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Global-scale Joint Body and Surface Wave Tomography with Vertical Transverse Isotropy for Seismic Monitoring Applications T1.2-P18

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Abstract We continue to develop more advanced models of Earth's global seismic structure with specific focus on improving predictive capabilities for future seismic events. Our most recent version of the model combines high-quality P and S wave body wave travel times and surface-wave group and phase velocities into a joint (simultaneous) inversion process to tomographically image Earth's crust and mantle. The new model adds anisotropy (known as vertical transverse isotropy) to the model, which is necessitated by the addition of surface waves to the tomographic data set. Like previous versions of the model the new model consists of 59 surfaces and ~1.6 million model nodes from the surface to the core-mantle boundary, overlaying a 1-D outer and inner core model. The model architecture is aspherical and we directly incorporate Earth's expected hydrostatic shape (ellipticity and mantle stretching). We also explicitly honor surface undulations including the Moho, several internal crustal units, and the upper mantle transition zone undulations as predicated by previous studies. The explicit Earth model design allows for accurate travel time computation using our unique 3-D ray tracing algorithms, capable of 3-D ray tracing more than 20 distinct seismic phases including crustal, regional, teleseismic, and core phases. Thus, we can now incorporate certain secondary (and sometimes exotic) phases into source location determination and other analyses. New work on model uncertainty quantification assesses the error covariance of the model, which when completed will enable calculation of path-specific estimates of uncertainty for travel times computed using our previous model (LLNL-G3D-JPS) which is available to the monitoring and broader research community and we encourage external evaluation and validation.

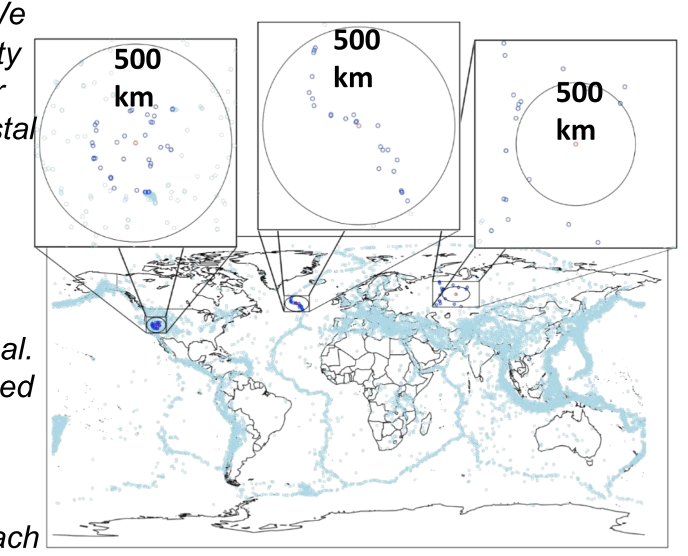
Body Wave Data

Phase	Number of Arrivals
P	2,553,180
Pn	266,882
PcP	34,031
pP	53,872
pwP	35,496
Pg	10,774
Pb	5,754
S*	20,728
Sn	76,183
SS*	17,835
ScS*	2,699
SKS*	5,642
SKKS*	2,605
sS*	1,463

*Waveform correlation picks

← Travel-time Data: *We used over 3 million high-quality arrival time measurements for teleseismic, regional and crustal phases. See Simmons et al. (2015).*

→ Global Multiple-event Location: *The Bayesloc multiple-event location procedure (Myers et al. 2007, 2009, 2011) was adapted to the global scale using an event clustering technique (described in Simmons et al. 2012). This stochastic approach has been demonstrated to produce accurate event locations that produce more*

