Differential Travel Time and T-star as Predicted by the Very Broadband Rheology Calculator

William Menke, June 2020

We illustrate the temperature and frequency dependene of differential travel time and t-star using the Very Broadband Rheology (VBR) calculator (Holtzman et al. 2019). VBR is a recently-developed MATLAB package for calculating isotropic mechanical properties across the entire band of geophysical time scales, from elastic to viscous, seismic wave propagation to convection, bridged by constitutive models for transient creep and anelasticity. It employs a forward modeling approach to calculate velocity, attenuation and viscosity across a specified frequency band for input arrays of state variables (temperature, pressure, grain size, stress, melt fraction, composition). It can be used to infer mantle thermodynamic state from observed seismic properties such as shear wave velocity and intrinsic attenuation, across the frequency band of the measurement.

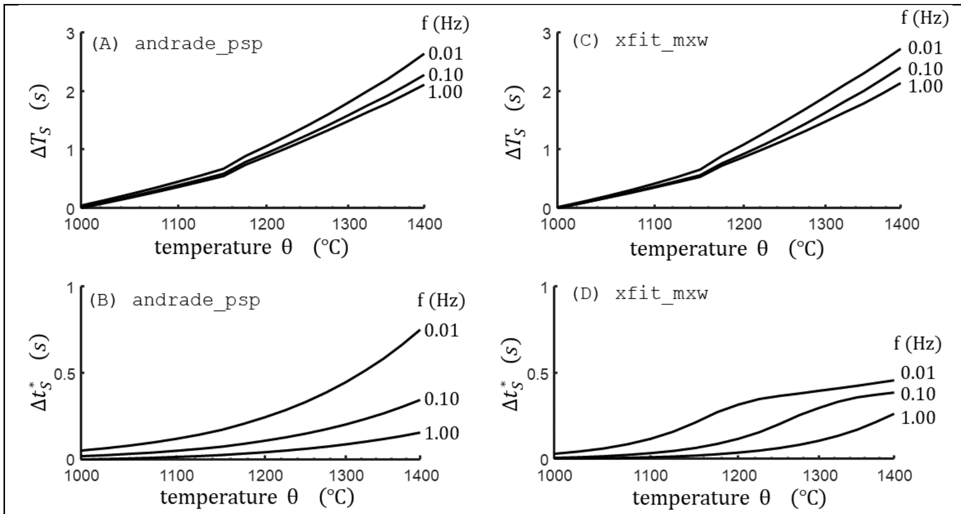

Fig. 1. S-wave differential travel time ΔT_S and differential t-star Δt_S^* as a function of mantle potential temperature θ. (A) Plot ΔT_S vs. θ (black curves) for several different frequencies, as predicted by the VBR calculator using the *andrade_psp* method. (B) Plot Δt_S^* vs. θ (black curves) for several different frequencies, using the andrade_psp method. (C) and (D) Same as A and B, except for the xfit_mxw method.

We use a simple, 200-km thick Earth model with one free parameter, mantle potential temperature θ, to compute T_S and t_S^* by integrating along a vertical raypath. Differential quantities ΔT_S and Δt_S^* are then computed with reference to the lowest temperature, highest frequency case considered, because it has the fastest travel time and lowest attenuation. VBR provides four distinct methods, *eburgers_psp*, *andrade_psp*, *xfit_mxw* and *xfit_premelt*, of which *andrade_ps* and *xfit_mxw* are the most dissimilar.

Results indicate that for the high temperature range, $\Delta T_S \approx 2-3\ s$ and $\Delta t_S^* \approx 0.5-1.0$ s (Figure 1). The calculations also indicate that *andrade_ps* and *xfit_mxw* methods have similar $\Delta T_S(f)$ behavior, even for the extreme temperature of $\theta = 1400$°C. Each exhibits very moderate dispersion of $d\Delta T_S/df \approx 0.2$ s/log$_{10}$Hz, with the difference between them less than 0.05 s/log$_{10}$Hz.

Distinguishing the methods on the basis of $\Delta T_S(f)$ requires a challenging level of accuracy. The $\Delta t_S^*(f)$ for the xfit_mxw method exhibits stronger variability than it does for the *andrade_ps* method, especially at the high-θ, low-f range (Figure 2). This difference arises because the α of the xfit_mxw method is anomalously low (close to $\alpha = 0$) in this range. Consequently, $\Delta t_S^*(f)$ might make a better discriminant than $\Delta T_S(f)$.

Some authors have asserted that in the presence of melt, $\alpha \approx 0$, and that consequently effect of temperature and melt can be distinguished on the basis. We note, however, that if it were shown that the *xfit_mxw* method best fits the true Earth, then α could not be used in this way.

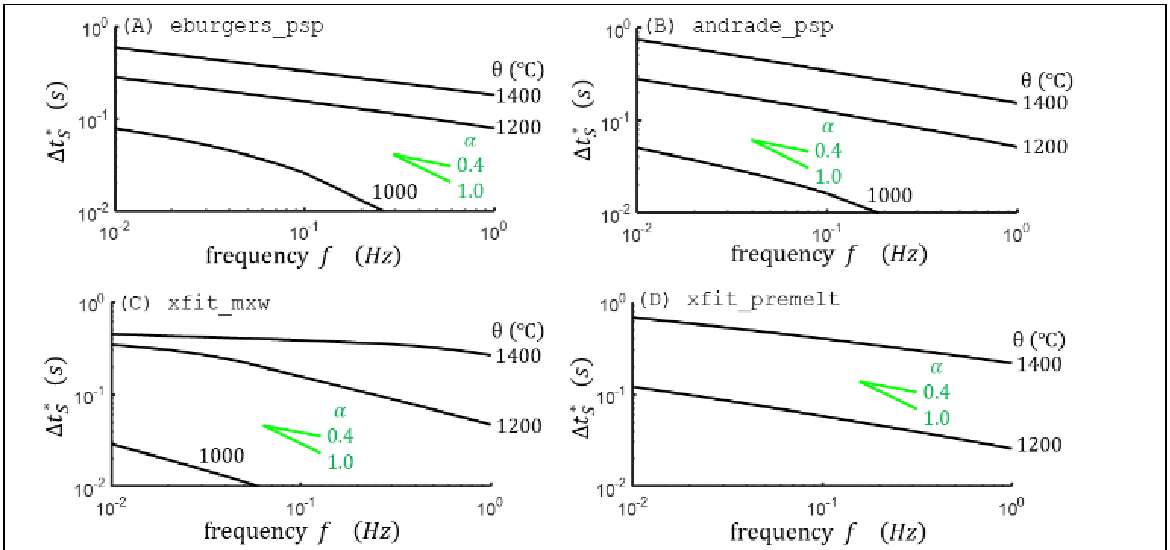

Fig. 2. S-wave differential t-star Δt_S^* as a function of frequency f. (A) Plot Δt_S^* vs. f (black curves) for several different frequencies, as predicted by the VBR calculator using the *eburgers_psp* method. Power law behavior $\Delta t_S^* \sim f^{-\alpha}$ is shown for comparison (green) (B), (C) and (D) Same as (A), except for Andrade_psp, xfit_mxw, and xfit_premelt methods, respectively.

Holtzman, B.K., Havlin, C., Hopper, E., Bellis, C., Russell, J.B., Lau, H.C.P., Lin, P.Y., 2019, The Very Broadband Rheology Calculator: a tool for inference of thermodynamic state of the upper mantle from frequency-dependent mechanical behavior Fall Meeting Abstract S23G-0723, American Geophysical Union, Washington D.C.