An Estimation of the Efficacy of Methane Radiative Forcing Using Radiative Kernels

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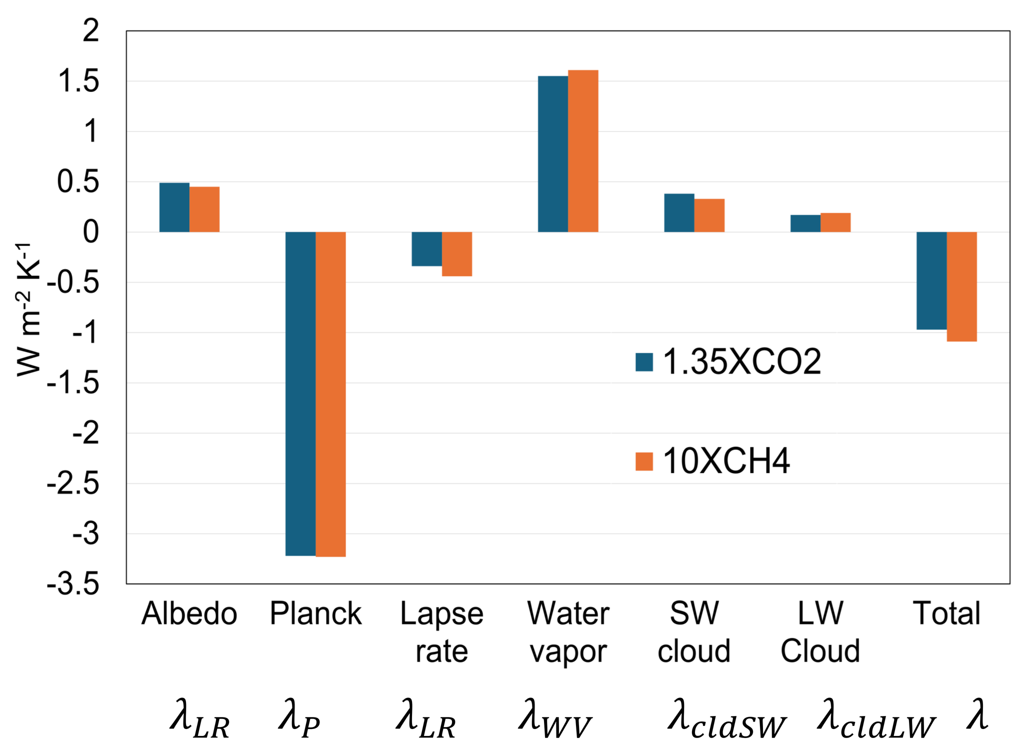
Objective

- Climate feedbacks are processes accompanying climate change that amplify or dampen the initial climate response to radiative forcing.
- In this study we estimate how, for comparable global mean surface warming in CO_2 and CH_4 forcing experiments, differing spatial patterns of radiative forcing are associated with distinct feedback responses.

Model & Experiments

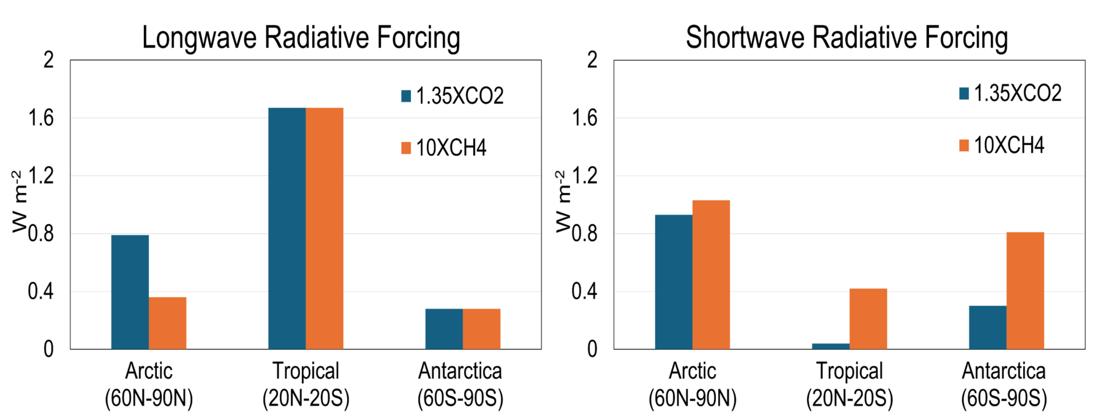
- We used the NCAR CESM 1.0.4 CAM5 model in two configurations:
  1) Prescribed Sea Surface Temperature (SST)
  2) Slab Ocean Model (SOM)
- Experimental setup:
  1) Control run ('CTL')
  2) A 35% increase in CO_2 concentrations relative to preindustrial values ('1.35XCO2').
  3) A tenfold increase in CH_4 concentrations relative to preindustrial values ('10XCH4').

