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Synchronization of chaotic modulated travelling waves in coupled rotating annuli

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Synchronization is now well established as a phenomenon where coherent behaviour between two or more otherwise autonomous nonlinear systems subject to some degree of coupling is developed and maintained. Such behaviour has mostly been studied to date, however, in relatively low-dimensional discrete numerical systems or networks, and very simple laboratory experiments. But the possibility of similar kinds of behaviour in continuous or extended spatiotemporal systems has many potential practical implications, especially in geophysics. Recent investigations have found that some atmospheric teleconnections of oscillatory climate phenomena can be better understood and analysed via chaos synchronization theory. The use of well-controlled laboratory analogues may therefore have an important role to play in the study of natural systems that can only be observed and for which controlled and repeatable experiments are impossible. The laboratory experiment that we use in our research is the thermally driven, rotating baroclinic annulus. The combined effect of differential heating in the horizontal direction and uniform background rotation leads to the formation of a zonally-symmetric jet flow around the annulus that may become unstable to travelling baroclinic waves and exhibit a wide range of flow regimes including steady amplitude travelling waves, periodic amplitude modulated waves and a range of more complex spatiotemporal flows, culminating in forms of geostrophic turbulence. Motivated in part by studies of quasi-periodic and chaotic 'index cycles' in previous laboratory experiments using the baroclinic annulus, we have investigated synchronization effects in a pair of baroclinically unstable flows in both periodic and chaotic regimes, thermally coupled via their (zonally symmetric) boundary conditions. When the coupling strength and the de-tuning were systematically varied, the experiment showed clear signs of phase synchronization. By increasing or decreasing the mismatch between the two sub-systems we could move from completely uncorrelated behaviour to imperfectly phase-synchronized states, and finally to fully synchronized regimes. Although the coupling used so far in our experiments is quite schematic when compared with explicit geophysical analogues such as in a baroclinic, midlatitude storm zone in the atmosphere or oceans, there is no reason to believe that the occurrence of synchronization effects is particularly sensitive to the precise way in which the systems are coupled, so long as the influence is coherent and mainly via the zonal mean flow. The potential implications of these effects in the long-term climate variability of the Earth will be discussed further.