



HAL
open science

Identifying global seismic anisotropy patterns by correlating shear-wave splitting and surface wave data

Andreas Wüstefeld, Götz Bokelmann, Guilhem Barruol, Jean-Paul Montagner

► To cite this version:

Andreas Wüstefeld, Götz Bokelmann, Guilhem Barruol, Jean-Paul Montagner. Identifying global seismic anisotropy patterns by correlating shear-wave splitting and surface wave data. *Physics of the Earth and Planetary Interiors*, 2009, 176 (3-4), pp.198. 10.1016/j.pepi.2009.05.006 . hal-00573464

HAL Id: hal-00573464

<https://hal.science/hal-00573464>

Submitted on 4 Mar 2011

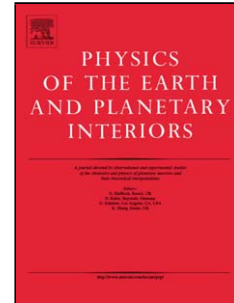
HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Accepted Manuscript

Title: Identifying global seismic anisotropy patterns by correlating shear-wave splitting and surface wave data

Authors: Andreas Wüstefeld, Götz Bokelmann, Guilhem Barruol, Jean-Paul Montagner



PII: S0031-9201(09)00126-5
DOI: doi:10.1016/j.pepi.2009.05.006
Reference: PEPI 5173

To appear in: *Physics of the Earth and Planetary Interiors*

Received date: 2-12-2008
Revised date: 8-5-2009
Accepted date: 12-5-2009

Please cite this article as: Wüstefeld, A., Bokelmann, G., Barruol, G., Montagner, J.-P., Identifying global seismic anisotropy patterns by correlating shear-wave splitting and surface wave data, *Physics of the Earth and Planetary Interiors* (2008), doi:10.1016/j.pepi.2009.05.006

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

1 Identifying global seismic anisotropy patterns by correlating 2 shear-wave splitting and surface wave data

3 Andreas Wüstefeld^{a,*}, Götz Bokelmann^a), Guilhem Barruol^a), Jean-Paul Montagner^b)

4 a) Université Montpellier II, CNRS, Géosciences Montpellier, F-34095 Montpellier cedex 5, France. fax: (33) 4 67 14 36 03,

5 b) Institut de Physique du Globe de Paris, 4 place Jussieu, Case 89, 75005 Paris, France.

6 *) now at Department of Earth Sciences, University of Bristol, BS8 1RJ, United Kingdom

8 Abstract

9 We compare a global compilation of shear-wave splitting measurements with azimuthal seismic
10 anisotropy parameters inferred from surface wave tomography. The currently available splitting
11 dataset is taken from a novel comprehensive collection of available publications that is updated
12 interactively online. The comparison between the two types of data is made by calculating
13 predicted splitting parameters from the anisotropic tomography model. Comparing these
14 predicted splitting parameters with the observed ones, we find a considerable correlation
15 between the two datasets at global scale. This result is noteworthy, since such correlation did not
16 seem to exist in previous studies. The spatial resolution associated with the two types of
17 methods is rather different. While surface waves have good vertical resolution and poor lateral
18 resolution of several hundreds of kilometers, SKS splitting measurements have good lateral, but
19 poor vertical resolution. The correlation can be understood in light of recent propositions that
20 anisotropy seen by SKS splitting constrains mostly the upper mantle, and therefore a similar
21 depth region as surface waves. The correlation also confirms the generally good quality of the
22 shear-wave measurements, as well as that of the anisotropic tomography model.

