Lapse rate, water vapor and heat transport feedbacks and their role in polar amplification - estimated "on-line" in a general circulation model

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Summary

A series of aquaplanet experiments with an atmosphere GCM investigates the relative roles of forcing and feedbacks in creating a polar amplified temperature response to a CO_2-doubling. By locking the feedbacks on-line, we are able to determine the temperature response associated with the individual feedbacks.

The surface albedo feedback is excluded in these experiments and the cloud feedback is found to give only a small response. The water vapor feedback is found to double climate sensitivity, both globally *and* regionally. The forcing is seen to counter polar amplification while the Planck and lapse rate feedbacks act strongly in favor.

Experimental configuration

The NCAR CAM3 is run at T42 horizontal resolution coupled to an aquaplanet slab ocean model. We take water vapor and cloud fields from standard $1xCO_2$ and $2xCO_2$ experiments and read them back into the model at 1-hour intervals in both fixed SST (dom) and slab ocean model experiments.

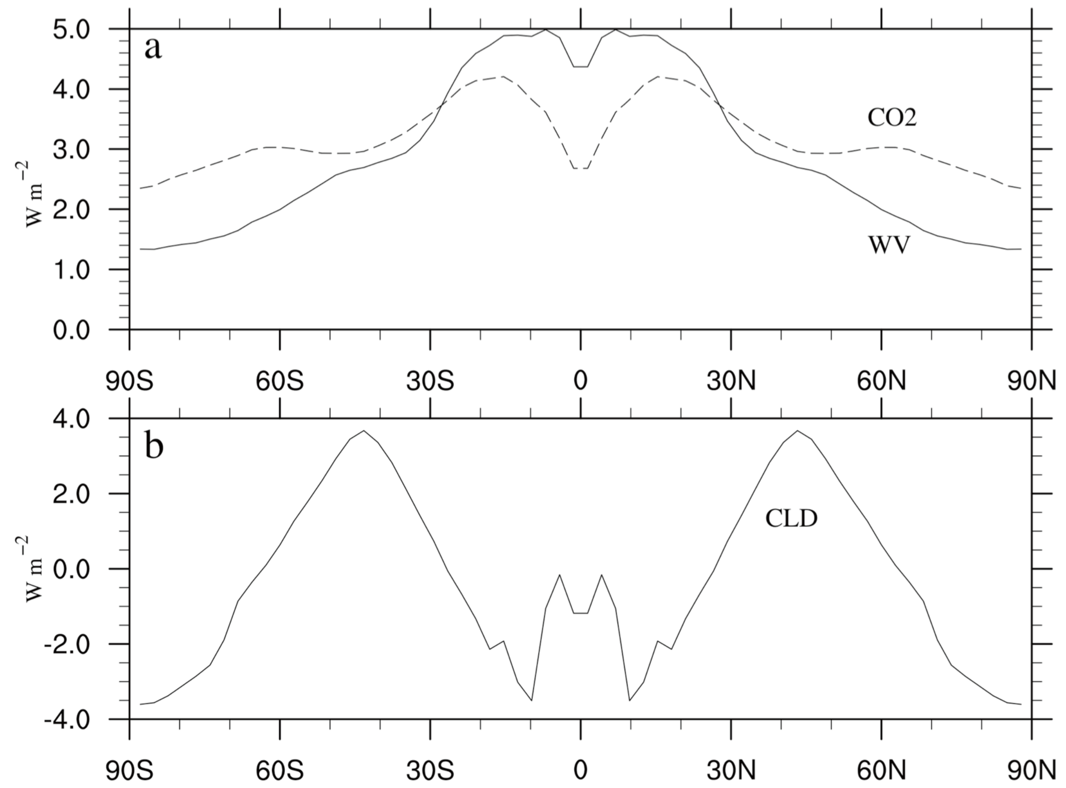
From the dom experiments we can asses the individual radiative effects of the forcings and the feedbacks. From the slab ocean experiments we can determine the climate response associated therewith.

Experiment	CO_2 conc	Water vapor	Cloud	shifted
domCTRL	1×	1×	1×	
domCTRLshift	1×	1×	1×	1yr
domCLD	1×	1×	2×	
domWV	1×	2×	1×	
domWV&CLD	1×	2×	2×	
domWV&CLDshift	1×	2×	2×	1yr
domCO2shift	2×	1×	1×	1yr
CTRL	1×	1×	1×	1yr
CLD	1×	1×	2×	
WV	1×	2×	1×	
WV&CLD	1×	2×	2×	1yr
CO2	2×	1×	1×	1yr
CO2&CLD	2×	1×	2×	
CO2&WV	2×	2×	1×	
CO2&WV&CLD	2×	2×	2×	1yr

Forcing and feedbacks

The top panel shows the forcing (CO2) and the radiative effect of the water vapor feedback (WV) for a doubling of CO_2.

