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Rethinking wave-kinetic theory applied to zonal flows[1]

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Over the past two decades, a number of studies have employed a wave-kinetic theory to describe fluctuations interacting with zonal flows. Recent work has uncovered a defect in this wave-kinetic formulation: the system is dominated by the growth of (arbitrarily) small-scale zonal structures. Theoretical calculations of linear growth rates suggest, and nonlinear simulations confirm, that this system leads to the concentration of zonal flow energy in the smallest resolved scales, irrespective of the numerical resolution [1,2]. This behavior results from the assumption that zonal flows are extremely long wavelength, leading to the neglect of key terms responsible for conservation of enstrophy. A corrected theory, CE2-GO, is presented; it is free of these errors yet preserves the intuitive phase-space mathematical structure [1,2]. CE2-GO properly conserves enstrophy as well as energy, and yields accurate growth rates of zonal flow. Numerical simulations are shown to be well-behaved and not dependent on box size. The steady-state limit simplifies into an exact wave-kinetic form which offers the promise of deeper insight into the behavior of wavepackets. The CE2-GO theory takes its place in a hierarchy of models as the geometrical-optics reduction of the more complete cumulant-expansion statistical theory CE2 [3,4]. The new theory represents the minimal statistical description, enabling an intuitive phase-space formulation and an accurate description of turbulence-zonal flow dynamics.

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