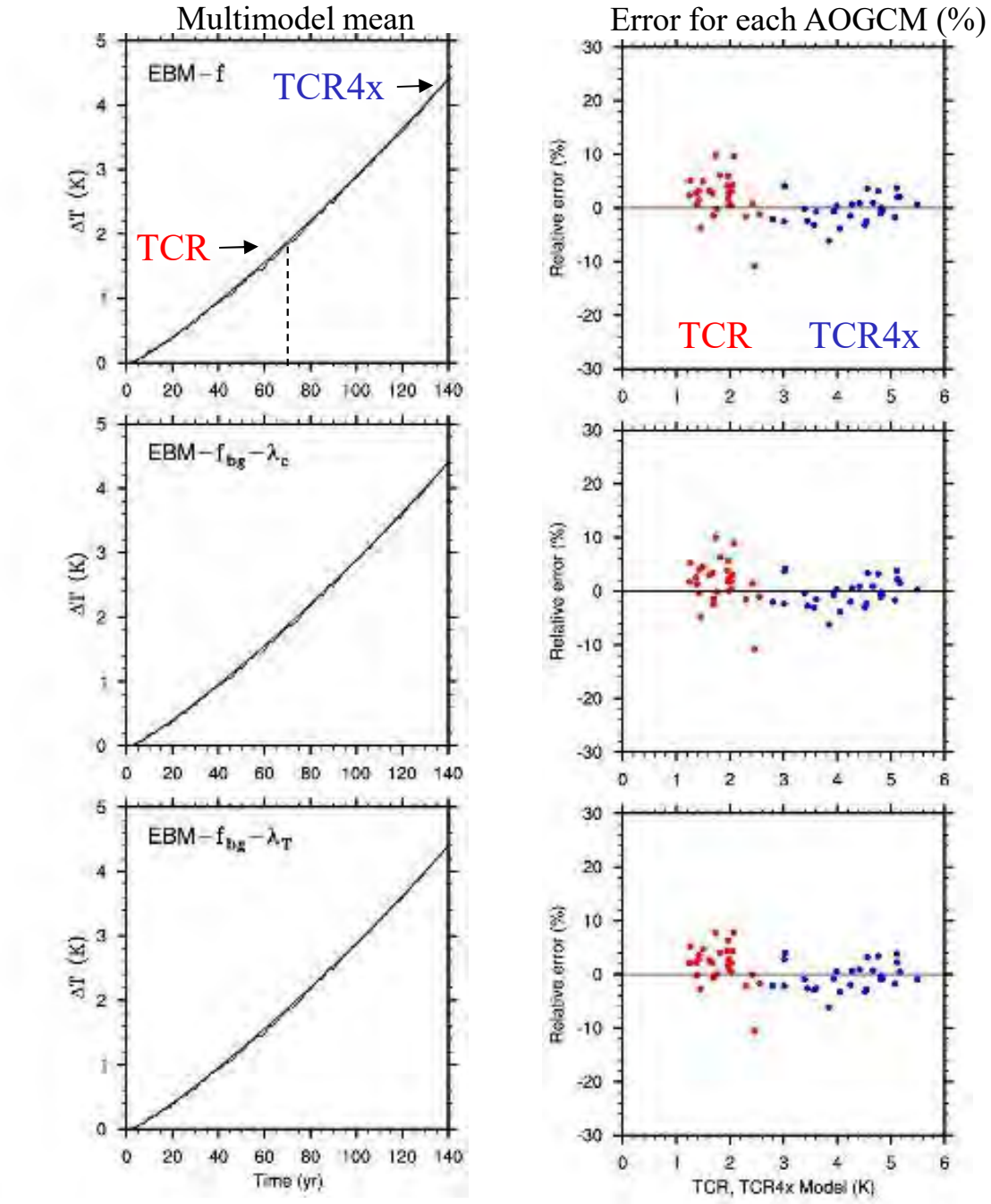


Representation of the 1% CO_2 yr^{-1} by each EBM

- Quadratic ERF
- λ = constant

- Quadratic ERF from BG14
- λ = f([CO_2])

- Quadratic ERF from BG14
- λ = f(ΔT)



Similar reduction of the spread

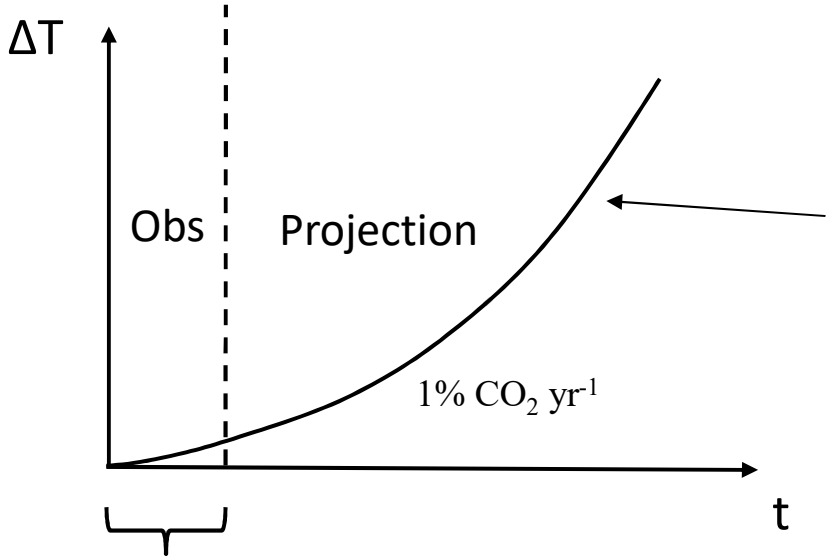
Outlines

- State dependencies of λ and CO2-forcing relationship in CMIP5

- Importance of CO_2-ERF relationship and state dependencies of λ for constraining climate projections ?

→ Use idealized scenarios
→ Use the 2-layer EBM calibrated with CMIP5 models as a perfect model

