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Arctic Oscillation regime behaviour in an idealized atmospheric circulation model as a result of almost-intransitivity

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A quasi-geostrophic, hemispheric three-level atmospheric model with horizontal T21 resolution is driven by Northern Hemisphere's T21 topography, whereas its thermal and surface forcing are determined by an automated, iterative tuning procedure. The zonal parts of the forcings are tuned to produce a realistic zonal wind profile for northern winter, while non-zonal thermal forcings are adjusted to obtain time-averaged non-zonal diabatic heating fields equal to wintertime observations. The perpetual winter model simulation reproduces observed wintertime climatology and patterns of low-frequency variability with accuracy. The model exhibits two significant circulation regimes which correspond to the positive and negative phase of the Arctic Oscillation (AO), respectively.

An explanation of the dynamical structures underlying the model's regime behaviour is suggested by the results of a series of model experiments, in which the tuning procedure is repeated using lower values of surface friction. The weaker surface friction is, the more distant and pronounced the two AO regimes become, indicated by increasing geopotential standard deviation at polar latitudes and also by the AO index distribution, the bimodality of which is becoming more and more extreme. The regime persistence, but also the model's sensitivity with respect to forcing changes dramatically increase. Due to this sensitivity, the tuning procedure fails to reproduce the observed zonal climate if the strength of the surface friction is below some critical value. Rather, the model's climate flips between the two extreme AO phases from one tuning

iteration to another, but still allows for rare jumps to the other regime, respectively.

Based on these results, the two regimes observed in the control simulation are interpreted as a feature of the attractor's large-scale geometry in phase space, not necessarily requiring the existence of steady states embedded in the attractor. In the case of very low surface friction, the attractor evidently consists of two lobes connected by a thin channel, a structure qualitatively similar to Lorenz' attractor. The almost-intransitivity of the system generates the persistence of the regimes, the irregularity of the transitions and ultra-low frequency variability. Increase of the surface friction makes the two lobes approach each other and strengthens the connection between them, thus shortening the lifetime of regimes and increasing the frequency of transitions.