23 1. Introduction

24 Seismic waves are arguably the most powerful geophysical tools to investigate the Earth's deep
25 interior. Anisotropy is one of the many material properties that affect seismic wave propagation. It
26 manifests itself as a dependence of wave speed on direction. Such anisotropy can be caused by

27 structural variability, e.g. thin layers of alternating elastic properties (Backus, 1962) or fluid-filled
28 cracks (Crampin, 1984; Kendall et al., 2006). A second origin which is widely accepted to
29 dominate at mantle depths is the preferred orientation of anisotropic minerals by strain (e.g.,
30 Nicolas and Christensen, 1987). Olivine plays a major role in the anisotropy of the Earth's mantle
31 because it represents the primary constituent of the upper mantle and is more anisotropic than the
32 other minerals. At upper mantle conditions olivine deforms by dislocation-creep (Nicolas and
33 Christensen, 1987), and therefore aligns its main crystallographic axes with respect to structural
34 directions (lineation, pole of the foliation), therefore producing a large-scale anisotropy detectable
35 by seismic waves that is correlated with the geometry of strain in the upper mantle. Identifying the
36 orientation of seismic anisotropy and its strength can thus help to constrain deformation at depth.
37 Comparing seismic anisotropy with other observables such as gravitation and topography (Simons
38 and van der Hilst, 2003) or the magnetic anomalies (Bokelmann and Wüstefeld, 2009; Wüstefeld
39 et al., 2009) is helpful for understanding tectonic processes acting within the Earth, both, ancient
40 ones recorded within the lithosphere, and more recent ones in the asthenosphere.

41 Hess (1964) was the first to measure azimuthal anisotropy from Pn travel-time variations beneath
42 the northern Pacific and to interpret these variations in terms of mantle flow induced by sea-floor
43 spreading. Since these pioneering works, a variety of techniques have been proposed for detecting
44 seismic anisotropy. These include relative P-wave delay times (e.g., Babuska et al., 1984;
45 Bokelmann, 2002), P-wave polarization (Bokelmann, 1995; Schulte-Pelkum et al., 2001; 2003;
46 Fontaine et al., 2009), shear-wave splitting (for references see below) and radial and azimuthal
47 anisotropic surface-wave tomography (e.g., Montagner, 1986, Nishimura and Forsyth, 1988;
48 Montagner and Tanimoto, 1991).

49 The most direct evidence of seismic anisotropy is the splitting of shear-waves. Anisotropic media
50 are indeed birefringent, splitting the incoming shear waves into two perpendicularly polarized
51 waves that propagate at different velocities. At the Earth's surface, it is therefore possible to
52 quantify anisotropy by measuring the two splitting parameters δt and Φ . The difference in arrival
53 times (δt) between the two split shear waves (Figure 1) depends on both the anisotropy strength

54 and the length of the travel path through the anisotropic medium. The azimuth Φ of the fast split
55 shear wave polarization planes is related to the orientation of the anisotropic structure. Initially
56 limited to direct S waves from local events (Ando and Ishikawa, 1980), the technique is now
57 widely adopted for core-transiting phases such as SKS, SKKS, and PKS (e.g., Vinnik et al., 1984,
58 1989; Silver and Chan, 1991; see Savage, 1999 and Fouch and Rondenay, 2006 for a review).
59 Travelling on nearly vertical paths, teleseismic shear-waves provide measurements of anisotropy
60 beneath a seismic station with a relatively good lateral resolution of few tens of kilometers
61 (Fresnel-zone width) but with poor vertical resolution. The teleseismic shear-wave splitting
62 technique has become popular in the last decades for performing anisotropy measurements that
63 help revealing present or past mantle deformation processes. This technique has been widely
64 applied in several geologic settings: Subduction zones (e.g., Levin et al., 2004; Margheriti et al.,
65 2003; Nakajima and Hasegawa, 2004), rifts (e.g., Kendall, 1994; Gao et al., 1997; Walker et al.,
66 2004; Kendall et al., 2005), hotspots (e.g., Barruol and Granet, 2002; Walker et al., 2001; 2005),
67 oceanic islands (e.g., Behn et al., 2004; Fontaine et al., 2005, 2007), orogens (e.g., Barruol et al.,
68 1998; Flesch et al., 2005) and stable continental environments (e.g., Fouch et al., 2000; Heintz and
69 Kennett, 2005; Fouch and Rondenay, 2006; Assumpção et al. 2006).