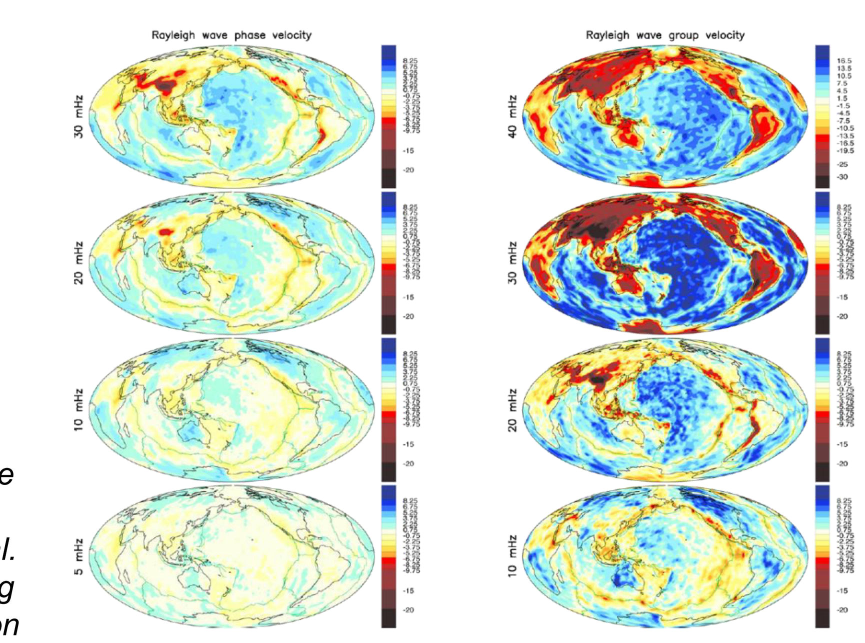


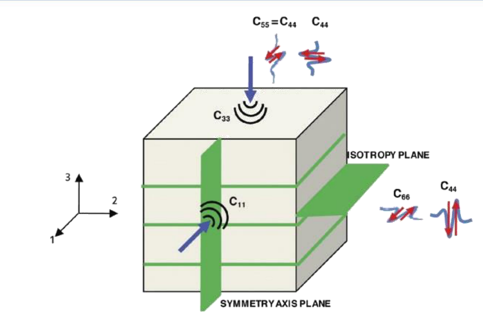
Surface Wave Constraints and VTI media

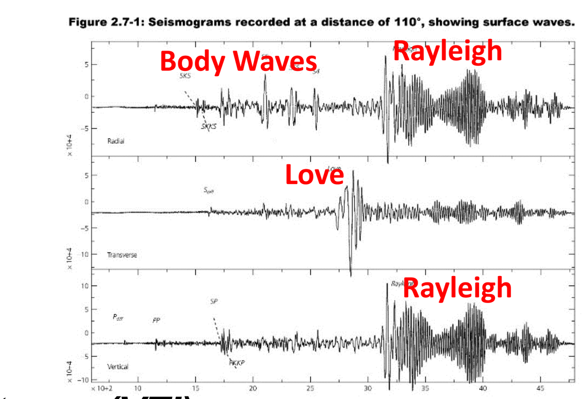
Wave	Periods
Love Phase	33-133 sec
Love Group	33-100 sec
Rayleigh Phase	29-200 sec
Rayleigh Group	25-133 sec

*Constraints derived from phase and group velocity maps (surface wave dispersion models) constructed by *Ma et al.* (2014) and *Ma & Masters* (2014).

→ Surface wave velocity maps: *We incorporated phase and group velocity constraints from surface models constructed with millions of surface wave measurements (Ma et al. 2014; Ma & Masters 2014). Combining these maps, we constructed dispersion curves at specified locations and fit these curves in the joint body-surface wave model.*