Feedback Parameters

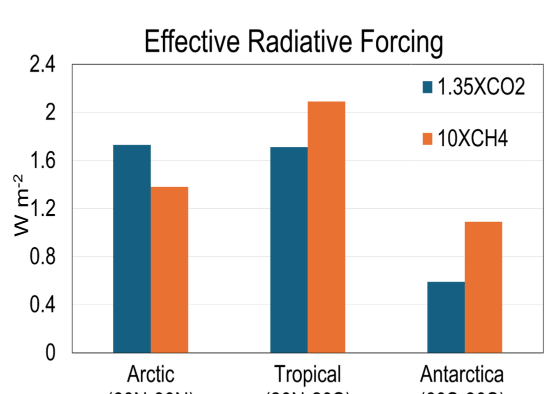


- Individual feedback parameters are estimated using the radiative kernel technique, and cloud feedbacks are estimated by calculating the adjusted change in cloud radiative forcing (Shell et al., 2008; Soden et al., 2008).

Radiative Forcing (all-sky)

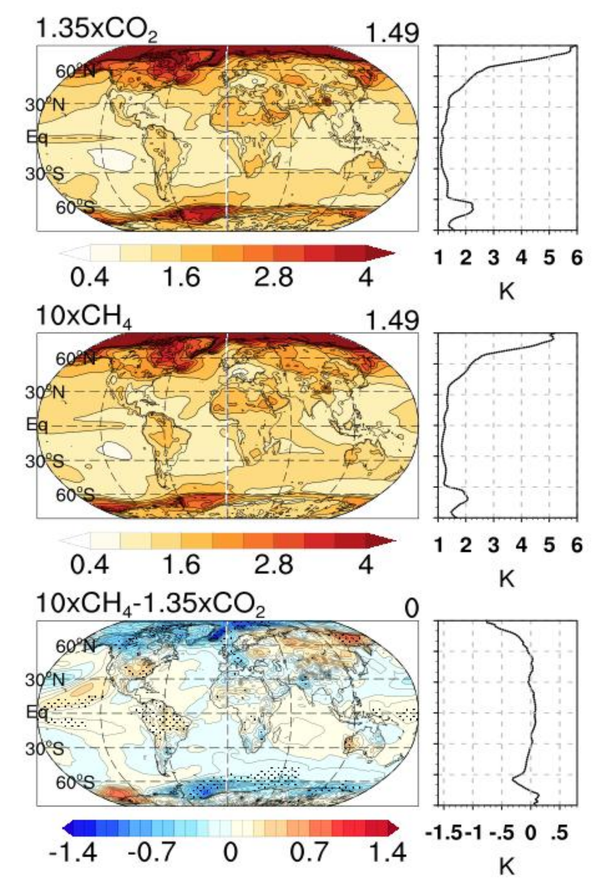


- Longwave (LW) forcing for CO_2 is larger in the Arctic and comparable in the tropics.

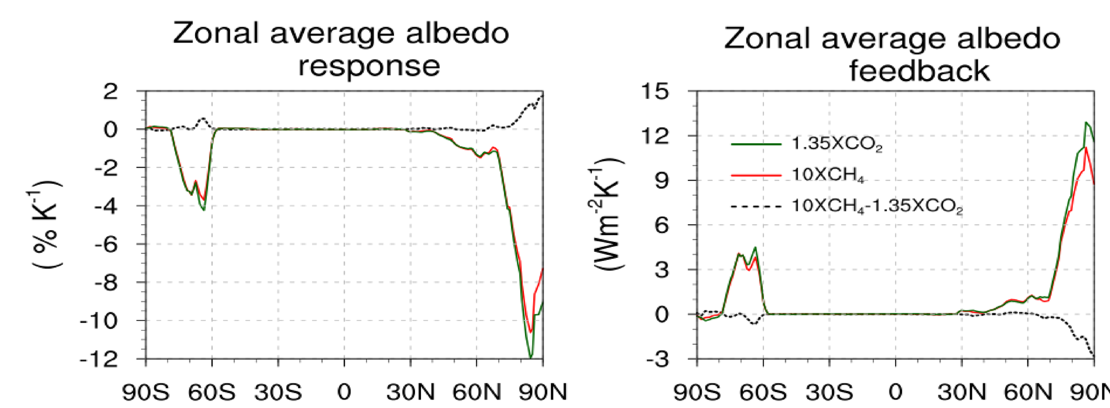


- Effective radiative forcing (ERF) for CH_4 (1.68 W m^{-2}) is larger than CO_2 (1.48 W m^{-2}); the larger ERF is mainly due to the large shortwave (SW) forcing across latitude belts for CH_4.