70 Azimuthal anisotropy was initially deduced from surface waves by Forsyth (1975), then by
71 Nishimura and Forsyth (1988) in Pacific and by Montagner and Tanimoto (1991) at global scale.
72 The ever-growing dataset of seismic stations and recordings have allowed, over the years, to
73 significantly improve spatial resolution of azimuthally anisotropic tomographic models (e.g.,
74 Trampert and Woodhouse, 2003; Smith et al., 2004; Debayle et al., 2005; Maggi et al., 2006). By
75 using the surface wave (Rayleigh and Love) frequency dependence on their penetration depth,
76 surface wave tomography provides a relatively good vertical resolution of velocities and
77 anisotropy down to the transition zone although the lateral resolution is relatively poor, generally
78 not better than several hundreds of kilometres. In addition to the good vertical resolution, surface
79 wave tomography has the advantage of providing a continuous and global-scale coverage of
80 azimuthal anisotropy, except in poorly covered areas. This is in sharp contrast to the resolution of

81 teleseismic shear-wave splitting measurements which provide localized measures of anisotropy
82 directly beneath a seismic station.

83 Given the constraints on deformation within the Earth that seismic anisotropy offers, there is much
84 interest in understanding the origin of that anisotropy. Comparing observed fast directions with
85 absolute plate motion directions is of interest (e.g., Vinnik et al., 1984; Silver and Chan, 1991;
86 Montagner, 1994), since anisotropy in the asthenosphere, if caused by relative motion between
87 plates and deeper interior of the Earth, should have fast directions parallel to plate motion. On the
88 other hand, fossil anisotropy in the lithosphere does not need to show a correlation with current
89 plate motion directions. It is also of interest to compare seismic anisotropy with predicted seismic
90 anisotropy from flow calculations that have become available in recent years. That has been done
91 at regional scale (Griot et al., 1998; Fouch et al., 2000; Becker et al., 2006), and also at global
92 scale (Behn, et al., 2004; Becker et al., 2007; Conrad et al., 2007).

93 This study addresses the question whether shear-wave splitting observations and surface wave
94 azimuthal anisotropy can be used interchangeably for the comparison with flow models. The
95 different spatial resolution of the two types of data may result in significant differences: surface
96 waves offer vertical resolution, while body waves offer lateral resolution. Furthermore, shear-wave
97 splitting observations have mostly been made on continents (Figure 1), whereas surface wave
98 models offer some resolution at all places of the Earth's surface, although poor ray coverage may
99 result in weak constrains in some regions. A further complication for comparing the two datasets
100 arises from the fact that the anisotropy is mainly characterised by two parameters, fast orientation
101 and strength. A good coherence in one parameter does not necessarily means a good coherence in
102 the other.

103 So far, there have been only few attempts to directly relate body-wave and surface wave
104 anisotropy. Because the two techniques sample the anisotropy along vertical and horizontal
105 propagation directions, respectively, the results cannot be compared directly. Montagner, et al.
106 (2000) proposed to predict splitting parameters from a multi-layer anisotropic surface wave model.
107 That study has suggested reasonable correlation at regional scale in some regions, but at global

108 scale there did not appear to be a clear correlation. The possibility was discussed that the spatial
109 resolution of the two techniques is perhaps too different to allow realistic comparisons.

110 In this paper we follow the approach of Montagner et al. (2000), and we study the relation between
111 anisotropy measures from shear-wave splitting and surface wave models at global scale, as well as
112 for a few selected key regions. We will in fact show that there is indeed a correlation at global
113 scale, and discuss its implications. In the first part of the paper, we present the new shear-wave
114 splitting dataset. In the second part we present the prediction of splitting measurements obtained
115 from recent surface wave tomography and in the third part, we compare the observed splitting data
116 with the predicted parameters.

