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On transit-time distributions in unsteady circulation models

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In a diffusive geophysical flow, there is not a single timescale or unique pathway for passive scalar transport from the reservoir's surface into the interior because of irreversible diffusive mixing processes. Instead, there is a range of pathways and hence a transit-time distribution (TTD) since last surface contact. We explain the issues that arise when considering TTDs for unsteady flows and discuss approaches to finding the TTD in numerical circulation models. In particular, two complementary approaches are possible: First, the adjoint tracer equation can be used to find the TTD directly for each point of interest. This method is computationally efficient but requires an adjoint tracer model. Second, ensembles of impulsive tracer integrations can be used, exploiting some important, and previously unreported, statistical properties of the TTD. This method is less computationally efficient, but is simpler to implement. Illustrations and tests of each method are presented for barotropic double-gyre circulations. The trade-offs between computational expense and numerical convergence are discussed.