Importance of pattern effect for constraining climate projections : method



Reality : EBM with pattern effect

$$\lambda_{transient}(t) = \lambda + \frac{(\varepsilon - 1)H(t)}{\Delta T(t)}$$

Assume we can measure $\lambda_{transient}$ but not λ and ε

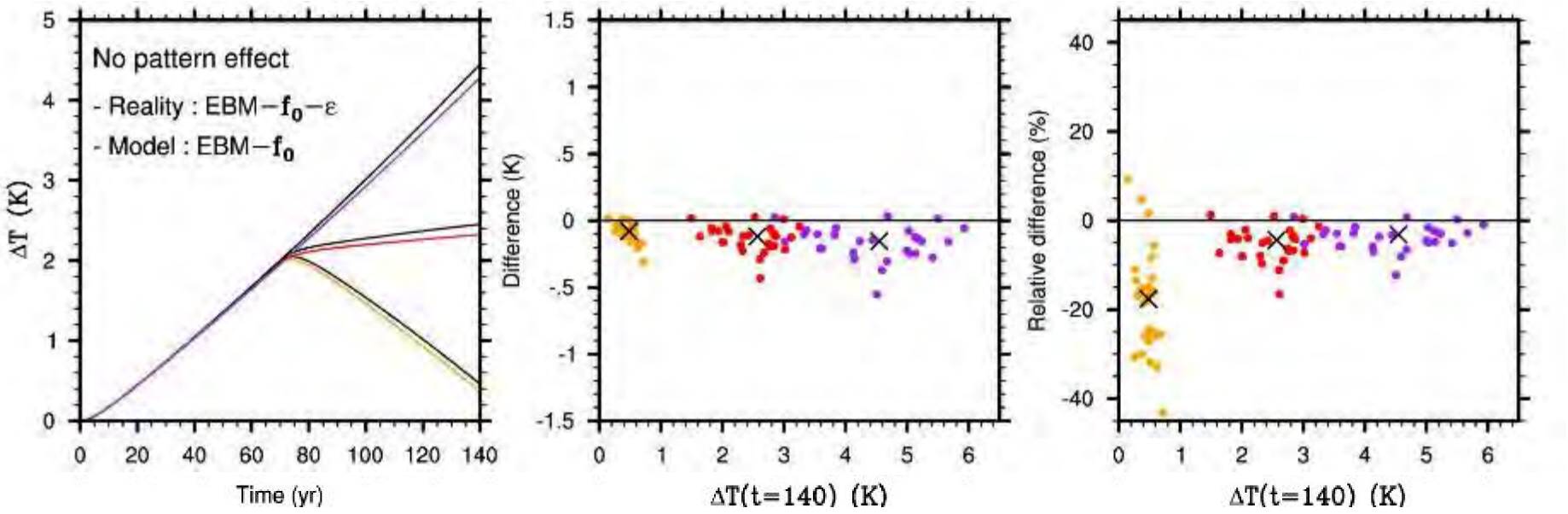
Projection with $\lambda_{transient} = cste = observed\ value$ → Error in projected warming ?

Use the value at t → 0

Importance of pattern effect for constraining climate projections

Reality : EBM with **pattern effect** $\lambda_{transient}(t) = \lambda + \frac{(\varepsilon - 1)H(t)}{\Delta T(t)}$

Estimation : EBM with **constant** $\lambda_{transient}$ estimated at **t → 0 yr**



Neglecting the pattern effect to constrain TCR4x → **median relative error of only 3 %**

Importance of CO2-ERF relationship and/or equilibrium state dependent λ

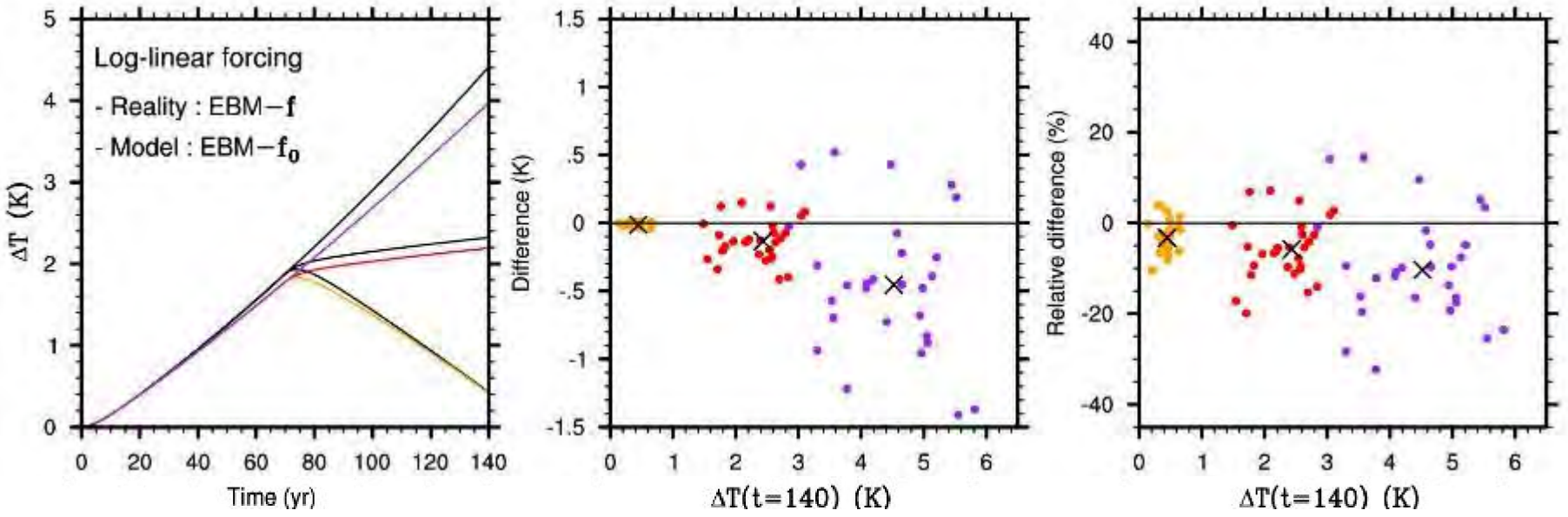
Effects can not be dissociated

→ Use one EBM with one single effect
and assume it well represents all the 3 effects

Importance of CO2-ERF relationship and/or equilibrium state dependent λ

Reality : EBM with **quadratic forcing with f model dependent** $F_4\,[(1-f)log_4\,c + f\,(log_4\,c)^2]$