117

118 **2. World-wide shear-wave splitting results**

119 Over the past decades, a large number of shear-wave splitting studies have been published. Some
120 of these studies have analyzed sets of globally distributed stations (e.g. Silver, 1996; Barruol and
121 Hoffmann, 1999), while most focused on regional networks of stations, providing detailed
122 knowledge on specific areas. Ever-larger temporary seismic arrays (e.g. USArray) and long-
123 running permanent stations make the available shear-wave splitting dataset grow rapidly, and the
124 need for a central depository for all available splitting measurements has been evoked (e.g., Fouch
125 and Rondenay, 2006). Evans et al., (2006) present a shear wave splitting database, where they re-
126 calculated available broadband stations. Our approach is different from that. In order to make all
127 the published splitting data easily available in a homogeneous format, we developed an interactive
128 database. The main features of this shear-wave splitting database are that the user may: i) Enter
129 new splitting data via a web interface, ii) Search the database for a specific station or within a
130 region, iii) Download the whole splitting parameters and corresponding bibliographic references
131 and iv) Visualize the database, e.g. through GoogleEarth. Such an approach ensures that results of
132 individual studies will be taken into account by the community, as users of splitting data will

133 always find the most “up-to-date” information. This database is available on the “Geosciences
134 Montpellier” website at the address <http://www.gm.univ-montp2.fr/splitting/DB>.

135 As of June 2008, the database contains 2566 entries from 133 referenced studies (see Figure 2a).
136 Note that the database is a collection of the work of various authors over many years, using a
137 broad range of filters and possibly quality control factors. The global splitting delay times show an
138 approximately log-normal distribution with most values between 0.4 and 1.4 sec and a maximum
139 at 1 sec (Figure 3a, b). This distribution is in agreement with earlier studies, e.g. that of Silver
140 (1996). Petrophysical analyses of upper mantle rocks sampled in orogenic or ophiolite peridotite
141 massifs, or as kimberlite or basalt xenoliths suggest that such a mean delay time requires a 100 to
142 150 km thick anisotropic layer (Mainprice and Silver 1993, Ben Ismail and Mainprice, 1998;
143 Mainprice et al., 2000, Ben Ismail et al., 2001). We note that fast-axis orientations prefer E-W
144 orientations, which are interesting in the light of speculations of uniform global plate motion
145 relative to the underlying mantle (Doglioni, 1994; Steinberger and O’Connell, 1998; Doglioni et
146 al., 2003). However, these statistics have to be considered with care, for two reasons: i) The ocean-
147 continent discrepancy: Most splitting data originated from continents, where the azimuth may be
148 dominated by frozen-in lithospheric anisotropy. Only a small amount of splitting data originated
149 from oceanic environments where one could expect to observe present-day processes related to
150 asthenospheric flow. ii) Seismic stations are not evenly distributed worldwide. Temporary
151 experiments generally gather many instruments in a small area (e.g., Barruol et al., 1998; Walker
152 et al., 2005; Flesch et al., 2005), which may cause a bias in statistical analyses. Furthermore, the
153 different continents are not equally well sampled, and there is indeed an over-representation of
154 North America and Western Europe in the dataset.

155

156 **3. Predicting shear-wave splitting parameters from surface wave data**

157 Montagner et al. (2000) developed a method to predict splitting parameters from surface-wave
158 anisotropy results. Their approach is not unlike that of several earlier studies that discuss the effect

159 of multiple anisotropic layers on the effective splitting parameters (Silver and Savage, 1994;
 160 Wolfe and Silver, 1998; Rumpker and Silver, 1998; Saltzer et al., 2000). The fast axis Φ as well as
 161 the delay time δt of a vertically propagating SKS phase that results from a (weak) anisotropic layer
 162 is related to the elastic parameters $G_s = C_{45}$, $G_c = \frac{1}{2}(C_{55} - C_{44})$, and $L = \frac{1}{2}(C_{44} + C_{55})$ that
 163 can be obtained from surface wave studies (Montagner, 1986). This can be generalized for
 164 multiple layers. Montagner et al. (2000) have proposed a first-order expansion that is valid at
 165 periods larger than 10 seconds, e.g. for SKS and SKKS waves. Under that assumption, splitting
 166 delay and fast direction can be predicted by a simple integration along the (assumed vertical) ray
 167 path, as

