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How will polar amplification change standing Rossby waves?

Kial D. Stewart[1*], Callum J. Shakespeare[1] & Thomas G. Schmaltz[2]

[1]Australian National University
[2]University of New South Wales
*kial.stewart@anu.edu.au

1. INTRODUCTION

Rossby waves are responsible for the majority of the weather experienced by the majority of Australians. It is estimated that 70-80% of total precipitation over southern Australia is associated with Rossby waves, including the winter snowfalls that are crucial for the Australian alps [1]. The meridional meanders of Rossby waves sweep cold Antarctic air masses northwards over the Australian continent, and bring warm tropical air southwards. Stalled or quasi-stationary Rossby waves lead to persistent extreme weather events such as heat waves, cold spells, droughts and floods.

Rossby waves are challenging to model, in part due to their wide range of dynamically-active scales; they are energised at the baroclinic scale, exist primarily at the planetary scale, and dissipate through wave breaking at the turbulent scale. Numerical simulations require at least 4 orders of magnitude of dynamically active scales; this is equivalent to a global model with a 1km grid, or a 10m DNS domain with 1mm grid. In addition to their substantial horizontal resolution requirements, Rossby waves tend to operate with both barotropic and baroclinic dynamics: their largest scales are typically barotropic, while their generation and dissipation processes are typically baroclinic; this means they require sufficient vertical resolution to support these baroclinic dynamics, but this resolution isn't necessarily needed for their barotropic processes.

The difficulty in modelling Rossby waves means there remain many unanswered questions about their most fundamental dynamics, let alone how their behaviour will change into the future. For example, Rossby waves are sensitive to the meridional temperature difference between the equator and poles, and this temperature difference is decreasing as a result of anthropogenic climate change, a phenomenon referred to as polar amplification. Many of the effects that polar amplification will have on Rossby wave behaviour remain uncertain; including whether Rossby waves will amplify their north-south meanders, or how the nature of the variability associated with Rossby waves will change. New approaches to modelling Rossby wave dynamics are needed to address these pertinent questions.

2. APPROACH

We use the Large Rotating Annulus (LRA) in the Climate & Fluid Physics Laboratory at the Australian National University (e.g., [2]). The LRA is a 1.6 m diameter, 0.4 m deep annulus tank mounted on a platform that is able to rotate at a prescribed rate. The annulus sidewalls are able to be held indefinitely at different temperatures; this sidewall temperature difference ΔT drives a convective overturning within the working fluid, which in turn maintains a background stratification (N) and geostrophic turbulence throughout the annulus. One unique aspect of the LRA is a mechanism which allows for a piece of isolated topography to be differentially rotated about the annulus at a prescribed rate and excite flow-topography interactions; by transforming our frame of reference into that of the differentially-rotating topography, the working fluid appears to move with a prescribed zonal (azimuthal) velocity U.

Our comprehensive suite of experiments systematically vary the annulus rotation rate, the sidewall temperature difference, and the topography rotation rate through a wide range of parameter space [3]. We identify forcing configurations that are of geophysical relevance and support standing Rossby waves [4]. Here we focus our analysis on a subset of experiments, and quantify the effect of sidewall temperature difference ΔT, zonal flow speed U, and background potential vorticity gradient β.

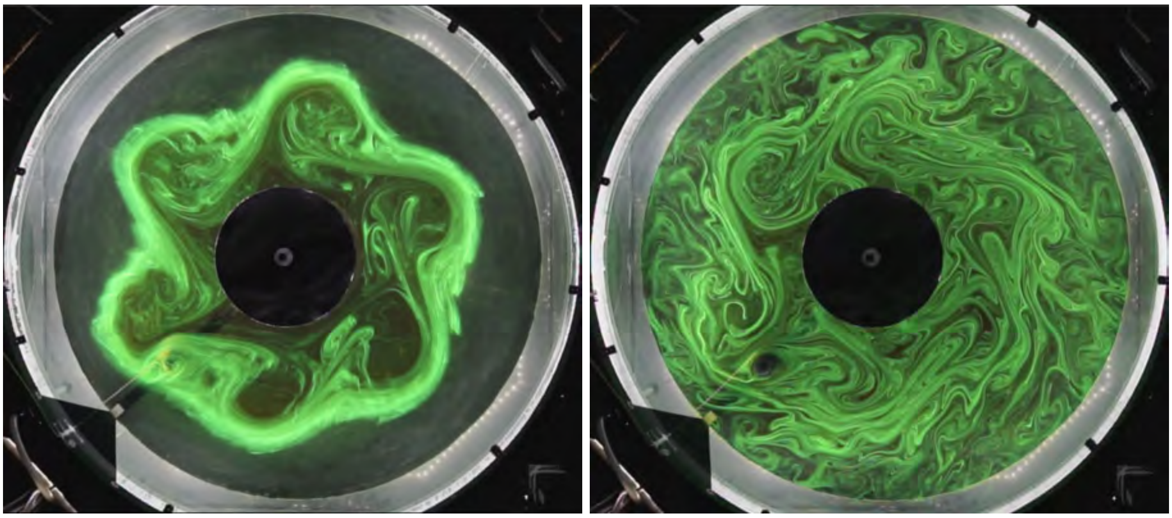

Figure 1. Passive dye tracer visualisations are used to highlight the dynamical differences and similarities between the small and large sidewall temperature difference cases (left and right, respectively). The full video of this comparison can be found here *FluidsIn4K*

3. RESULTS

Reducing the sidewall temperature difference has the effect of reducing the stratification, and thus reducing the baroclinicity of the system. This in turn reduces the relative amount of variability at higher frequencies and smaller length scales, which is apparent in Fig. 1. The lower frequency and larger lengthscale variability appears remarkably insensitive to the sidewall temperature difference.

The zonal wavelengths of the standing Rossby waves λ are set by the canonical relationship given by the square root of the zonal flow speed to the background potential vorticity gradient β, as $\lambda = 2\pi\sqrt{\frac{U}{\beta}}$. The experiments exhibit excellent agreement with this relationship. This relationship also captures the meridional extent of the meanders associated with the Rossby waves.

The total variability in a given experiment can be decomposed into that which is standing (relative to the topography) or transient. Whether a given experiment has predominantly standing or transient variability is a useful indication of its characteristic state; this is quantified by a variability ratio. In terms of this variability ratio, the response of the system to changes in experimental parameters is complicated and interdependent on the 3 parameters. We introduce a non-dimensional term $U\beta/N^2$ which represents the 3 experimental parameters and captures the response of the variability ratio trends.

4. FUTURE WORK

The experiments here are all run with a steady zonal flow speed. This is not the case in reality; winds vary substantially seasonally, and this has implications of the Rossby wave dynamics. Future experiments will explore this effect, in an attempt to understand the seasonality of variability; for example, why does spring tend to be stormier than autumn?

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