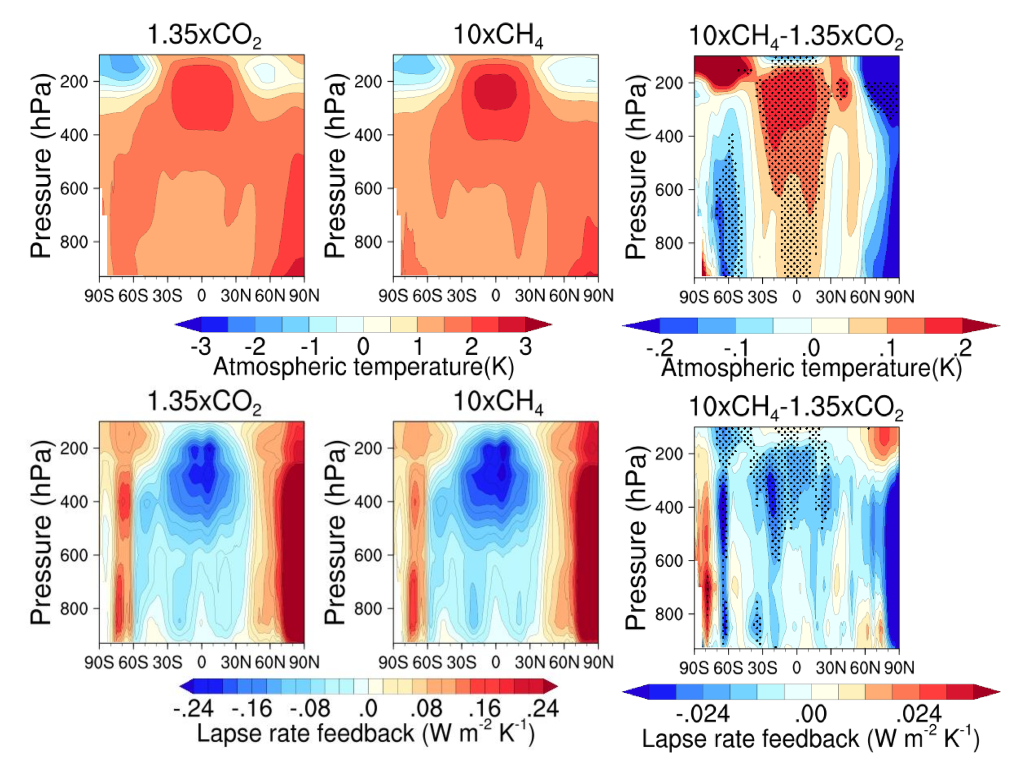
Surface Temperature Change & Surface Albedo Feedback



- Surface temperature change (ΔT_s) is larger for CO_2 in Arctic latitudes and compensated by larger warming by CH_4 in tropics and Antarctic latitudes.
- Stronger polar warming leads to larger albedo feedback for CO_2 (0.49 W m^{-2} K^{-1}) compared to CH_4 (0.45 W m^{-2} K^{-1}). CH_4's atmospheric SW absorption reduces surface SW radiation compared to CO_2.