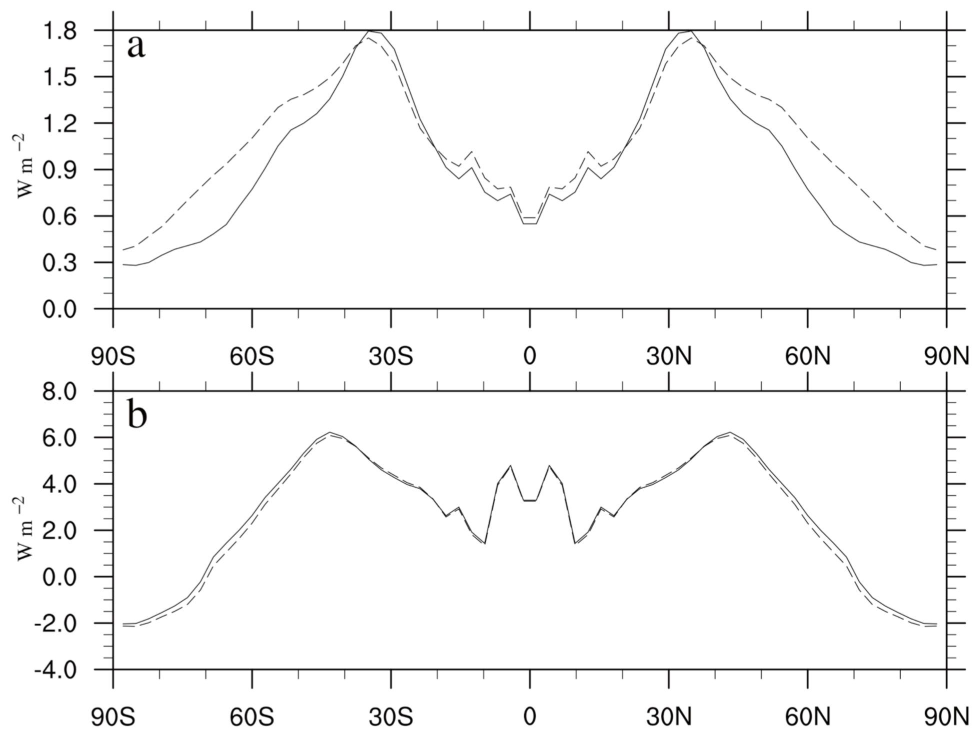
Both have global means of about 3.5 W m^{-2}, but the WV has a considerably stronger low-latitude weight. The bottom panel shows the effect of clouds which globally is very small (~0.02 W m^{-2}).



Water vapor and cloud de-correlation

The natural correlation between clouds and water vapor in the free-feedbacks experiments cannot be maintained when water vaper and cloud fields from different climates are mixed. This de-correlation has a considerable radiative effect (top panel, solid domCTRLshift−domCTRL and dashed domWV&CLDshift−domWV&CLD).

The effect is avoided by shifting cloud and water vapor fields relative to each other in all runs including the CTRL. The bottom panel shows the effect of using $2xCO_2$ water vapor and cloud fields in the shifted case and in the unshifted case (solid domWV&CLDshift-domCTLshift, dashed domWV&CLD−domCTRL).