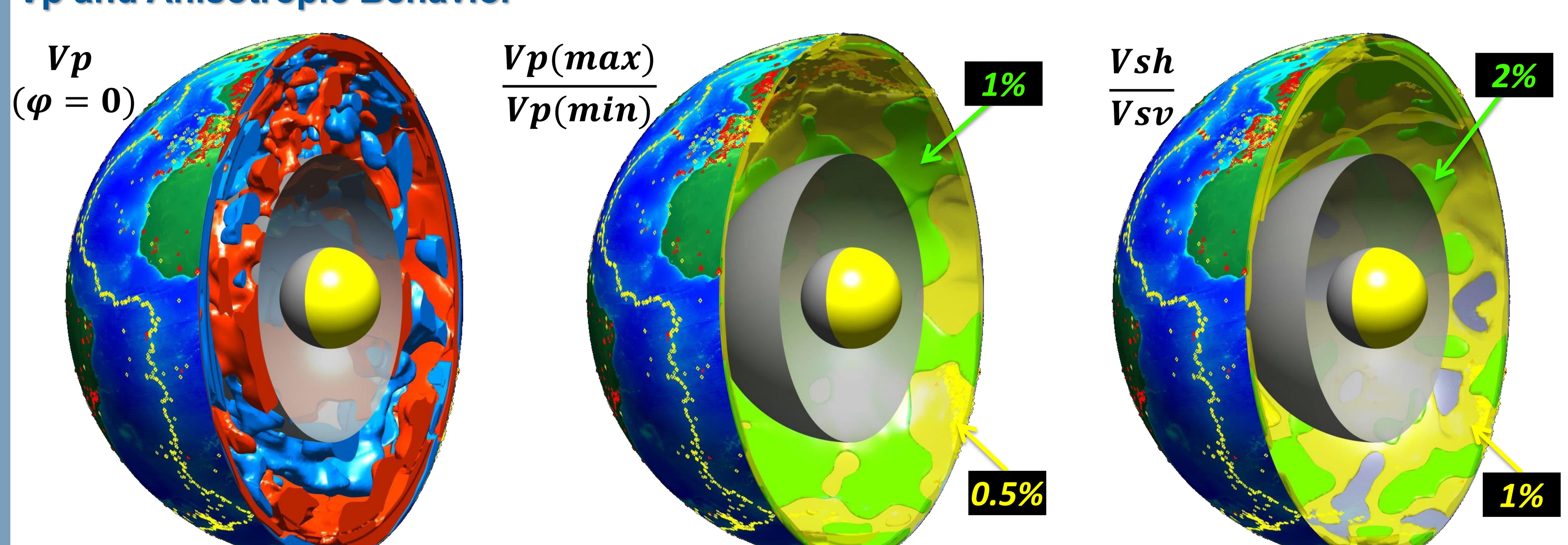


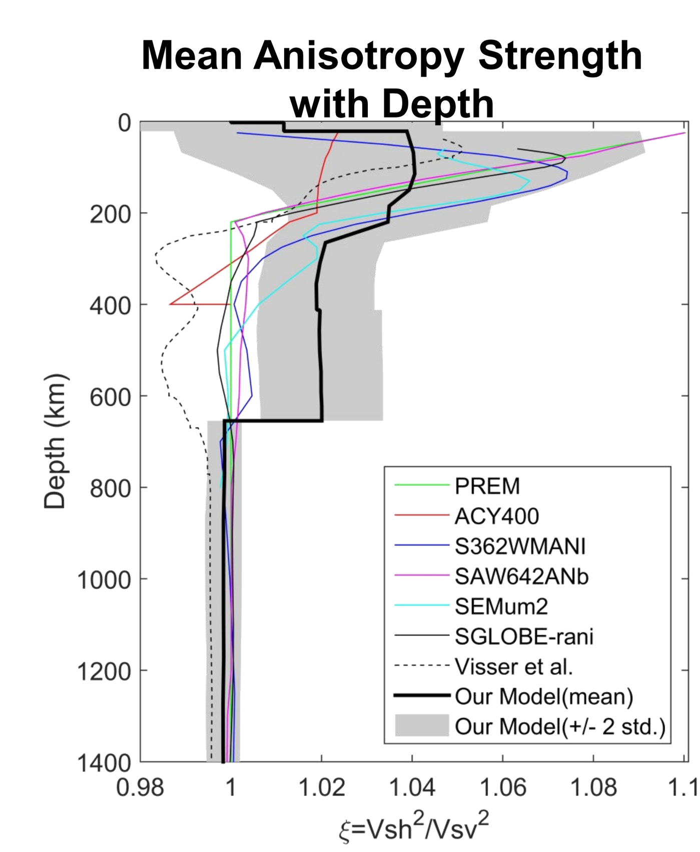
Vertical Transverse Isotropy (VTI): *Layering in the Earth causes seismic waves to propagate at different velocities depending the propagation direction relative to vertical incidence. In addition, waves with different particle motions travel at different speeds in VTI media, most notably observed in the different velocity of Rayleigh waves (dominant Sv energy) and Love waves (dominant Sh energy). A single term is often invoked to describe the differences between these laterally travelling waves. However, 5 parameters are needed to fully describe VTI for waves travelling in arbitrary directions (e.g. Body Waves).*

SPiRaL Earth Model - Radially isotropic (anisotropic) model of P and S wave speeds (vertical shear speed shown here)

