**Climate Dynamics manuscript No.**
(will be inserted by the editor)

# Shortwave and longwave contributions to global warming under increasing $CO_2$.

**Aaron Donohoe · Kyle C. Armour · Angeline G. Pendergrass**

Manuscript submitted November 6, 2013

## REFERENCES

Murphy, D., S. Solomon, R. Portmann, K. Rosenlof, and F.P.M., 2009: An observationally based energy balance for the earth since 1950. *J. Geophys. Res.*, **114**, D17 107.

Aaron Donohoe · K.C. Armour

Dept. of Earth, Atmospheric and Planetary Sciences, Room Number 54-918, 77 Massachusetts Avenue, Cambridge, MA 02139-4307. E-mail: thedhoe@mit.edu

A.G. Pendergrass

Department of Atmospheric Sciences, University of Washington, Seattle, Washington

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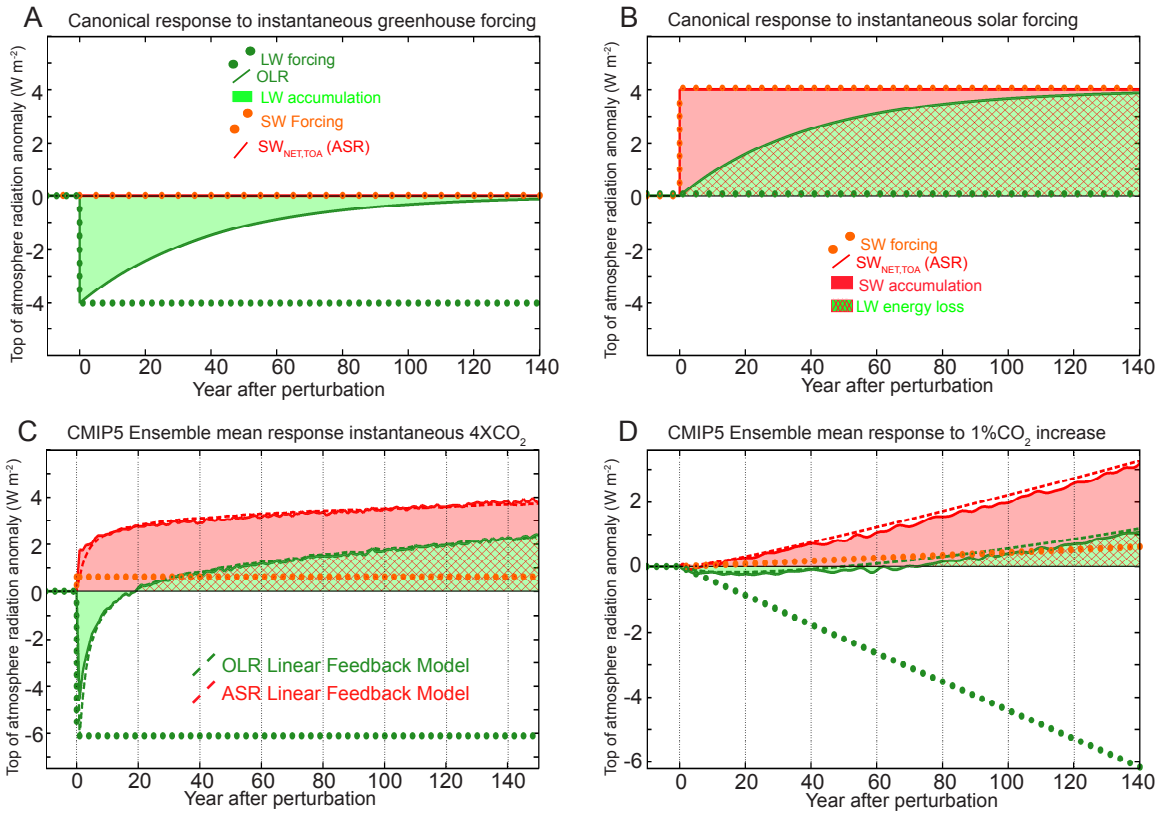


FIG. 1. (A)Idealized response of global mean radiation at the top of atmosphere to an instantaneous greenhouse forcing (green dots) assuming no shortwave feedback and a radiative adjustment e-folding time of 20 years. The solid green line is the OLR. The red line is the anomaly in net shortwave at the TOA (ASR). The shaded green area is the longwave energy accumulation. (B) As in (A) but in response to an instantaneous SW forcing (red dots). In this case, the net energy accumulation is the difference between the SW energy accumulation (the shaded red area) and the LW increase (the hatched green area where the hatching indicates that the LW response leads to a cooling of the climate system). (C) The ensemble average global mean TOA response to an instantaneous $CO_2$ quadrupling in the CMIP5 4X$CO_2$ experiments. The shaded area represents the energy accumulation by SW (red) and LW (green) anomalies and the hatched red area indicates energy loss by LW processes. The dashed red and green lines show the predicted ensemble average ASR and OLR response from the linear feedback model used in this study. (D) As in (C) except for the CMIP5 ensemble average radiative response in the 1% $CO_2$ increase per year experiments.