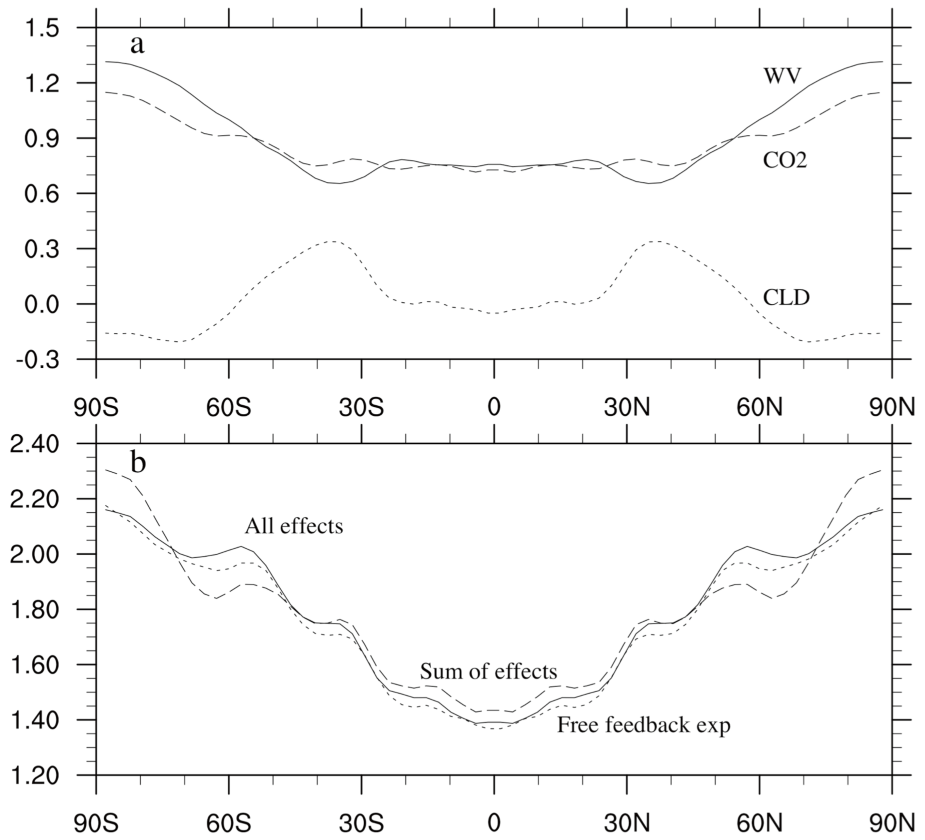


Surface temperature response

The top panel shows the response in surface temperature due to forcing (CO2), water vapor (WV) and clouds (CLD). The radiative effect of the water vapor and the associated atmospheric circulation changes are seen to double climate sensitivity both globally and regionally.

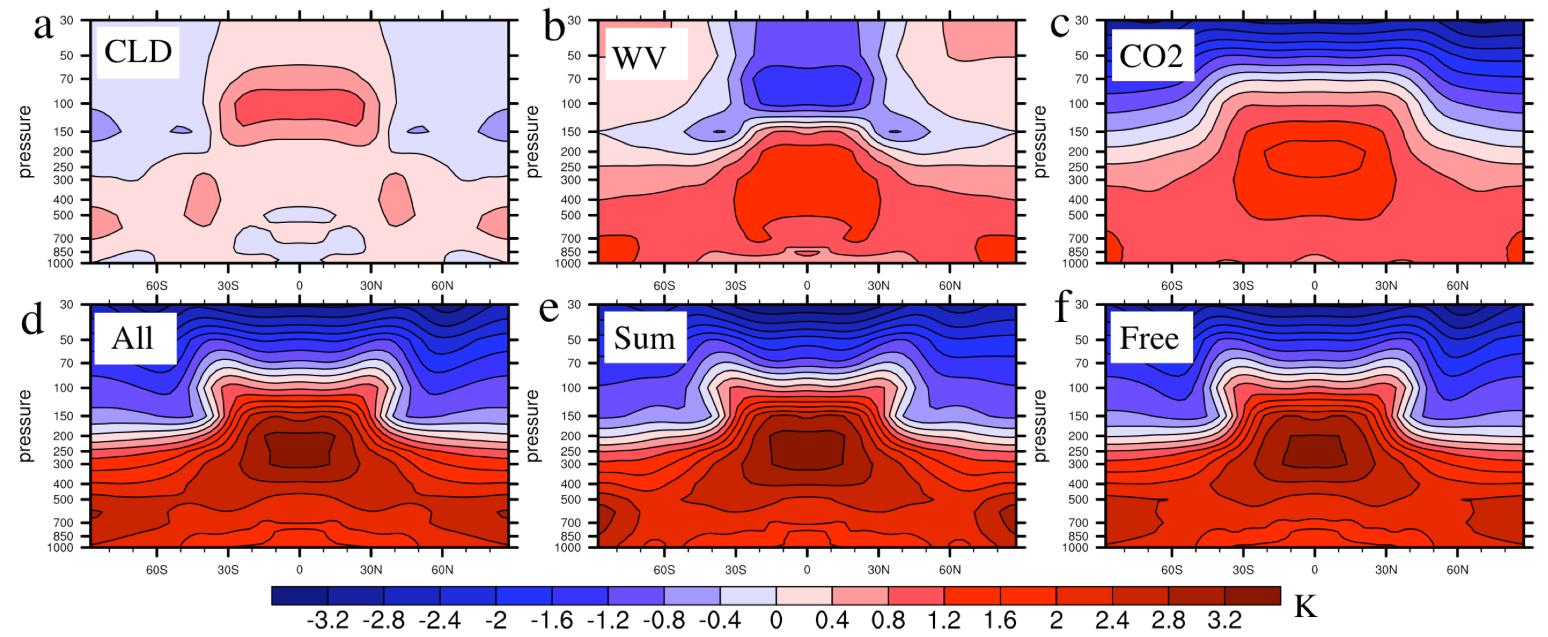
The polar amplified response associated with the forcing only is reinforced by the water vapor-induced climate change.