Estimation : EBM with **Log forcing** with F_4 estimated at t→ 0

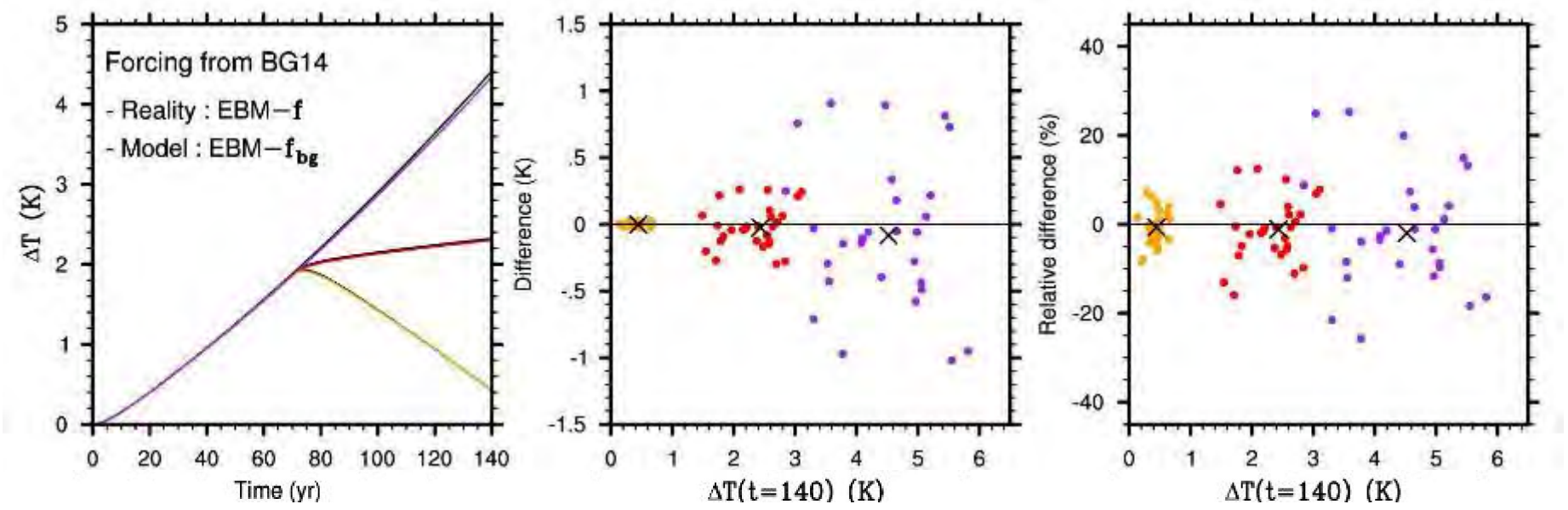


→ **Median error = -10 % , large spread**

Importance of CO2-ERF relationship and/or equilibrium state dependent λ

Reality : EBM with **quadratic forcing with f model dependent** $F_4\,[(1-f)log_4\,c + f\,(log_4\,c)^2]$

Estimation : EBM with **BG14 quadratic forcing** with F_4 estimated at t→ 0

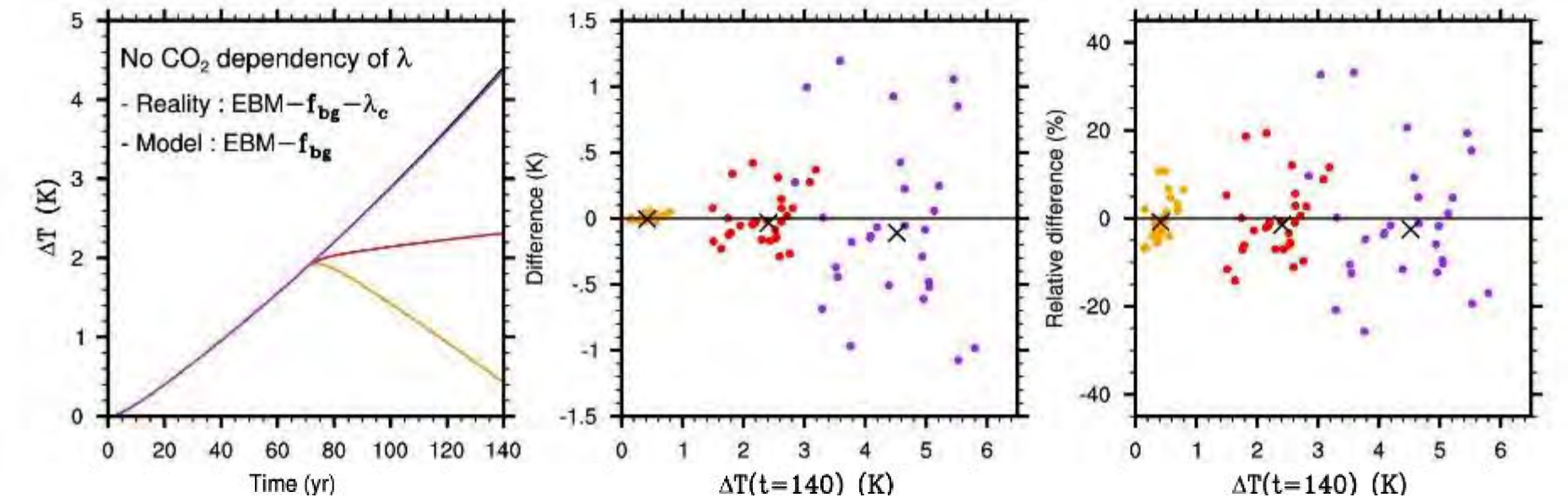


→ **Median error = 0 % , large spread**

Importance of CO2-ERF relationship and/or equilibrium state dependent λ

Reality : EBM with BG14 quadratic forcing and **CO_2-dependent λ**

Estimation : EBM with BG14 quadratic forcing and **constant λ** estimated at t→ 0

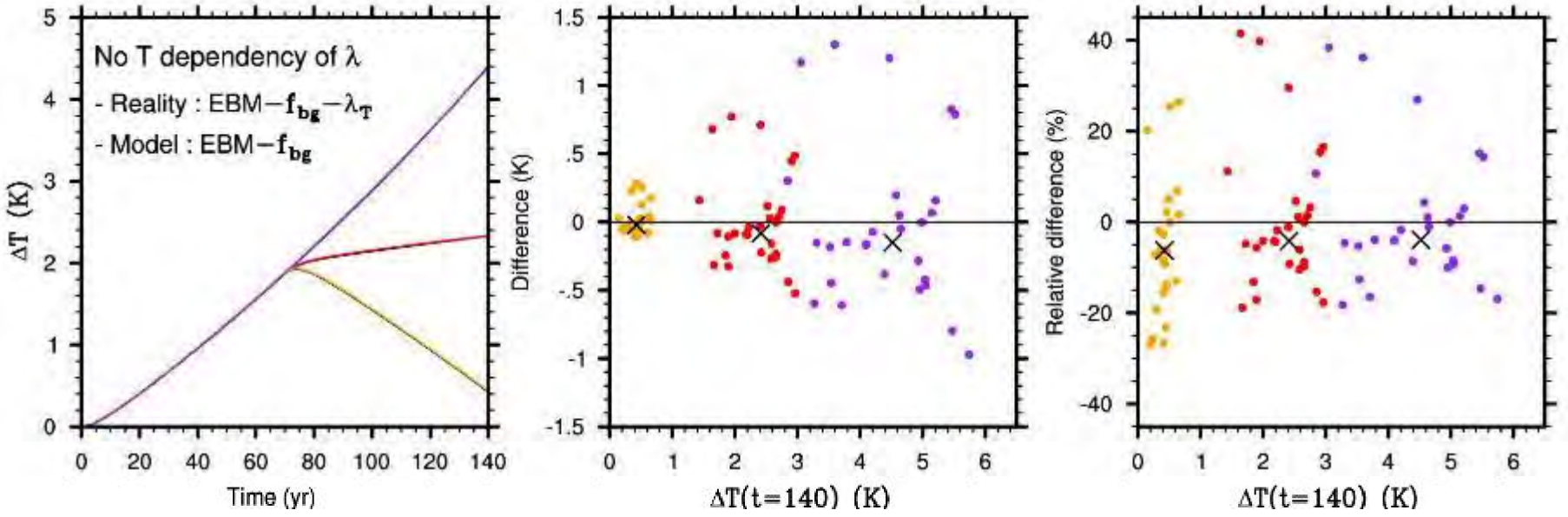


→ Same results : median error = 0 % , large spread

Importance of CO2-ERF relationship and/or equilibrium state dependent λ

Reality : EBM with BG14 quadratic forcing and **T-dependent λ**

Estimation : EBM with BG14 quadratic forcing and **constant λ** estimated at t→ 0



