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Why are subtropical low-level cloud feedbacks positive in climate models?

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Climate models generally show positive cloud feedbacks in the subtropics in response to globally increasing sea surface temperatures (SSTs), associated with reductions in low-level cloud fraction. Previous studies have shown that idealised 'aquaplanet' experiments forced with zonally symmetric SSTs subject to a uniform 4K warming reproduce the global cloud feedbacks from more realistic model configurations well. Here we investigate the physical mechanisms of positive subtropical low-level cloud feedback by performing sensitivity experiments with HadGEM2-A in aquaplanet configuration.

We explore the possibility that low-level cloud feedbacks are positive because of the relatively weak rate of increase global precipitation and surface evaporation with global SST, which is limited to 2-3%/K by the radiative cooling rate of the atmosphere, compared to the 7%/K increase in specific humidity required to maintain boundary layer relative humidity with warming, which is determined by the saturation specific humidity via the Clausius-Clapeyron relation.

Various studies have argued that if relative humidity is approximately constant under climate change then horizontal and vertical gradients in specific humidity will increase at 7%/K, implying a stronger rate of drying of the boundary layer by large scale advection and sub-grid mixing. Here we test the hypothesis that the low-level cloud feedback is positive because surface evaporation is unable to increase at the 7%/K which would be required to balance this enhanced drying in the subtropical boundary layer. We do this by prescribing a zonal climatology of surface evaporation in the HadGEM2-A aquaplanet experiments, and by forcing it to increase at 7%/K in a climate change experiment.

Forcing the surface evaporation to increase at 7%/K results in a negative shortwave cloud feedback and an increase in low-level cloud fraction in the subtropics between 10 and 30 degrees N/S, reversing the sign of the feedback and low-level cloud response compared to the standard model configuration. The signs of the global cloud feedback and the global low-level cloud fraction response are also reversed. These results support the hypothesis that positive low-level cloud feedback is caused by the relatively weak rate of increase in surface evaporation compared to that of the saturation specific humidity in the boundary layer.