Figure 1. Development of a barotropically unstable initial state for a model set-up with a strong narrow jet at 45°N. The plot shows a Hovmöller diagram of the meridional wind component of the transient part of the flow, \(v_0\), averaged over 30 – 60°N. A sine wave with eastward phase velocity. This behavior allows us to eliminate the transient part of the solution by simple time averaging. More specifically, for each model run we performed a 100-day long model integration and extracted the stationary part \(\overline{v}\) of the flow by averaging over the last 90 days (the initial 10 days were discarded in order to eliminate initial transients).

For illustration we consider two very different background flows, one with pure solid body rotation (corresponding to \(U_J = 0\) m s\(^{-1}\)) and one with a strong narrow jet superimposed (corresponding to \(U_J = 40\) m s\(^{-1}\)). The two latitudinal profiles \(U_J(\phi)\) are depicted in Fig. 2. The corresponding numerical solutions for \(\overline{v}\) are presented in Fig. 3. In the case of the solid-body rotation, the transients have died out after about 10 days such that the solution for \(v\) at later times (not shown) is practically indistinguishable from the time average \(\overline{v}\) displayed in Fig. 3a. By contrast, in the strong jet case there is strong transience throughout the integration, but these transients are effectively eliminated by the time averaging leaving us with the forced stationary part \(\overline{v}\) displayed in Fig. 3b.

Figure 2. Latitudinal profiles of the background zonal wind \(u_0(\phi)\) for the strong narrow jet case (solid line) and for the pure solid body rotation case (dashed line).

Apparantly, for pure solid body rotation (Fig. 3a) there is a wavetrain emanating from the pseudo-orography; downstream of the source the individual troughs and ridges develop a strong NE-SW tilt and the wavetrain crosses the equator and disperses into the Southern Hemisphere (Hoskins et al., 1977; Hoskins and Karoly, 1981). At the same time, the wave signal is damped with increasing distance from the wave source, which is due to our relaxation term in (4). The cross-equatorial propagation implies that some 180° downstream of the Rossby wave source the wavetrain is found in the Southern Hemisphere and the Northern Hemisphere is practically devoid of any wave signal at these longitudes.

By contrast, the solution for the strong jet case (Fig. 3b) indicates that the majority of the wave signal remains in the Northern Hemisphere midlatitudes, and only a rather small fraction of the wave signal follows a great circle into the Southern Hemisphere. This behavior is consistent with the notion that a strong narrow jet acts as a waveguide (Manola et al., 2013). As a consequence, in this case the majority of the wave signal 180° downstream of the Rossby wave source has remained in the Northern Hemisphere midlatitudes. Later in section 4.1 we will use the striking difference in behavior between these two contrasting scenarios to define a quantitative measure for “waveguidability”.

3 Theoretical concepts

Before we do so, however, we review in this section some well-known concepts for the analysis of stationary Rossby waves and their propagation in a spherical domain. This will help us to interpret our results in the later parts of the paper.