168

$$\begin{aligned}
 d\bar{t} &= \sqrt{\left(\int_0^a \sqrt{\frac{\rho}{L}} \frac{G_c}{L} dz\right)^2 + \left(\int_0^a \sqrt{\frac{\rho}{L}} \frac{G_s}{L} dz\right)^2} \\
 \bar{\phi}_{fast} &= \frac{1}{2} \arctan\left(\frac{\int_0^a \sqrt{\frac{\rho}{L}} \frac{G_s}{L} dz}{\int_0^a \sqrt{\frac{\rho}{L}} \frac{G_c}{L} dz}\right)
 \end{aligned} \tag{1}$$

170 where a corresponds to the maximum depth extent of the tomographic model and ρ is the density
 171 of each layer. In the following we will use the global tomographic model of Debayle et al. (2005).
 172 Figure 2b shows predicted shear-wave splitting for that model, integrating from 500 km to 50 km
 173 depth (thus excluding the negligible influence of the crust).

174

175 Debayle et al. (2005) have used observations of fundamental and higher-mode Rayleigh waves,
 176 and among the 100779 ray paths, they include many short epicentre-station paths, which give
 177 particularly strong constraints. The inversion has used a spatially variable cell size determined
 178 using Voronoi tessellation, and the smallest cells have sizes of about 200 km. Since anisotropic
 179 and isotropic variations often occur together, it is not likely that the very small variations are
 180 resolved. Therefore, the tomographic inversion has also imposed a spatial smoothness constraint
 181 via a Gaussian correlation function with standard deviation of 400 km. It is clear that resolution

182 must vary strongly with location along the Earth's surface, due to the variable ray coverage. In
183 places where the coverage is particularly good, resolution will be better, but it is not quite clear
184 what the resolution limit is. In principle, a Voronoi technique is well-adapted for optimally
185 extracting information in this situation. In any case, a lower bound on resolution is imposed by the
186 smoothness constraint corresponding to length scales of 400 km.

187 Figure 3c-f presents the statistical distribution of the predicted splitting parameters. The delay
188 times range between 0 and 2 s, with a maximum of the distribution around 0.5 s, for both
189 continental and oceanic environments. The predicted splitting delay times are thus systematically
190 smaller delay than the observed ones (Figure 3a, b). Potential causes for this bias may be i) the
191 damping that is necessarily applied during the surface-wave inversion, leading to an
192 underestimation of parameters, ii) an underestimation of true lateral variations due to an
193 insufficient lateral resolution of surface waves and/or iii) incompatibilities between the
194 assumptions of anisotropy systems inherent to both methods. We choose to show the angular
195 distribution separately for continental (Figure 3c, d) and oceanic regions (Figure 3e,f). For oceanic
196 environments, the predicted splitting orientations display hardly any azimuthal preference on a
197 global scale. However, for continental areas there are two maxima of predicted fast directions, a
198 stronger one in N-S direction, and a weaker one in E-W direction. The N-S predicted fast
199 directions appear primarily in Africa, north-east Asia, and Australia (Figure 2b), where station
200 coverage for observed splitting measurements is poor. Such a discrepancy between predicted and
201 observed fast split direction statistics could therefore be related to the extremely uneven station
202 coverage present in the splitting database. However, at least for Africa, the N-S orientation is in
203 accordance with recent surface wave tomographic models (Sebai et al.; 2006; Montagner et al.,
204 2007). The E-W maximum is much less pronounced for surface waves than that for body waves,
205 and it therefore does not serve to confirm this as a continental feature at the largest scale.

