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An energy balance model exploration of the impacts of interactions between surface albedo, water vapour and clouds on polar amplification

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The interactions between surface albedo, water vapour and clouds, and how these interactions change with carbon dioxide (CO_2) concentrations in the atmosphere, are examined with a newly developed energy balance model. A particular focus is the non-linear interactions of these climate system attributes on polar amplification. Polar amplification is defined here as the ratio of the annual rate of surface warming over the polar regions (latitudes poleward of 60o) to the surface warming over equatorial regions (latitudes equatorward of 30o), and is termed the polar amplification factor. Changes in surface albedo plays a major role in polar amplification as might be expected, due to its amplifying effects of CO_2 -induced warming of the polar regions, and relatively small warming effects in the equatorial regions. When considered in isolation from the other climate system components, i.e. when water vapour and cloud cover are prescribed, changes in surface albedo result in a polar amplification factor of 4.83 for a doubling of CO_2, compared to 5.54 for the full feedback simulation, i.e. the simulation where all three components are allowed to simultaneously change with temperature. In our simple model framework, changes in surface albedo are responsible for ∼43% of the polar warming from the full feedback run, and ∼49% of the equatorial warming. The polar amplification for the simulation with isolated climate feedback from cloud cover variations is smaller than the simulation with isolated surface albedo feedback, mainly due to a weaker warming in the polar regions. The polar amplification factor for the isolated cloud cover feedback simulation is 3.73, contributing ∼30% of the warming in the polar regions to the full feedback simulation and ∼45% in the equatorial regions. The amplifying effect from changing surface albedo on polar warming and polar amplification is enhanced when surface albedo interacts with cloud cover or water vapour. The polar amplification factor is found to be largest (7.12) in the simulation when surface albedo and cloud cover are allowed to interact with the climate system, and water vapour is prescribed. However, the strongest warming in the polar regions is found for the full feedback simulation. In contrast to changes in surface albedo and cloud cover, water vapour also significantly enhances warming in the equatorial regions, which reduces polar amplification, even though water vapour enhances warming in the polar regions. The polar amplification factor for the simulation with an isolated water vapour feedback is 2.07. The contribution from the water vapour feedback to warming in the polar regions is ∼24% for the full feedback run, and ∼65% of the full feedback run in the equatorial regions.