

## ***Interactive comment on “The exponential eigenmodes of the carbon-climate system” by M. R. Raupach***

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Raupach proposes a theoretical framework to explain the near-constancy of a range of ratios among variables of the climate-carbon cycle system (the airborne fraction (AF), the cumulative airborne fraction (CAF), the sink uptake rate ( $k_S$ ), and the ration  $T/QE$  of warming ( $T$ ) to cumulative carbon emissions ( $QE$ )) over the historical period and to explore the validity of this constancy in the future. The author demonstrates that for linear systems (Lin) with exponential forcing (Exp) all ratios among fluxes and perturbed state variables are constant. He further shows that this LinExp idealization applies approximately to the climate-carbon system over the historical period. It then follows from the theory that AF, CAF,  $k_S$  and  $T/QE$  are constant, consistent with observations. Given the likely breakdown of both the Lin and Exp idealizations, the author shows that these

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quantities will no longer be constant in the future, except for the ratio  $T/QE$ .

### General comments

This is an interesting paper as it proposes a consistent theoretical framework explaining the observed constancy of some ratios among variables of the climate-carbon system, and their deviation from constancy under future scenarios. The paper is clearly structured and well written. A bit more care could be devoted to the validation of the simple climate-carbon cycle model used to explore the validity of the LinExp idealization in the future, as the version of the model used in this paper has not been previously published.

### Specific comments

Abstract, last sentence, “This theory assists in establishing both the basis and limits of the widely assumed proportionality between  $T$  and  $QE$ , at about 2 K per trillion tons of carbon.” This sentence is misleading. At first, I read it to suggest that “the limit of the widely assumed proportionality between  $T$  and  $QE$  is established at 2 K per trillion tons of carbon”, a limit not supported by the findings in the paper.

p. 1111, l. 21: What is the distinction between impulse response function (IRF), a concept often used in the literature, and pulse response function (PRF) as used in this paper?

p. 1112, l. 23, “subject to checking later”: Please provide a specific reference.

p. 1121, l. 16-17, “Figure 6 shows good agreement . . .”: It is difficult to see this with the axis scaling used in Fig. 6. I suggest to include an additional figure showing  $[CO_2]$  and  $T$  over the historical period only.

p. 1121, l. 21, “. . . and agree well with model ensemble projections of IPCC AR4”. Which projections are you referring to? The proportionality of  $T$  and  $QE$  was not discussed in AR4, nor can it be inferred from most AR4 models because of lack of an interactive carbon cycle. More appropriate references are C4MIP models, for which

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T/QE is analyzed in Matthews et al. (2009).

p. 1122, l. 15: Is “conservative” the right word here? Perhaps use “less sensitive”?

p. 1126, l. 1: It has been suggested that the near-constancy of T/QE over time arises from a cancellation of a decreasing CAF, and an increasing temperature change per unit atmospheric CO<sub>2</sub> (Matthews et al., 2009). How do the findings in this paper relate to this hypothesis?

p. 1123, l. 18, “. . .are within the range found in carbon-climate model intercomparisons”. Which quantities did you compare exactly? The [CO<sub>2</sub>] values are not adequate terms of comparison because of the different emission scenarios used in C4MIP and this study.

p. 1124, l. 3: I suggest to be more specific and replace “far in the future” with “after year 3000”.

p. 1126, l. 6: A reference to McDougall et al., Nat. Geosc., 2012 could be included.

p. 1134, Eq. A30: It is not immediately obvious how you obtained the equality in Eq. A30. Provision of a bit more detail would be helpful.

p. 1149, Table 3: It would be helpful if you could provide actual values for the parameters in the second half of the table, instead of referring the reader to R2011.

#### Editorial comments

p. 1110, l. 11: There is an extra “is”.

p. 118, l. 12: The sentence is incomplete.

p. 1130, Eq. A18: In my version, there appears to be a dot on top of the L.

p. 1137, l. 6: There is an extra “the”.

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