206

207 4. Comparing observed and predicted SKS splitting

208 The two datasets we compare have rather different distribution on the Earth's surface. While the
 209 splitting parameters are obtained at unevenly distributed seismic stations (Figure 2a), the predicted
 210 splitting values from the surface wave model of Debayle et al. (2005) are evenly distributed on a
 211 $1^\circ \times 1^\circ$ grid (Figure 2b). Comparing the two datasets therefore requires interpolation. Interpolating
 212 sparse vectorial data as splitting measurements onto a regular grid is possible (Bird and Li, 1996;
 213 Lucente et al., 2006), but to avoid stability problems due to the different spatial support, we prefer
 214 to follow the approach proposed by Montagner et al. (2000), i.e., we linearly interpolate the
 215 regular grid of the predicted anisotropy parameters to the location of each splitting measurement.

216 The correlation between the observed and predicted datasets is then obtained by using an adapted
 217 form of the coherence function initially defined by Griot et al. (1998). This mathematical function
 218 quantifies the correlation between two vectorial data sets on a sphere (co-latitude Θ , longitude Ψ)
 219 by taking into account the two anisotropy parameter pairs $(\Phi_1, \delta t_1; \Phi_2, \delta t_2)$. Since each parameter
 220 pair corresponds to a phase and amplitude, a natural form of the coherence between two
 221 continuous fields on the sphere is

$$222 \quad C(\alpha) = \frac{\iint_{\Theta \Psi} \left\{ dt_1(\Theta, \Psi) * \sin \Theta * dt_2(\Theta, \Psi) * \sin \Theta * \exp \left(-\frac{(\phi_1(\Theta, \Psi) - \phi_2(\Theta, \Psi) + \alpha)^2}{2D_{corr}^2} \right) \right\} d\Theta d\Psi}{\sqrt{\iint_{\Theta \Psi} dt_1(\Theta, \Psi)^2 * \sin^2 \Theta d\Theta d\Psi} \sqrt{\iint_{\Theta \Psi} dt_2(\Theta, \Psi)^2 * \sin^2 \Theta d\Theta d\Psi}}$$

223 (2)

224 The phases (fast directions) enter through an exponential form that is normalized by a “correlation
 225 factor” D_{corr} . This formula does not require an alignment of the two sets of fast axes. The test
 226 orientation α can vary between -90° and $+90^\circ$ and allows testing for an angular bias between the
 227 two datasets. The normalization in the conventional fashion ensures that the coherence varies
 228 between 0 (uncorrelated) to 1 (perfect correlation). An anti-correlation between the fast axes
 229 would show up as a peak at $\pm 90^\circ$.

230 If $C(\alpha)$ is represented by a horizontal line, the two models are uncorrelated. A Gaussian shape of
231 $C(\alpha)$ indicates a certain coherence, with the location of the peak corresponding to the mean
232 rotation between the models. Figure 4a illustrates this by comparing the $1^\circ \times 1^\circ$ predicted splitting
233 dataset with itself. As expected, this results in a Gaussian distribution with a maximum value of 1
234 oriented at 0° . Figure 4b shows the coherence of the predicted splitting data on a 1° grid with that
235 of a 10° grid. Maximum values are considerably smaller than 1 now, and the distributions are
236 much wider, reflecting the added variance from the interpolation using the 10° grid. In fact, there is
237 much variation of predicted fast directions in Figure 2b, at scales below 10° .

238

239 **4.1. Global correlation of splitting parameters**

240 Montagner et al. (2000) compared splitting parameters as predicted by a global anisotropic
241 tomography model (Montagner and Tanimoto, 1991) with the shear-wave splitting results
242 compiled by Silver (1996). The results suggested a fairly good coherence at regional scale (for
243 instance in the Western United States and in Central Asia), but no clear coherence at global scale.
244 The authors have attributed the latter to the different depth and lateral sensitivity in both datasets.
245 Surface waves are best resolved in oceanic environment, where large-scale structures are expected
246 but where station coverage and therefore shear-wave splitting measurements are sparsely
247 distributed in that environment. In contrast, shear-wave splitting has a relatively good lateral
248 resolution and may evidence short scale variations in upper mantle structures beneath the
249 continents that are hardly visible from surface wave analyses. The authors also suggested that the
250 usually-performed single-layer inversion for splitting parameters may represent an
251 oversimplification that contributes to the missing global correlation.

