STOCHASTIC AVERAGING AND JET FORMATION IN TURBULENT PLANETARY ATMOSPHERES

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Geophysical turbulent flows (atmospheric and oceanic) are characterized by their self-organisation into large scale coherent structures: jet-streams, cyclones, anti-cyclones [2]. These structures result from the balance between the energy injected by turbulent fluctuations and the energy dissipated, it is thus a non-equilibrium system. The jet streams are the main structures in the Earth atmosphere: jet streams are strong jets in high altitude and middle latitudes, and they are a consequence of the self-organization of geostrophic turbulence forced by baroclinic and barotropic instability.

In a turbulent context, the understanding of jet formation requires averaging out the effect of rapid turbulent degrees of freedom in order to describe the slow evolution of the jet structure. Such a task, an example of turbulent closure, is usually extremely hard to perfom for turbulent flows. We will present a theory in order to describe the effective dynamics of the large scales of these turbulent flows, in the context of the quasi-geostrophic model [7], following an approach developped in [5]. We prove that stochastic averaging can be performed explicitly in this problem, which is unusual in turbulent systems. We explain that this approach is valid when a time scale separation between the spin up (forcing and dissipation time of the zonal jet) and the inertial time exists. It is then possible to integrate out all fast turbulent degrees of freedom, and to get explicitly an equation that describes the slow evolution of zonal jets.

This equation is a stochastic differential equation for a one dimensional field (the zonal velocity), with multiplicative noise. This equation describes the attractors for the dynamics (alternating zonal jets, the number of which depends on the force correlation function), and the relaxation towards those attractors. We describe regimes where the system has several attractors for the same force correlation function.

The deterministic part of this equation is a non-linear Fokker-Planck equation, that was obtained previously on a phenomenological ground (SSST in [3] CE2 in [4], [6]), based on the study of a quasilinear approximation of the dynamics. Our theoretical result thus explains on a theoretical ground the past successes of quasi-linear approaches. It also allows to go further, as the stochastic part can explain departures from the quasi-linear approximations and explain rare transitions between two different attractors. This stresses the limitations of the quasilinear approximation.

Would this approach be relevant for describing the dynamics of planetary jets in more realistic models, for instance based on primitive equations ? As shown by recent numerical work ([1], see figure 1), a quasilinear approximation seems to give a good qualitative description of the jet stream structure, when compared with the full non-linear dynamics. Triggered by these very encouraging numerical results, we will discuss the generalization of our theoretical approach on more realistic models of the geostrophic turbulence. This will allow to go beyond the quasi-linear approach and will provide essential tools in order to predict very efficiently the self-organization of jets in planetary atmospheres.

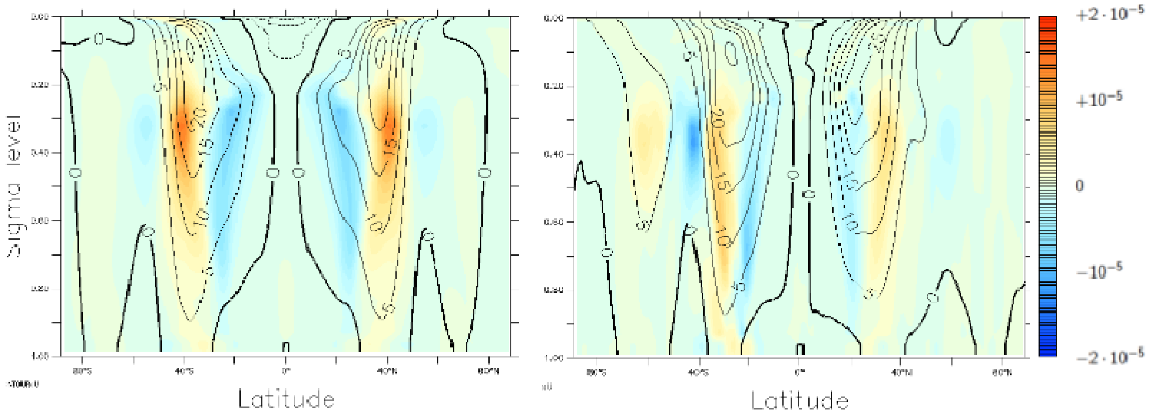

Figure 1. In the above figures are represented two results of numerical simulations of atmospheric flow (primitive equations on a rotating sphere). The sigma level represents the altitude. The colors represent the intensity of the Reynolds' stress (whose divergence is the contribution of turbulent fluctuations to the mean flow), and the black lines are the isolines of the mean flow (averaged in the direction parallel to the equator). We can see the formation of two strong jets (around 25 m/s), the jet streams. The result of the full non-linear simulation (left-hand figure) agrees with the result of the quasi-linear one (right-hand figure), particulary for the mean flow.

References

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