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Is 2-D turbulence relevant in the atmosphere?

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Starting with (Taylor, 1935), the paradigm of isotropic (and scaling!) turbulence was developed initially for laboratory applications, but following (Kolmogorov, 1941), three dimensional isotropic turbulence was progressively applied to the atmosphere. Since the atmosphere is strongly stratified, a single wide scale range model which is both isotropic and scaling is not possible so that theorists had to immediately choose between the two symmetries: isotropy or scale invariance. Following the development of models of two dimensional isotropic turbulence ((Fjortoft, 1953), but especially (Kraichnan, 1967) and (Charney, 1971)), the mainstream choice was to first make the convenient assumption of isotropy and to drop wide range scale invariance. Starting at the end of the 1970's this "isotropy primary" (IP) paradigm has lead to a series of increasingly complex isotropic 2D/isotropic 3D models of atmospheric dynamics which continue to dominate the theoretical landscape. Justifications for IP approaches have focused almost exclusively on the horizontal statistics of the horizontal wind in both numerical models and analyses and from aircraft campaigns, especially the highly cited GASP (Nastrom and Gage, 1983), (Gage and Nastrom, 1986; Nastrom and Gage, 1985) and MOZAIC (Cho and Lindborg, 2001) experiments. Since understanding the anisotropy clearly requires comparisons between horizontal and vertical statistics/structures this focus has been unfortunate.

Over the same thirty year period that 2D/3D isotropic models were being elaborated, evidence slowly accumulated in favour of the opposite theoretical choice: to drop the isotropy assumption but to retain wide range scaling. The models in the alternative paradigm are scaling but strongly anisotropic with vertical sections of structures becoming increasingly stratified at larger and larger scales albeit in a power law manner; we collectively refer to these as "SP" for "scaling primary" approaches. Early authors explicitly using SP models to explain their observations include ((Van Zandt, 1982), (Schertzer and Lovejoy, 1985), (Schertzer and Lovejoy, 1987), (Fritts et al., 1988), (Tsuda et al., 1989), (Dewan, 1997; Lazarev et al., 1994), (Gardner et al., 1993), (Hostetler and Gardner, 1994). In addition, many experiments found non-standard vertical scaling exponents thus implicitly supporting the SP position. Today, state-of-the-art lidar vertical sections of passive scalars (Lilley et al., 2004) or satellite vertical radar sections of clouds give direct evidence for the corresponding scaling (power law) stratification of structures. State-of-the-art drop sondes have even been used to show that the IP standard bearer - 3D isotropic Kolmogorov turbulence - apparently doesn't exist in the atmosphere at any scale at least down to 5 m in scale or at any altitude level within the troposphere (Lovejoy et al., 2007). At the same time, massive quantities of high quality satellite data have directly demonstrated the wide range horizontal scaling of the atmospheric forcing (long and short wave radiances; see e.g. (Lovejoy et al., 2009a)) and numerical atmospheric models and reanalyses have been shown to display nearly perfect (scaling) cascade structures over their entire available horizontal ranges (Stolle et al., 2009). This shows also that the source/sink free "inertial ranges" used in IP models are at best academic idealizations.

The IP/SP opposition is arguably a main contributor to today's lack of scientific consensus about the scale by scale statistical structure of both the atmosphere and of atmospheric models and reanalyses. In order to resolve the deadlock, either the IP camp must show how the findings of wide range vertical and horizontal scaling can be adequately explained through a hierarchy of isotropic models, or the SP camp must explain the key aircraft and numerical model results cited against them as evidence of two (or more) isotropic regimes. In this talk we review the debate and argue that now exactly such a reinterpretation of the aircraft data has been found (Lovejoy et al., 2009b). We argue that the debate has now been decisively resolved in favour of the SP approaches so that neither 2-D isotropic nor 3D isotropic turbulence – are relevant in the atmosphere.

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