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Factors for the meridional and vertical asymmetries of the global warming.

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This paper examines several prominent thermodynamic and dynamic factors responsible for the meridional and vertical warming asymmetries using a moist coupled atmosphere-surface radiative transportive climate model. A coupled atmosphere-surface feedback analysis is formulated to isolate the direct response to an anthropogenic greenhouse gas forcing from individual local feedbacks (water vapor, evaporation, surface sensible heat flux, and ice-albedo), and from the non-local dynamical feedback. For the same amount of anthropogenic greenhouse gases, the radiative forcing is stronger in low latitudes, leading to a direct response (initial warming) that is stronger in low latitudes in both the atmosphere and surface. By the physical nature of the greenhouse effect, the initial warming is always stronger at the surface in both low and high latitudes. Due to the non-perfect absorber nature of the atmosphere, the initial atmospheric warming is also negatively correlated with the strength of (local and non-local) dynamic heating in the mean state. Because of a stronger mean dynamic heating in high latitudes due to the poleward heat transport, the atmospheric warming in high latitudes is much weaker than the warming implied by the external radiative forcing alone. As a result, the initial vertical warming asymmetry is weaker in low latitudes than in high latitudes. The water vapor feedback, as the external greenhouse gases, strengthens both the meridional and vertical asymmetries of the initial warming. The joint effect of the ice-albedo and dynamical greenhouse-plus feedbacks acts to amplify the high latitude surface warming whereas both the evaporation feedback and dynamical greenhouse-minus feedback cause a reduction of the surface warming in low latitudes, leading to a final surface warming that is stronger in high latitudes than low latitudes. It is the local dynamical feedback, mainly through cooling the surface by evaporation and warming the atmosphere by condensation, that acts to oppose the initial vertical warming asymmetry. The much stronger evaporation feedback leads

to a final warming in low latitudes that is stronger in the atmosphere than the surface. In high latitudes, both the dynamical greenhouse-plus and surface heat flux feedbacks act to oppose the vertical asymmetry of the initial warming whereas the ice-albedo feedback acts to strengthen it. However, the joint effect of the local and non-local dynamical feedbacks is too small to reverse the strengthened initial vertical warming asymmetry in high latitudes.