→ Similar results : median error = 0 % , large spread

Conclusion

- 2-layer EBM with pattern effect calibrated from abrupt4xCO2,

+ **quadratic forcing from line-by-line RT models** → median **TCR well represented**

Large spread due to i) deviation from BG14 forcing
ii) equilibrium-state dependencies of λ (on CO_2, T)

- Importance for constraining climate projections (use TCR_{4x}, $\Delta T_{stabilization}$, $\Delta T_{ramp\text{-}down}$)

→ **The (forced) pattern effect** is not important (3 % of error for TCR_{4x})

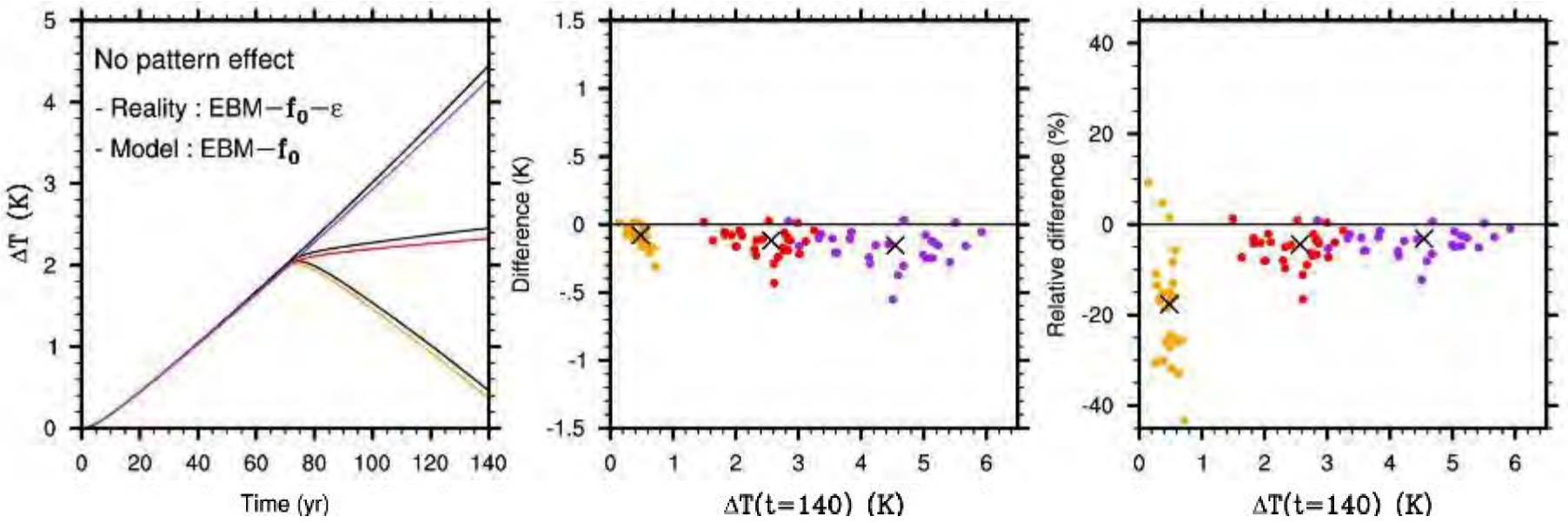
→ If AOGCMs correctly represent BG14 forcing, a **log forcing** lead to a error of -10 %

→ **Equilibrium state dependencies and/or deviation from BG14 forcing**
do not induce any systematic error when a BG14 forcing is used,
but contribute to increase uncertainties

Importance of pattern effect for constraining climate projections

Reality : EBM with pattern effect $\lambda_{transient}(t) = \lambda + \frac{(\varepsilon - 1)H(t)}{\Delta T(t)}$

Estimation : EBM with constant $\lambda_{transient}$ with value « measured » at **t → 0 yr**

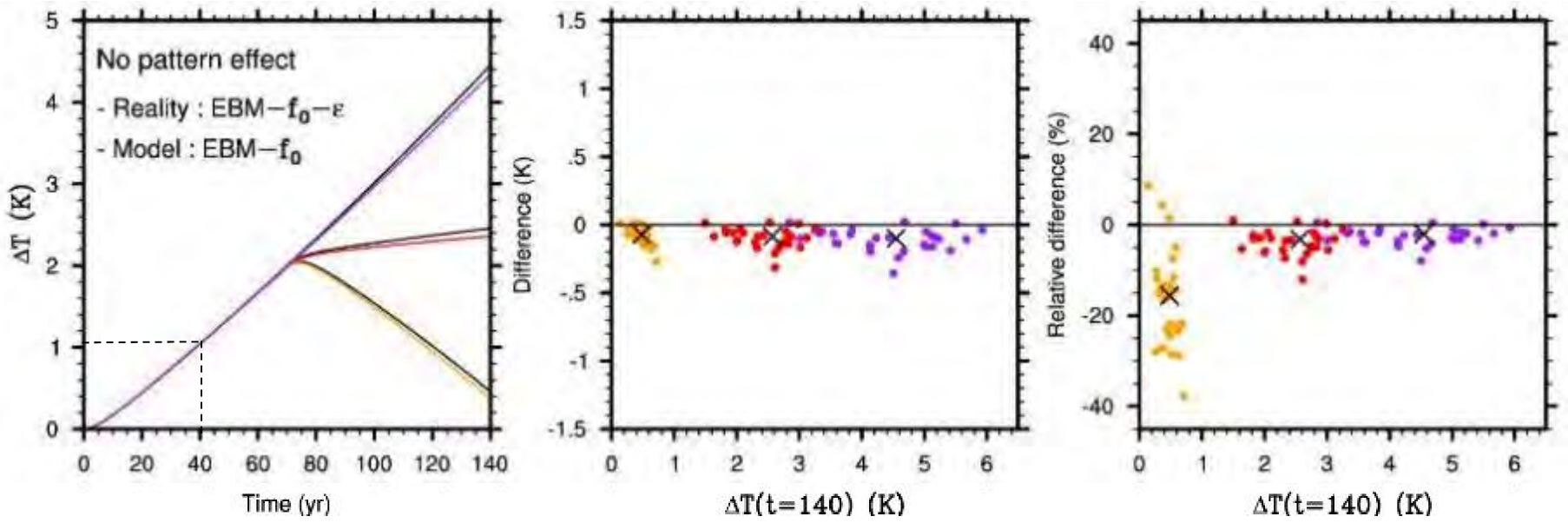


Neglecting the pattern effect to constrain TCR4x → **median relative error of only 3 %**