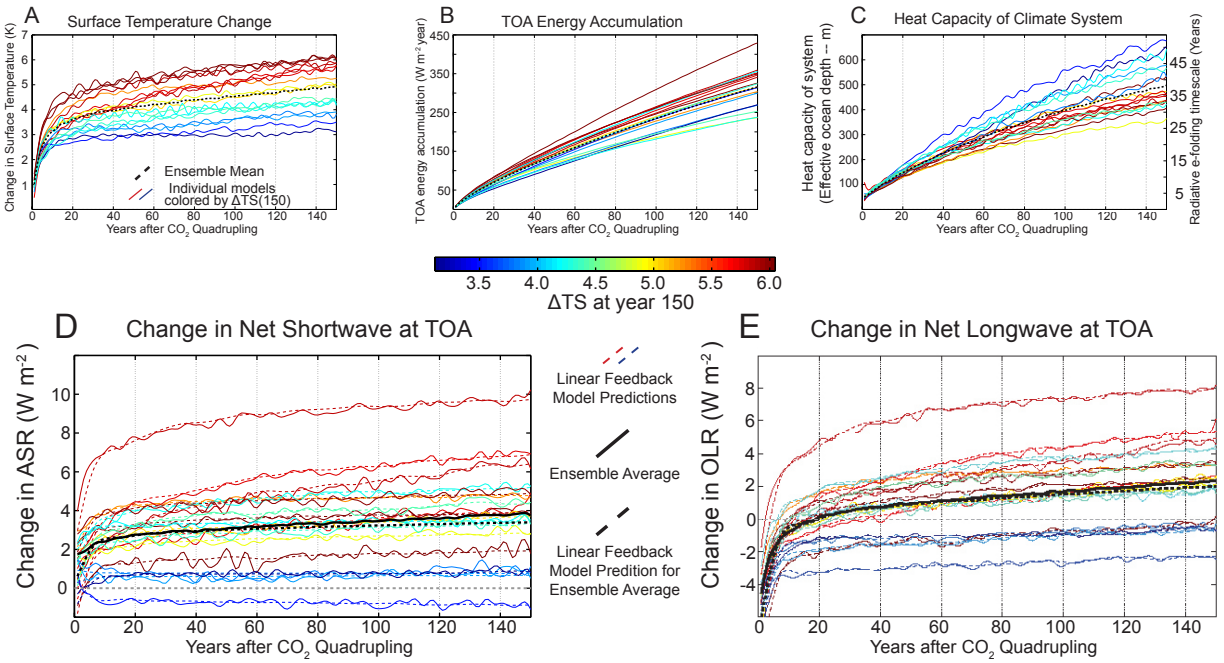


FIG. 2. (A) Time series of global mean surface temperature change in the CMIP5 instantaneous $CO_2$ quadrupling experiments. The individual models are indicated by the colored lines and are color coded by the temperature change at year 150 (with color bar provided in the middle of the figure). The ensemble average is shown by the dashed black line. (B) Time series of TOA accumulated energy balance with the same color coding as shown in (A). (C) The heat capacity of the climate system defined as (B) / (A). The heat capacity is indicated in units of the heat capacity of a column of ocean on the left axis and units of radiative e-folding time scale given the heat capacity divided by the ensemble average longwave feedback (1.76 W $m^{-2}$ $K^{-1}$). (D) Time series of net shortwave radiation at TOA (ASR) anomlay relative to the PI in the CMIP5 4X$CO_2$ simulations. The solid lines are the GCM values and the dashed lines are the predictions of the linear feedback model using the GCM specific LW and SW forcing and feedbacks and heat capacities. The solid black line is the ensemble mean of the GCM and the dashed black line is the prediction of the linear feedback model using the ensemble averaged feedbacks, forcings and heat capacity. (E) as in (D) except for the OLR response.

