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Rossby waves - do they exist?

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Rossby waves - do they exist?

"I often wondered what a Rossby wave was."

Sir Harold Jeffreys interviewed 1984 in Cambridge for the Roy Met Soc by Professor Michael McIntyre.

One day, while at ECMWF, I was asked over lunch by one of the scientists about the weather the coming weekend. -Oh, it will be fine, I said confidently, because a big "Rossby wave" is coming in!

One of the scientist at the table, a bright guy from a respected European university, reacted with disbelief: -But how can you *see* a "Rossby wave"? His question took me aback and all I could say was: -Well obviously Rossby himself had seen *something* way back in the 1930's!

It turned out that he, and obviously everybody else at the meteorological department at that university, had been told that you can only *detect* "Rossby waves" by some clever spectral analysis. After the lunch I went into the library and consulted the available meteorological textbooks. Reading them I became confused myself and began to wonder if "Rossby waves" existed at all. And if they did, perhaps only on pieces of paper on the scientists' desks.

Because the typical pedagogical approach was to make "Rossby waves" emerge out of mathematical manipulations of the basic equations of motion. That yields first of all the phase velocity which, in its most simple form, can be written

$$c = U - \frac{\beta L^2}{4\pi^2}$$

where U is the average zonal velocity in the troposphere (alternatively the 500 hPa zonal wind), L the wave length and β the meridional (north-south) variation of the Coriolis parameter ($\beta=2\Omega\cos\varphi$ where φ is the latitude).

The equation says simply that a "Rossby wave" moves eastward with the zonal flow, retarded due to a combination of the rotation of the earth and the wave length, the more the lower the latitude and/or longer the wave. Very long waves can remain stationary or even move westward, while smaller ways moves eastward. This was the gist of the famous Rossby (1939, 1940) papers and fits well into what we can see on the weather charts with blocking highs, cut-off lows and cyclones. In some textbooks even mountain lee waves are regarded as "Rossby waves". *But if all waves we see on the weather charts are "Rossby waves" - what's the point?*

This is not just a matter of semantics. As I have shown in articles about the history of numerical weather prediction (NWP) in Sweden and Britain, part of the success on the Swedish side, and the problems and frustrations on the British side, depended on a correct physical interpretation of Rossby's wave formula (Persson, 2005a, sec.3;2005b, sec. 3,4 and 6). In my view, the failure on the British side to make a correct interpretation not only delayed their NWP progress, *it prevented the Met Office to rise to the leading NWP centre in Europe and thereby paved the way for a separate European NWP centre*.

One reason for the confusion about how to interpret the wave equation became obvious almost immediately. Around 1940 there were already sufficient upper air data to make meteorologists see that most synoptic waves, long and short, were *baroclinic*, i.e. with strong horizontal thermal contrasts[1].

But the mathematics in Rossby's derivation (and most other derivations since then) assume a *barotropic* atmosphere, i.e. an atmosphere with no horizontal temperature contrasts. So how can such waves form in the absence of the well-known conversion between potential and kinetic energy? Already in the early 40's ideas seem to have formed that the waves were generated in other ways, e.g. by the β-effect or when winds passed over high mountains.

Because in a follow-up paper 1942 Rossby made the point (and would continue to make it during the rest of this life), that his theory was purely *kinematic* and was not supposed to answer the question of the ultimate cause of the waves. The long waves were, according to him, caused by all kind of physical processes and, although not barotropic, still may have their motion kinematically *described* as such for some limited time (Rossby, 1942, 1,13; Persson, 2005a, 138; Persson 2005b, 385).

A solution to the problem is therefore to stop talking about "Rossby waves" at all. In the 40's and 50's the long waves were called "planetary waves" and the shorter "cyclonic" or "synoptic" waves[2]. Just because their dynamics is affected by the same β-effect does, in my view, not constitute a reason to lump them together under the same label.

But what about the waves formed in the lee of mountains? Aren't they "Rossby waves"? The textbooks and a multitude of internet sites have wonderful descriptions of how a column of air, conserving its potential vorticity, is passing over a mountain ridge as a straight flow only to generate nice undulating "Rossby waves" on the lee side.

In a lecture 1993 Professor James R. Holton discussed this explanation, partly after Dale Durran (at his institution) and I (at ECMWF) had sounded the alarm to him that something was not quite correct. Holton agreed that this traditional textbook model is "inadequate" and quoted a series of previous scientists who had made the same critical points (Holton, 1993).

There is much more to say about the interpretation of mathematics in dynamic meteorology (see e.g. Persson, 2002, 2010). If this wonderful science might be seen as difficult it is not because of the mathematics, but of its counter-intuitive physical nature. *However, the main difficulties in dynamic meteorology are all those dodgy definitions, deceptive derivations and erroneous explanations we humans have introduced into it.*

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[1] The only difference was that in the long waves (and not in short waves) the isotherms (thickness lines or thermal wind) run quasi-parallel to the stream lines (isobars or geostrophic wind). This classified them as "equivalent barotropic" waves with some convenient mathematical properties.

[2] In *"Introduction to Geophysical Fluid Dynamics"* the author Benoit Cushman-Roisin makes clear in the preface that he will, "to maximize the physical interpretation" of concepts, use the expression "planetary wave" and not "Rossby wave" (Cushman-Roisin, 1994).

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