Raytracing

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Atmospheric Rossby waves identification and tracking with 'raytracing'

Summary

Planetary or atmospheric Rossby waves have large influence on weather and climate around the world. Such influences can happen even away from the waves sources through wave patterns that connects the atmosphere in two different regions away for miles. An example of this come from the El Niño Southern Oscillation (ENSO), in which the deep convection over tropical region of Pacific ocean trigger disturbances in the atmosphere leading to planetary waves able to travel through extratropical regions affecting their climate and weather. Latent heat sources, such those by ENSO, is not the only source for Rossby waves triggering (Hoskins and Karoly (1981); Ambrizzi and Hoskins (1997)). Detecting the triggering regions of these waves, their characteristics, where they pass and where they go is of uppermost importance for research, assignment, monitoring and forecasting of weather and climate. Therefore, the detection and tracking of atmospheric Rossby waves is of paramount importance for scientists, climatologists, meteorologists and students wishing better understand the dynamics of the atmosphere.

The Group of Climate Studies (in Portuguese, GrEC; www.grec.iag.usp.br) is center for studying the atmosphere located at the University of Sao Paulo. In this sense, the GrEC has a constant demand on identification and tracking of the atmospheric Rossby waves for studying climate and weather events, such as those described in Coelho et al. (2016) and Rehbein et al. (2018). This group is focused on the knowledge about the atmospheric dynamics. The demand for an automated, free, user-friendly and open source model is constant also by other groups. Therefore, we developed the R package `raytracing` to be used by any atmospheric dynamic researcher. Among the benefits of using R, includes its wide community and also because R can be installed in multiple operational systems(R Core Team (2020)).

Usage and theory

`raytracing` requires two basic parameters: the input data (a file containing zonal wind at the latitude/longitude grid in Network Common Data Form - NetCDF) and a first guess latitude and longitude coordinate pair.

All of this is organized in a single main function that coordinates the calculations according to predefined parameters. Other key functions also can be invoked as will be showed below. The data output format can also be defined, which can be a database (Comma-Separated Values, CSV) with characteristics and calculation results for each possible new wave position given the initial parameters and/or an object stored in memory of the R in data.frame format. From there, the user will be able to carry out the analyzes by generating figures according to their needs, being able to filter, for example, regions of arrival of wave rays.

These planetary waves can be approximated to the pure plane waves so that its group velocity or energy propagation $\bf{c}g$, that is, the velocity in which a wave package propagates, in the atmosphere can be found as a function of the frequency, using the dispersion relation in Eq. :

Where, $\overline{U}_M$ is the Mercator coordinate time-mean zonal wind, k is the zonal wave number, β_M is the Mercator coordinate analogous meridional gradient of absolute vorticity (β) times $cos(\phi)$. β is shown in the Eq. , and l is the meridional wave number.

From Eq. $\bf{{c}}_g$ is then obtained in Eq. :

Where the zonal group velocity (u_g) and meridional group velocity (v_g) are, respectively, demonstrated in Eq. and

Just as in ray optics or geometric optics, Hoskins and Karoly (1981) described that planetary waves follow a trajectory or ray perpendicular ahead of waves to any place in the direction of the local $\bf{{c}}_g$. In this way, the radius would be the path through which the energy would propagate at the same speed as $\bf{{c}}_g$. In order to find these rays or trajectories, we followed Yang and Hoskins (1996), using a single-step numerical method to obtain the numerical solutions for Eqs. and given a time interval Δt. This facilitated the validation of the package, comparing the results obtained here with those already known (e.g. Magaña and Ambrizzi (2005); Coelho et al. (2016); among others) that used Yang and Hoskins (1996).

Hoskins and Karoly (1981) also noticed that for the dispersion equation to be satisfied everywhere, l must vary along the wave trajectory, because the there is not a dependence on x and t, then k and ω must not vary. From the total wavenumber K, the zonal wave number k is obtained: $k = \frac{K}{a}$, where a is the Earth's radius.

In the case of a constant k and a $\omega = 0$, stationary Rossby waves emerge with a stationary wave number in Mercator coordinates K_s given by Eq. (Hoskins and Karoly (1981)). The same representation but considering Earth's sphericity is in Eq. (Hoskins and Ambrizzi (1993)). The stationary phenomena was found largely to explain weather and climate patterns around the world (Hsu and Lin (1992); Ambrizzi, Hoskins, and Hsu (1995); Magaña and Ambrizzi (2005); Coelho et al. (2016); among many others).

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