BLUE = High-velocity zones (> +0.5% δVs)
RED = Low-velocity zones (< -0.5% δVs

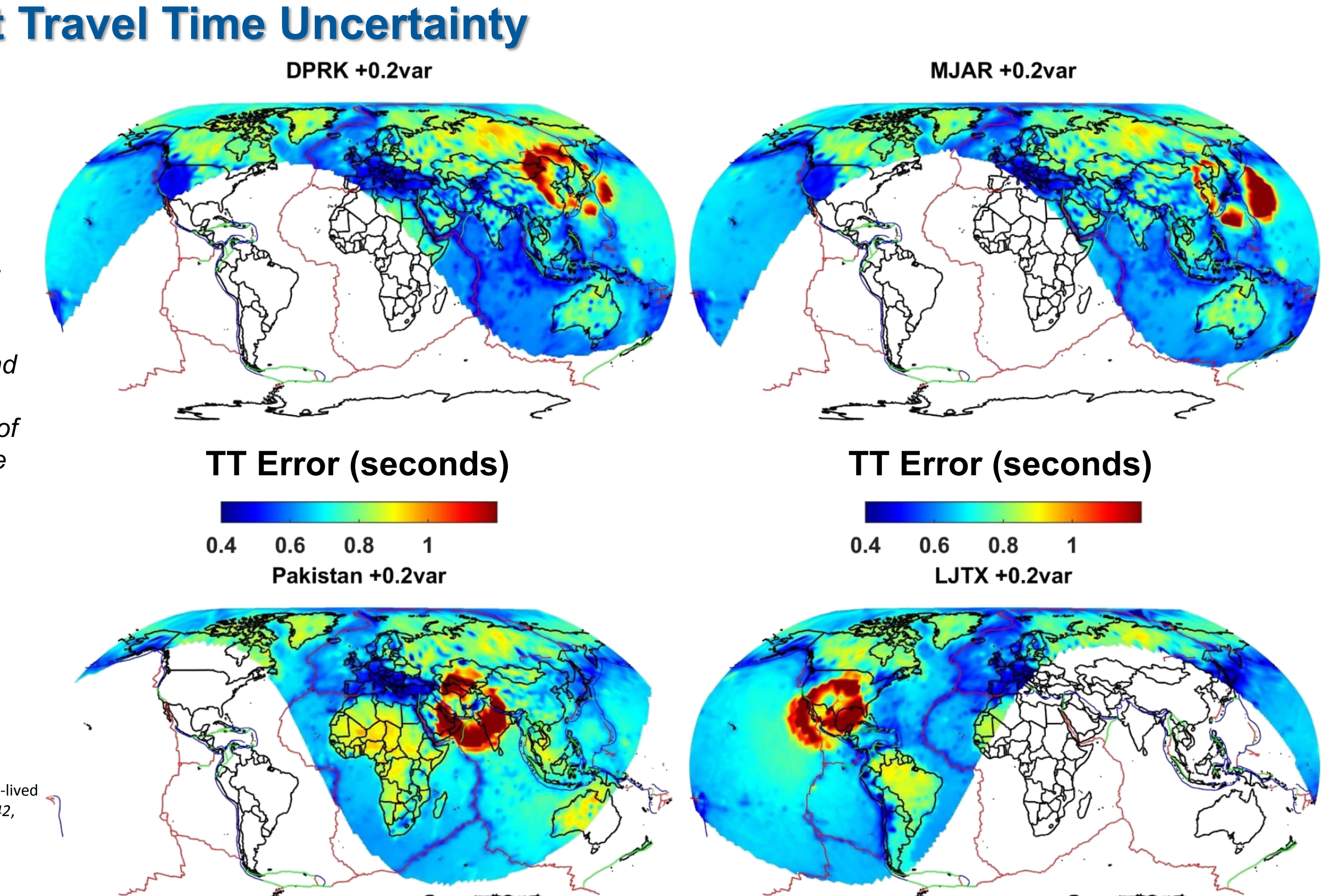
Vp and Anisotropic Behavior





Path-Dependent Travel Time Uncertainty

P-wave travel time uncertainties: *We computed the full model covariance of the LLNL-G3D-JPS model for uncertainty estimation. Shown here are some examples of station- and event-based uncertainty surfaces (standard deviation of travel times) for direct P-wave arrivals. These values could be included in station-phase travel time tables for use in location algorithms.*



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