Importance of pattern effect for constraining climate projections

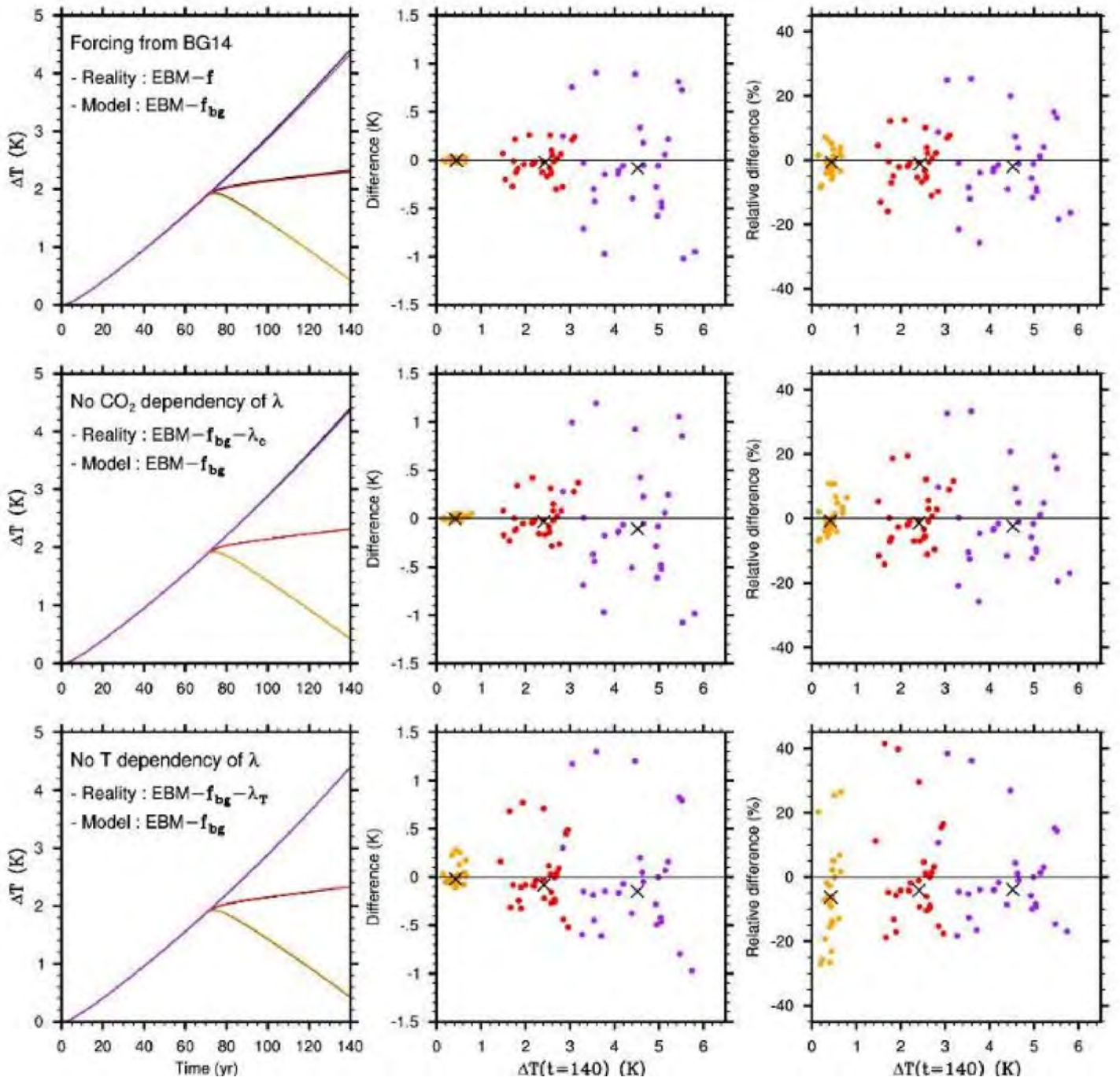
Reality : EBM with pattern effect $\lambda_{transient}(t) = \lambda + \dfrac{(\varepsilon - 1)H(t)}{\Delta T(t)}$

Estimation : EBM with constant $\lambda_{transient}$ with value « measured » at **t = 40 yr**