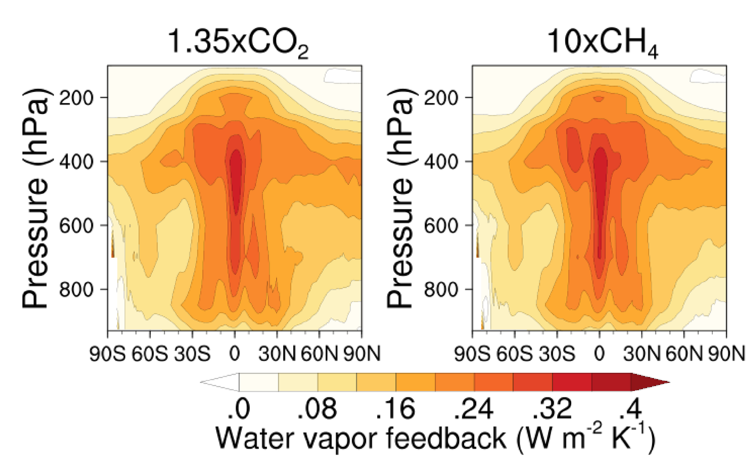


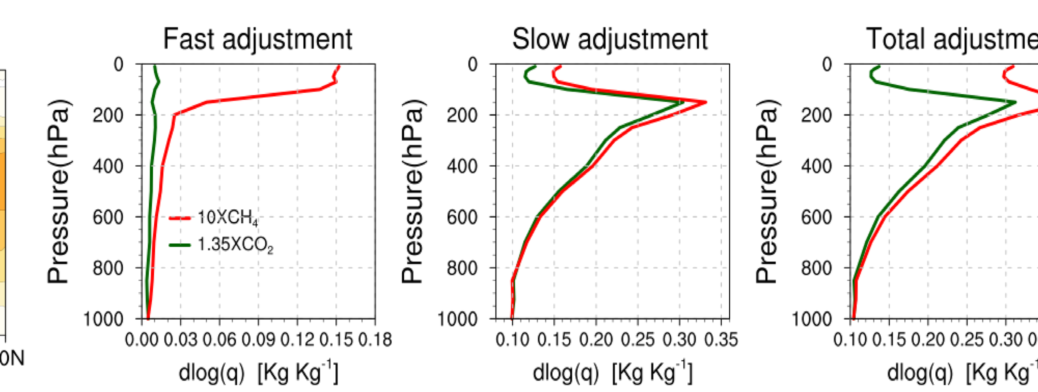
Atmospheric Temperature Change & Lapse Rate Feedback

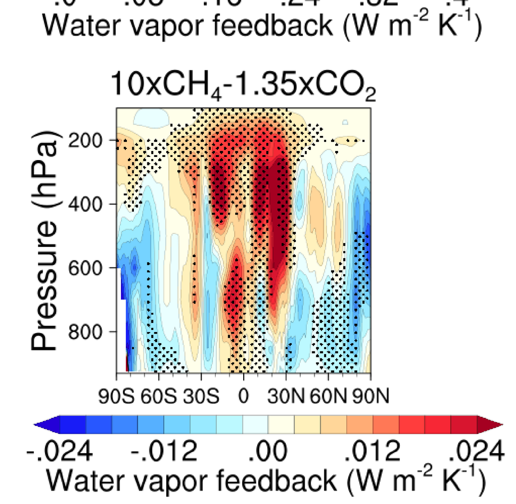


- In low latitudes, more upper-level warming in CH_4 case, due to larger low latitude warming as well as CH_4's SW absorption in upper tropospheric and lower stratospheric (UTLS) regions, translates into more negative λ_{LR}.
- In Artic regions, CO_2 has more positive λ_{LR} compared to CH_4, owing to larger warming for CO_2 especially in low to mid troposphere.