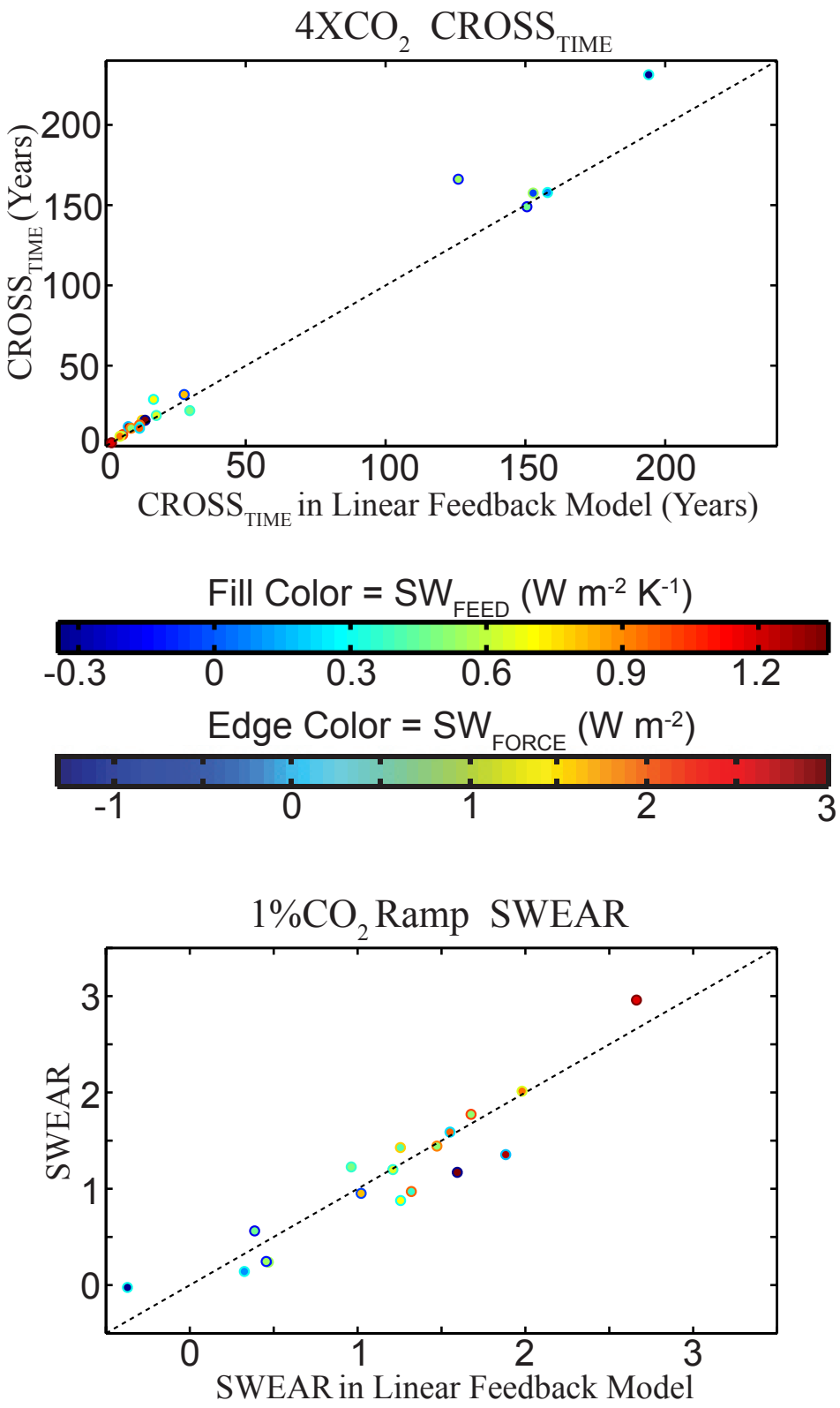


FIG. 3. (A) Scatter plot of $\mathrm{CROSS}_{TIME}$ in the CMIP5 4XCO$_2$ simulations and that predicted by the linear feedback model using the GCM specific $\mathrm{SW}_{FEED}$ and $\mathrm{SW}_{FORCE}$ and the GCM ensemble average $\mathrm{LW}_{FEED}$, $\mathrm{LW}_{FORCE}$ and heat capacity. The fill color of each circle indicates each GCM's $\mathrm{SW}_{FEED}$ and the edge color of each circle indicates the GCM's $\mathrm{SW}_{FORCE}$ with scales given by respective colorbars in the middle of the figure. The black dashed line is the 1:1 line. (B) As in (A) except for the SWEAR value in the 1% CO$_2$ increase runs.