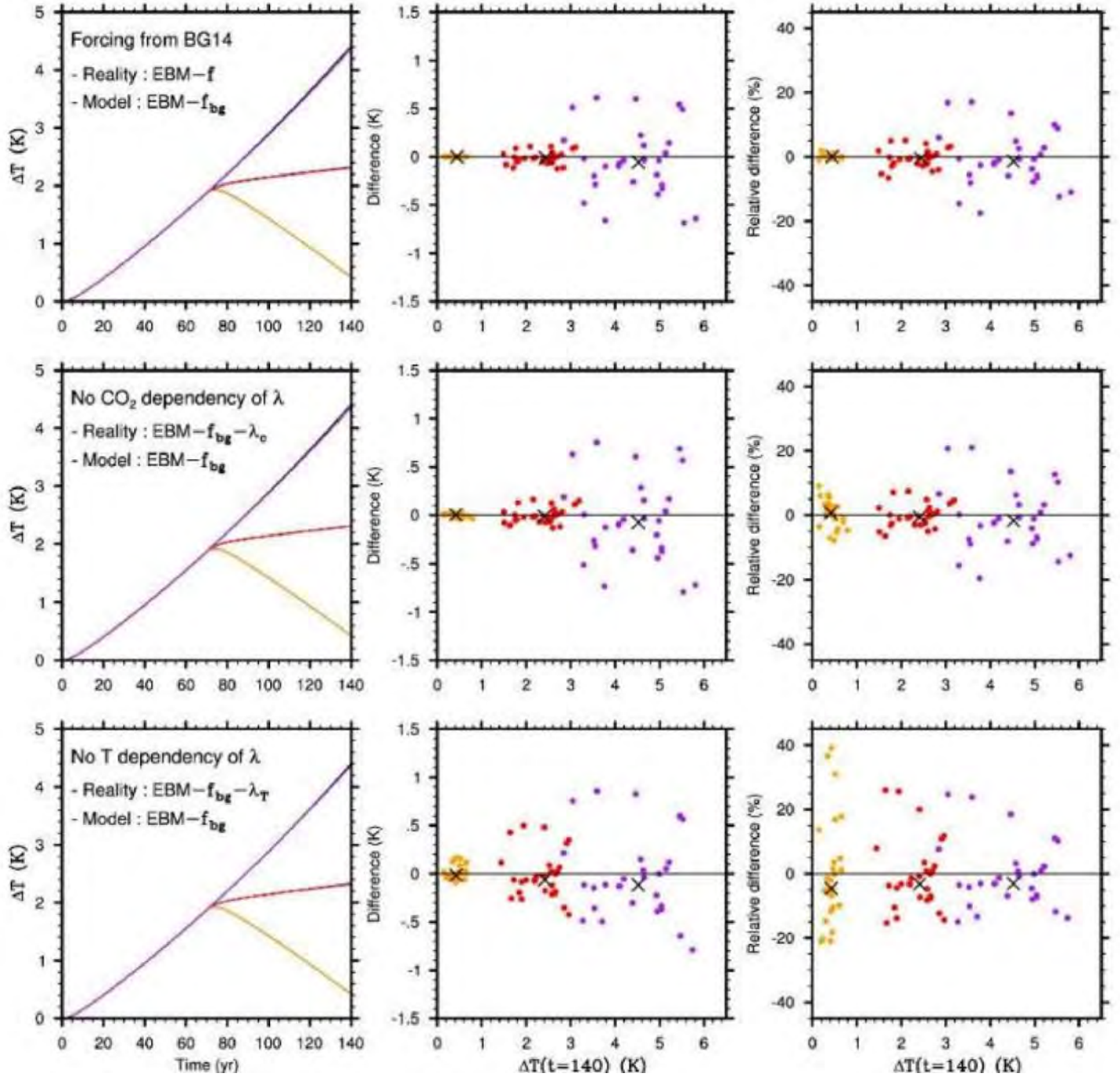


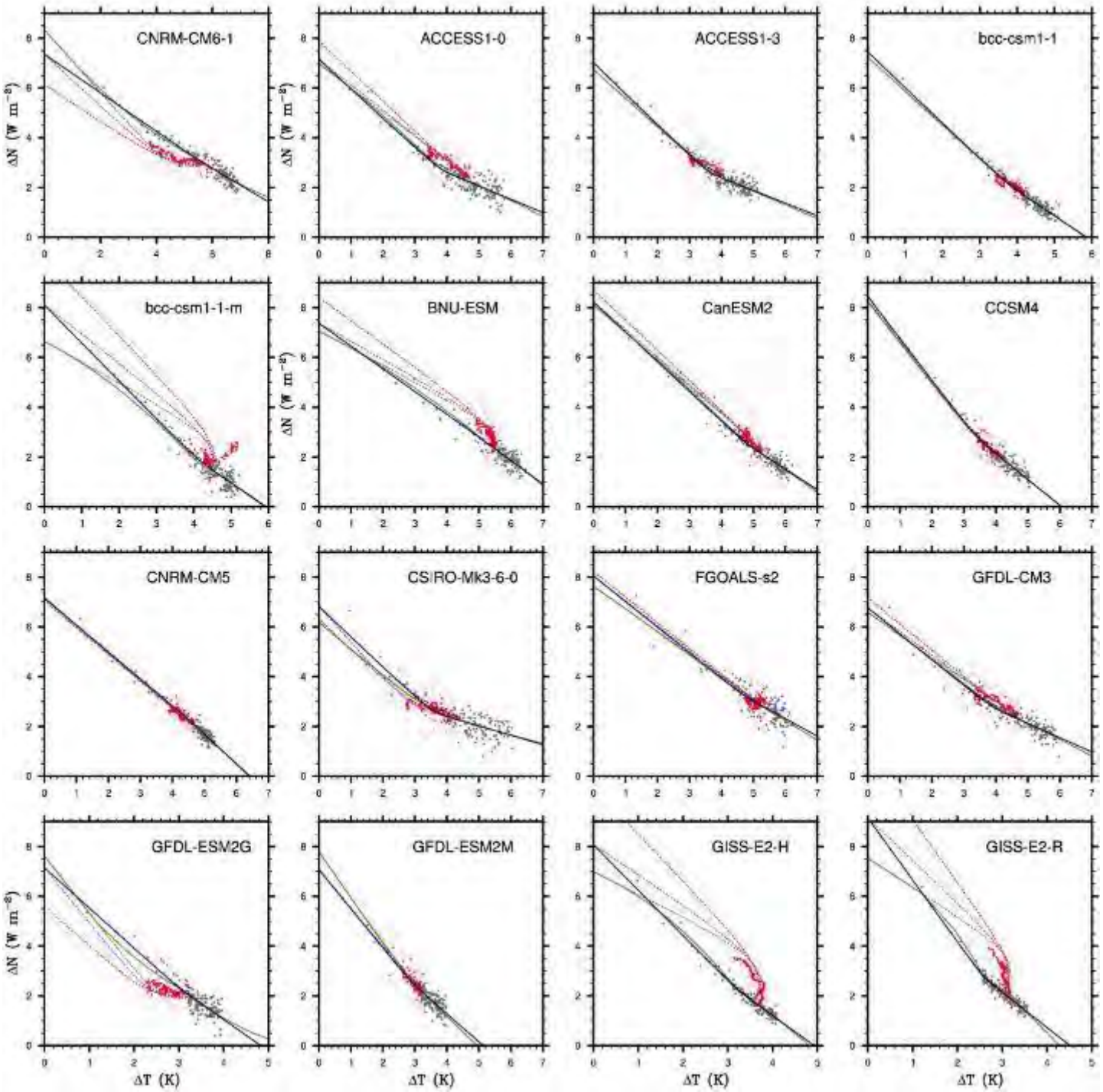
Neglecting the pattern effect to constrain TCR4x → **median relative error of only 3 %**