252 Figure 4c and d show the coherence of predicted splitting from the model of Debayle et al. (2005),
253 integrated between 50-500km depth, with the splitting database, taking into account the entire
254 database using gridding sizes of 1° and 10° , for the correlation lengths used previously ($D_{\text{corr}} = 5,$
255 10 or 20°). The coherence is slightly broader for the 10° grid (Figure 4d) than for the 1° grid

256 (Figure 4c). However, both comparisons give a rather good correlation of available splitting data
257 and anisotropic surface wave model, with a maximum centred near 0° misfit. This indicates that
258 the available splitting database sufficiently covers the globe, as it is insensitive to the resolution of
259 the surface wave model.

260 In the former study, Montagner et al. (2000) used the anisotropic surface wave model of
261 Montagner and Tanimoto (1991) and the splitting data collection of Silver (1996). The global
262 coherence was found to show a local minimum at 0° misfit, with local maxima on both sides. We
263 were able to roughly reproduce this behaviour by incorporating only the splitting measurements
264 available before 1997 (Figure 4e). Montagner et al. (2000) concluded that there is no global
265 correlation. In fact, Figures 4d-f suggest that the absence of correlation in that study was
266 apparently an effect of insufficient splitting data coverage and limited spatial resolution in
267 available surface wave models at the time. Since Fresnel zones of the commonly used SKS waves
268 are of the order of 100 km at upper mantle depths, and since splitting parameters vary at these
269 scale length (Figure 2a), averaging azimuthal anisotropy at scale larger than 10° introduce a too
270 large smoothing to preserve a good coherence between the body wave pattern and the large-scale
271 surface wave pattern.

272 The higher correlation of the new global set (Figure 4c) in comparison to sub-dataset of Silver
273 (1996; Figure 4e) may on the other hand reflect the numerous regional studies performed after
274 1996, that concentrate a large number of stations in relatively small areas, e.g. in the Eifel region
275 (Walker et al., 2005), and the Pyrenees (Barruol et al., 1998). This leads to regional biases. The
276 difference suggests that we should try to eliminate the regional biases if possible, or at least
277 eliminate the effect of the spatially varying data density where we have data. So far, all data points
278 enter equally into the coherence, and local studies with dense station coverage will thus have a
279 stronger effect on the coherence than sparsely instrumented areas. We address this problem by
280 gridding the splitting data. However, standard interpolation procedures are inappropriate when
281 interpolating sparse directional data on a sphere (Bird and Li., 1996). One approach to solve this
282 problem may be by using Voronoi cells, similar to the method of Debayle et al. (2005) or Larmat

283 et al. (2006). In this study, however, we follow a different approach: To account for both the
 284 amplitude and orientation of anisotropy we separate amplitude (delay time) and orientation (fast
 285 direction). The delay time is gridded using a standard cubic spline interpolation to give a map of
 286 gridded delay times T . The directional component of anisotropy is computed using an algorithm
 287 that has already been successfully applied to global stress data (Müller et al., 2003). The gridding
 288 algorithm is based on Watson (1985) and extended by a distance-weighting (Wehrle, 1998). For a
 289 series of unit vectors \vec{y} , given at positions \vec{x} , Watson (1985) proposes a technique that searches
 290 for a ‘predictor’ function $\vec{f}(\vec{x})$ that describes the vector field parallel (or anti-parallel) to \vec{y} . This
 291 is achieved by maximising the (quadratic) scalar product $P = \langle \vec{f}(\vec{x}_i)^T \vec{y}_i \rangle^2$. Furthermore, to be
 292 smooth, the (quadratic) scalar product of two neighbouring functions $N = \langle \vec{f}(\vec{x}_i)^T \vec{y}_j \rangle^2$ must be
 293 maximum as well. The resulting gridded vector field is thus the maximum of the following
 294 function $K(f)$:

$$295 \quad K(f) = \sum_{i=1}^n \left(Pd(\vec{x}_i, \vec{x}_i) + \lambda \sum_{j=1, j \neq i}^n Nd(\vec{x}_j, \vec{x}_i) \right) \quad (3)$$

