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Two-way mass transport across the potential vorticity contour

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Transport barriers in the atmosphere such as tropopause and polar vortex edge are usually defined by the local maximum of potential vorticity gradient on isentropic surfaces. In a region with large potential vorticity gradients, a strong restoring force against the meridional displacement of air parcels prohibits the meridional transport of the air parcels. At the same time, the potential vorticity contour behaves like a material surface since the potential vorticity is conserved following air parcel motion in the absence of diabatic and frictional effects. The stratosphere is nearly adiabatic and frictionless for several days or longer, so that the potential vorticity contour in the stratosphere accords well with the contours of mixing ratio of long-lived chemical tracers such as N_2O and CH_4. Thus estimates of mass flux across the potential vorticity contour make it possible to evaluate effects of cross-barrier tracer transport on the tracer distributions.

Mass transport across the potential vorticity contour is caused by the dissipation of potential vorticity anomaly due to frictional effects in the absence of diabatic effects. The frictional effects are mostly due to turbulent diffusion in the stratosphere. When the potential vorticity contour is sufficiently stretched and convoluted by planetary wave breaking and/or chaotic advection, turbulent diffusion effectively dissipates the small-scale potential vorticity anomaly and brings about mass transport across the potential vorticity contour. On the other hand, tracer flux across the potential vorticity contour is expressed as the product of tracer mixing ratio at the potential vorticity contour and mass flux across it. Then we need to evaluate separately inward and outward mass fluxes across the potential vorticity contour around the transport barrier with strong meridional gradients of tracer mixing ratio.

Following Nakamura (2004), we divided net mass flux across the potential vorticity contour into inward and outward components by assuming that frictional effects were induced by 2nd order horizontal diffusion. This analysis clarifies the net mass transport and mixing across the potential vorticity contour inside, in the edge region of, and outside the polar vortex. Furthermore, we suggest a method to evaluate local mass flux across the potential vorticity contour.