Water Vapor Feedback & Specific Humidity Change

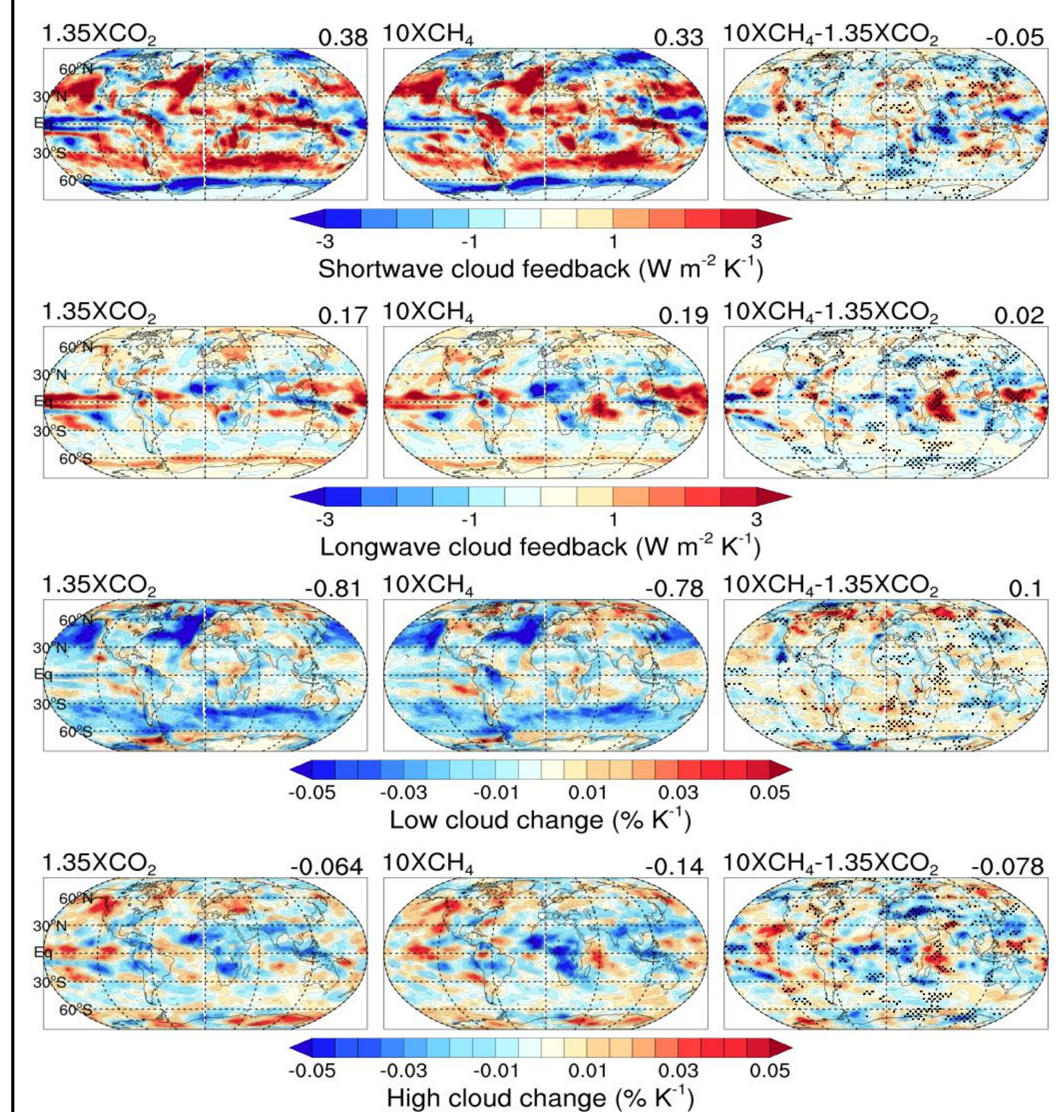






- At constant relative humidity, larger specific humidity (q) change in CH_4 in the tropical atmosphere translates to more positive λ_{WV} for CH_4.
- λ_{WV} is positive (1.55 for CO_2, 1.61 W m^{-2} K^{-1} for CH_4) in both the cases. Significant differences appear in λ_{WV}, especially in the tropical upper troposphere, where the LW kernel is largest.

Cloud Fraction Change & Cloud Feedbacks



- Owing to non-linearity of cloud feedback, we cannot use the kernel method, and calculated cloud feedback as the difference in cloud radiative forcing (CRF) (Ramanathan et al., 1977) between each forcing experiment ('1.35XCO2' & '10XCH4') and respective control ('CTL') run.
- Spatial patterns of cloud fraction change are similar in both cases, but CO_2 induces larger low cloud reductions, leading to stronger positive SW cloud feedback.
- LW cloud feedback differences, from reduction and formation of high clouds, lead to comparable global effects between CO_2 and CH_4 cases.

Summary & Conclusions

- CH_4 has a larger ERF compared to CO_2 to achieve the same global mean surface temperature change, and CH_4's efficacy is less than 1. Efficacy of the CH_4 using the feedback parameter,

$$e_{CH4} = \frac{\lambda_{CO_2}}{\lambda_{CH_4}} = \frac{-0.97}{-1.09} = 0.89$$

- The differences in λ mainly arise from: more negative (by -0.10 W m^{-2} K^{-1}) λ_{LR}, which is compensated to some extent by more positive (by 0.06 and 0.02 W m^{-2} K^{-1}) λ_{WV} and λ_{cldLW} respectively. Less positive λ_α and λ_{cldSW} also contribute to more negative λ for CH_4 forcing.
- CH_4's near-infrared SW absorption warms UTLS regions, leading to greater reduction in high clouds compare to low clouds, with the latter showing less reduction in CH_4 case.
- In polar regions in spite of larger SW forcing from CH_4 at top of the atmosphere, its albedo feedback is smaller owing to atmospheric SW absorption by CH_4.

References

- Ramanathan, V., 1977: Interactions between Ice-Albedo, Lapse-Rate and Cloud-Top Feedbacks: An Analysis of the Nonlinear Response of a GCM Climate Model.
- Shell, K. M., Kiehl, J. T. & Shields, C. A., 2008: Using the radiative kernel technique to calculate climate feedbacks in NCAR's Community Atmospheric Model. Journal of Climate 21, 2269–2282, https://doi.org/10.1175/2007JCLI2044.1.
- Soden, B. J., and I. M. Held, 2006: An Assessment of Climate Feedbacks in Coupled Ocean–Atmosphere Models. Journal of Climate, 19, 3354–3360, https://doi.org/10.1175/JCLI3799.1.

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