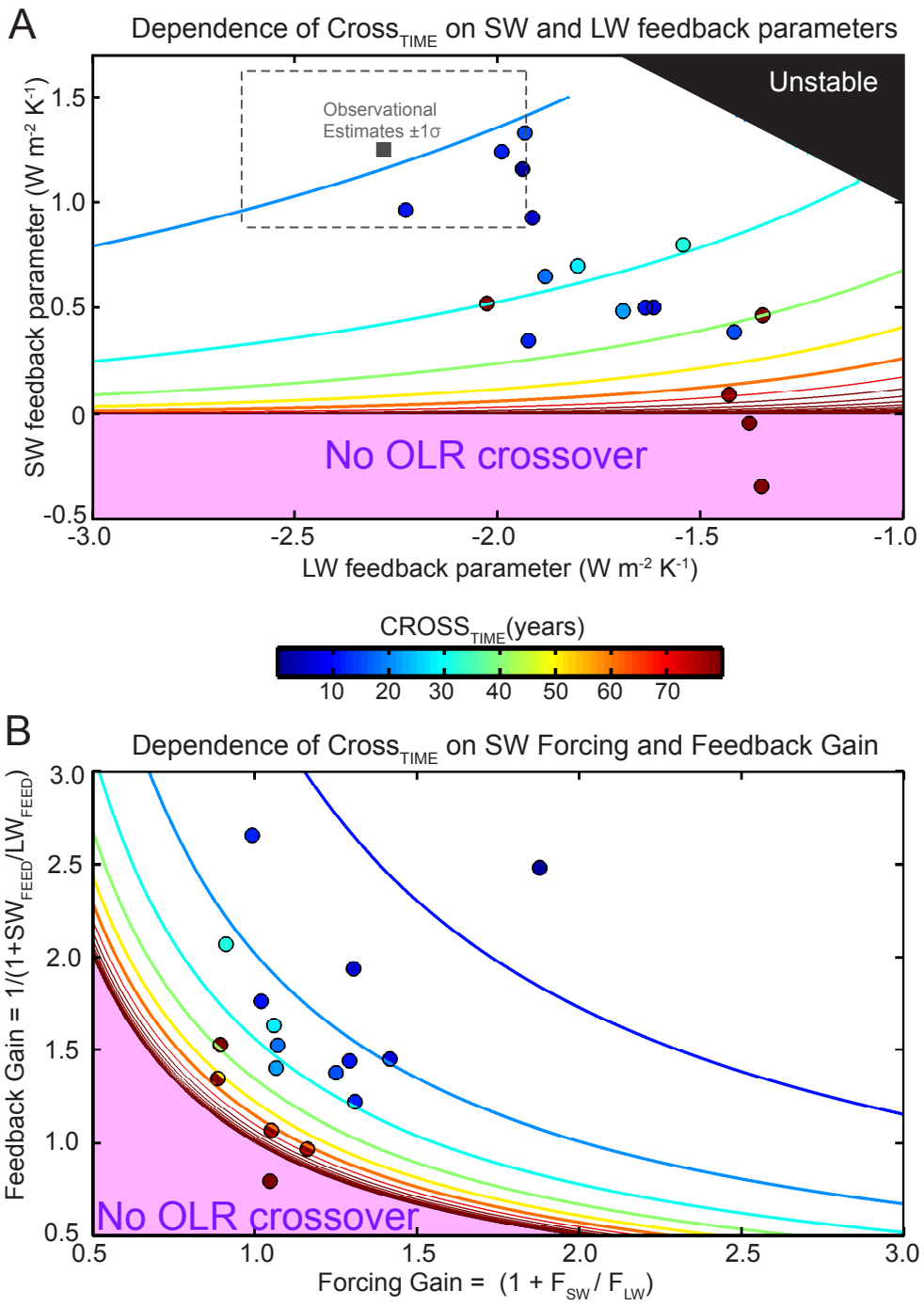


FIG. 4. (A) The sensitivity of CROSS$_{TIME}$ to longwave and shortwave feedback parameters (LW$_{FEED}$ and SW$_{FEED}$) in the linear feedback model of the response to an instantaneous greenhouse forcing assuming the forcing is all in the longwave and using a time invariant heat capacity of 33 W m$^{-2}$ year K$^{-1}$ – the GCM mean over the first 100 years). The contour interval is 10 years (the colorbar is below the panel). The shaded black region is the parameter space over which no equilibrium solution exists and the shaded purple region is the parameter space over which the OLR never returns to its unperturbed value. The individual GCM results are given by the circles which are color coded by the CROSS$_{TIME}$ in the model with the colorbar to the right. The filled gray square and the dashed lines represent the observational estimates of LW$_{FEED}$ and SW$_{FEED}$ ± one standard deviation (σ) taken from Murphy et al. (2009)(B) The sensitivity of CROSS$_{TIME}$ to the shortwave forcing gain (G$_{FORCE}$) and shortwave feedback gain (G$_{FEED}$) assuming an e-folding time equal to 29 years (the GCM mean) in Equation XXXXXX.