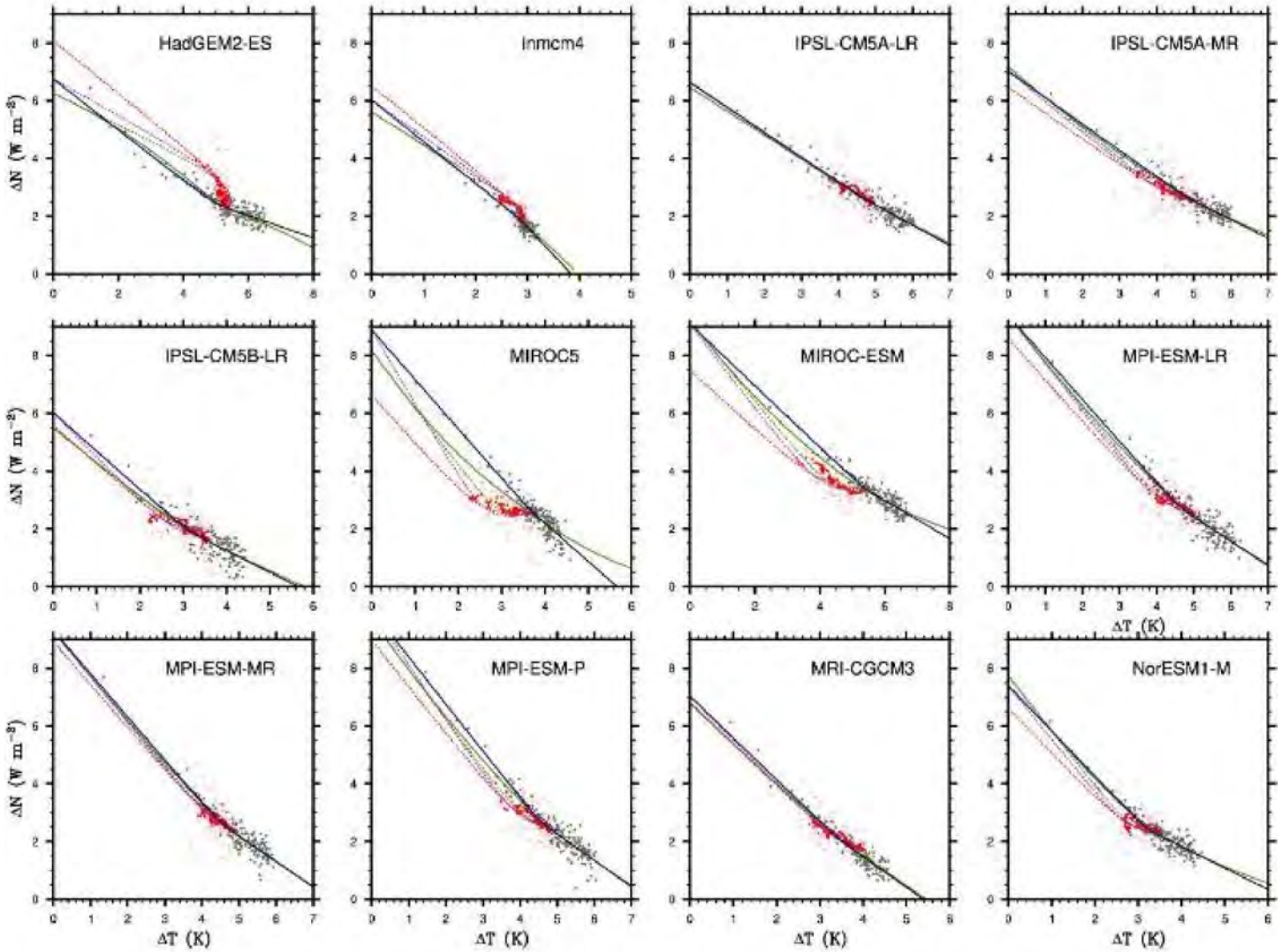
t → 0 yr


Forcing from BG14
- Reality : EBM−f
- Model : EBM−f_bg
No CO2 dependency of λ
- Reality : EBM−f_bg−λc
- Model : EBM−f_bg
No T dependency of λ
- Reality : EBM−f_bg−λT
- Model : EBM−f_bg
ΔT (K)
Difference (K)
Relative difference (%)
Time (yr)
ΔT(t=140) (K)

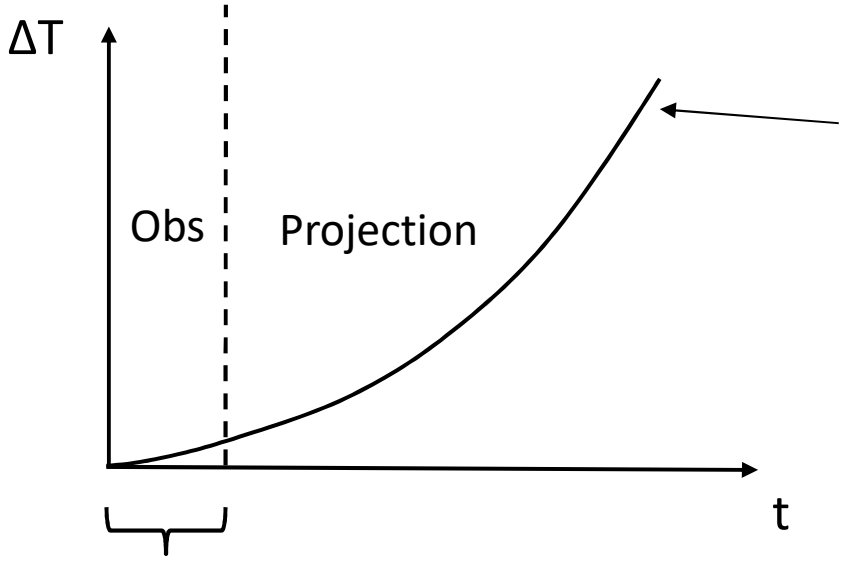
t = 40 yr


Forcing from BG14
- Reality : EBM−f
- Model : EBM−f_{bg}
No CO_2 dependency of λ
- Reality : EBM−f_{bg}−λ_c
- Model : EBM−f_{bg}
No T dependency of λ
- Reality : EBM−f_{bg}−λ_T
- Model : EBM−f_{bg}
ΔT (K)
Difference (K)
Relative difference (%)
Time (yr)
ΔT(t=140) (K)
ΔT(t=140) (K)


CNRM-CM6-1
ACCESS1-0
ACCESS1-3
bcc-csm1-1
bcc-csm1-1-m
BNU-ESM
CanESM2
CCSM4
CNRM-CM5
CSIRO-Mk3-6-0
FGOALS-s2
GFDL-CM3
GFDL-ESM2G
GFDL-ESM2M
GISS-E2-H
GISS-E2-R
ΔN (W m⁻²)
ΔT (K)


HadGEM2-ES
Inmcm4
IPSL-CM5A-LR
IPSL-CM5A-MR
IPSL-CM5B-LR
MIROC5
MIROC-ESM
MPI-ESM-LR
MPI-ESM-MR
MPI-ESM-P
MRI-CGCM3
NorESM1-M
ΔN (W m⁻²)
ΔT (K)