The bottom panel illustrates the linearity of the system's response by comparing the sum of the curves in the upper panel to the response in the case where all three are changed at the same time and that of the free-feedbacks experiments.



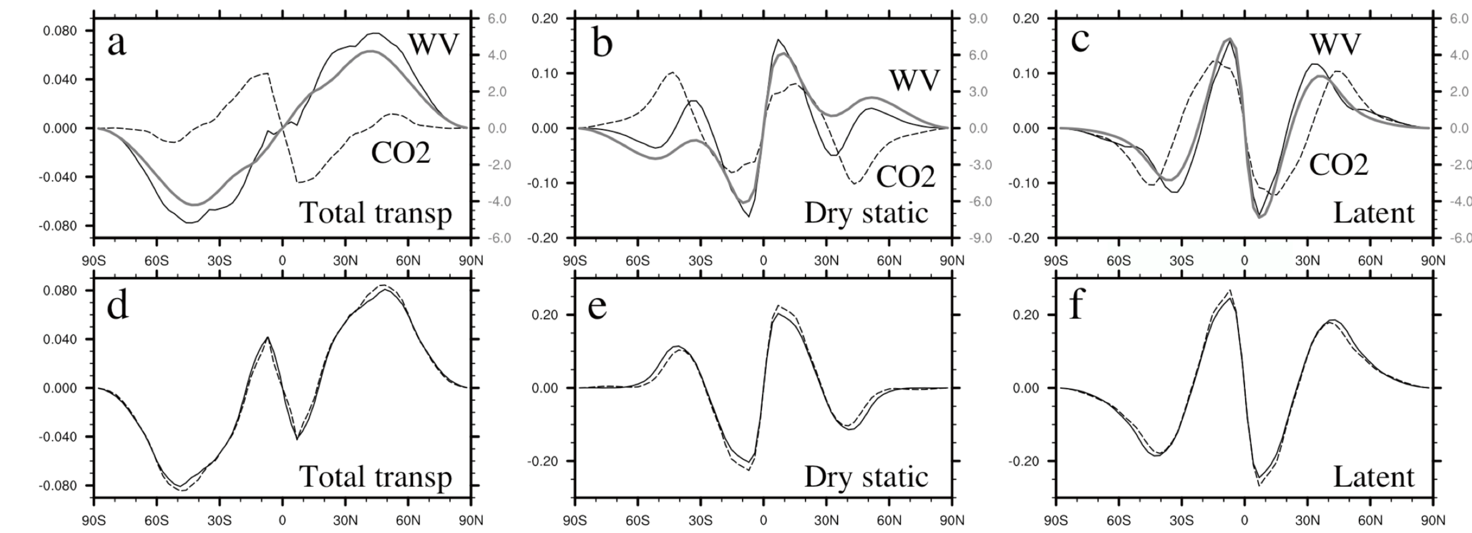
Atmospheric temperature response

The top panels show the responses to the individual changes (CLD, WV and CO2) while the lower panels illustrate the linearity of the response.



Meridional heat transports

A change in meridional energy transport in the WV experiment is exactly such as to counter the differences in radiative effects between WV and CO2. Due to this change, the surface temperature responses in WV and CO2 are very similar.



Polar amplification and the individual feedbacks

The table shows global, low- and high-latitude values of the individual feedback parameters (W m^{-2} K^{-1}). Shown also is the polar amplification (defined as the ratio of high- to low-latitude warming) as found when setting the feedback to its global value everywhere and when eliminating it altogether. A value less than 1.2 indicates that the process acts *in favor* of polar amplification.

Feedback	Symbol	Global	0-30°	30-90°	PA with global FB	PA without FB
Full					**1.2**	
Forcing	F_{CO2}	3.4	3.8	3.0	1.5	
Temperature	λ_T	−4.3	−5.3	−3.4	0.5	
Planck	λ_0	−3.2	−3.5	−3.0	0.9	
Lapse rate	λ_{LR}	−1.0	−1.8	−0.4	0.6	0.4
Water vapor	λ_{wv}	2.1	3.0	1.4	2.7	1.4
Transport	λ_H	0	−0.3	0.2	0.9	0.9
Temp. incl transp	$\lambda_{T,H}$	−4.3	−5.1	−3.5	0.5	
WV incl transp	$\lambda_{wv,H}$	2.1	2.6	1.8	1.8	1.2

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