Importance of pattern effect for constraining climate projections



Reality : EBM with pattern effect

$$\lambda_{transient} = \lambda + \frac{(\varepsilon - 1)H}{\Delta T}$$

Assume we can measure $\lambda_{transient}$ but not ε

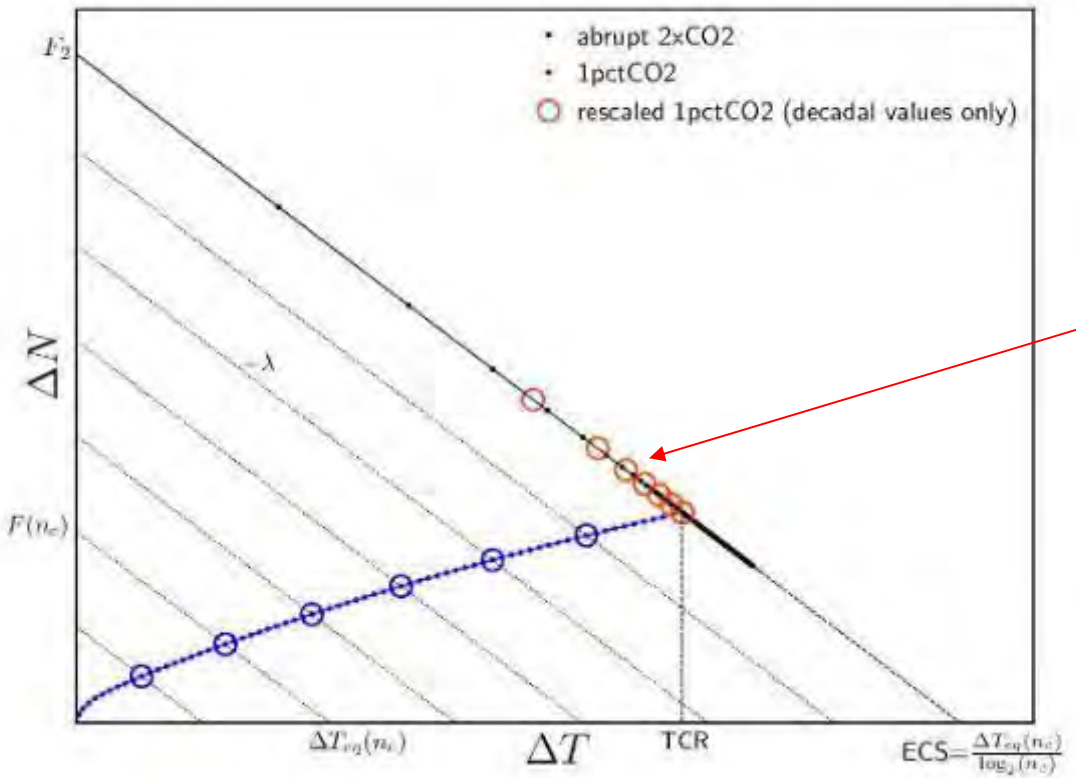
Projection with $\lambda_{transient} = cste = \ observed\ value$ → Error in projected warming ?

Use the limit of t=0 :

$= \lambda + (1 - \varepsilon)\gamma$

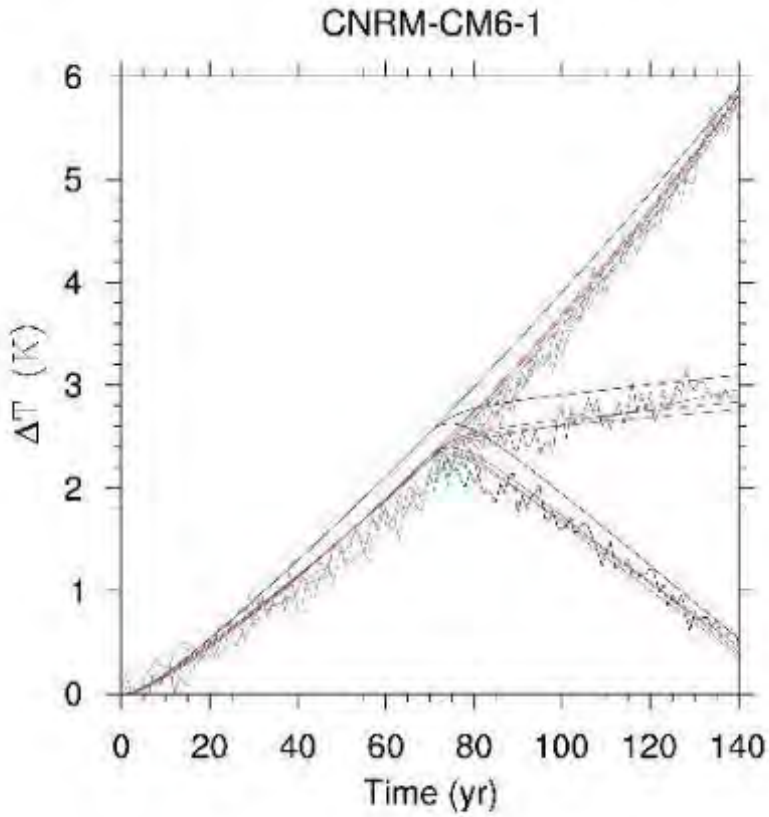
Linear forcing feedback framework

$$\Delta N = F(t) - \lambda\,\Delta T \quad \xrightarrow{\text{rescaling}} \quad \frac{F_{2\times}}{F(t)}\Delta N = F_{2\times} - \lambda\,\frac{F_{2\times}}{F(t)}\Delta T$$

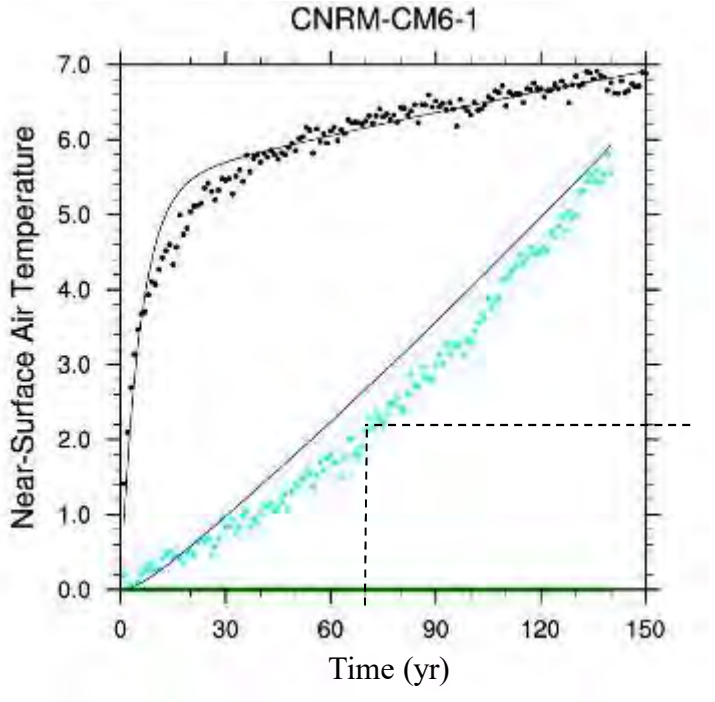


$$(\Delta T, \Delta N) \times \frac{F_{2\times}}{F(t)}$$

Any deviation from the abrupt2xCO2 line shows a limitation of the linear F-λ framework


CNRM-CM6-1
ΔT (K)
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140
Time (yr)

Limitation de l'EBM (avec ou sans ε) : biais TCR



TCR
(=ΔT à 2xCO2
i.e. t=70 ans)

Probablement en lien :
ΔT(t=2100) dans un RCP8.5
mieux correlé à « ECS » qu'à TCR
(Grose et al. 2018)

Explications possibles :
- forçage pas en log(CO2),
- lambda non constant (autre que pattern effect)
- Param de H

radiatif

OHU