296 As mentioned, the P-term achieves optimum fitting of the data, the N-term controls the
 297 smoothness of the resulting field. The weighting factor λ lambda thus controls the relative
 298 influence of the data fidelity and smoothness, respectively. The function $d(\vec{x}_i, \vec{x}_j)$ expresses the
 299 distance weighting of point \vec{x}_j at \vec{x}_i within a search radius R (Wehrle, 1998). The interpolated
 300 splitting “vector field” is then the linear combination of the gridded splitting amplitude and $K(f)$,
 301 calculated at the locations \vec{s}_i . These coincide with the grid points of the tomographic model and
 302 thus the location of the predicted splitting parameters.

$$303 \quad V = T|_{\vec{s}} * K(f)|_{\vec{s}} \quad (4)$$

304 Figure 5 shows an example result of that gridding for $R = 600$ km and $\lambda = 5$ on a $3^\circ \times 3^\circ$ grid. Null
 305 measurements, though important to constrain fast directions at individual stations (Wüstefeld and
 306 Bokelmann, 2007), are not taken into account.

307 Similar to Figure 4, we calculate the coherence functions of the predicted splitting with these
308 smoothed global datasets, to ascertain that the correlation between observed and predicted splitting
309 as described in the previous section, is not an artefact of the rather heterogeneous data density. If
310 the correlation is real, this helps to define the inherent lateral resolvability of anisotropy by the
311 used surface-wave model.

312 The results for various parameter combinations of R and λ are presented in Figure 6a (D_{corr} is fixed
313 to 10°). For all tests, there is a maximum near 0° , suggesting that there is indeed a correlation also
314 for the gridded data, similar to the global correlation found previously (Figure 4). The correlation
315 between the two datasets is therefore not an artefact of the uneven sampling.

316 Figure 6b shows the dependence of the coherence value at 0° on search radius for various λ .
317 Interestingly, the coherence decreases clearly below $R = 400\text{km}$ while it stays more or less
318 constant between 400 and 1000 km. Below $R = 400\text{km}$, the coherence shows a weak dependence
319 on smoothing parameter λ . This is as expected, since the effect of λ must be somewhat similar to
320 that of the search radius. Thus, the decrease of coherence below $R = 400\text{km}$ also manifests itself in
321 the λ values. A peak in coherence is obtained for strong smoothing with $\lambda = 10$ and 50 at search
322 radii of $R = 400$ km. Moreover, a plateau of relatively good coherence is found for $\lambda = 5$ and
323 R between 600 and 700 km.

324 Figures 6c and 6d are similar to 6a and 6b, but the order of each parameter ($\Phi_1, \delta t_1; \Phi_2, \delta t_2$) has
325 been randomised. In such random test any spatial coherence should be eliminated, unless there is
326 an inherent correlation, due to a non-random data distribution. Comparing Figure 6c with Figure
327 6a we note that coherence indeed drops sharply, indicating that the correlation observed in Figure
328 6a is indeed real. The weak residual coherence in Figure 3b thus shows the artefact of the non-
329 uniform distribution of splitting fast directions.

330 **4.2. Regional correlation of splitting parameters**

331 The previous section showed that anisotropy as determined from surface waves and those from
332 body waves show similar results on a global scale, though both methods sample the Earth at

333 different scales. In this section we discuss several regional subsets of different tectonic
334 background. Montagner et al. (2000) point out that several regional subsets have a rather good
335 coherence despite the poor global coherence obtained in their earlier study. They relate that
336 partially to an increased resolution of regional tomographic models used. We limit our comparison
337 here to regional subsets of the global model. Regional tomographic models might provide higher
338 resolution, yet a detailed comparison of all available models would be beyond the scope of this
339 study. Figure 7 illustrates the coherence function for several regional subsets in different tectonic
340 settings (subduction, rifts, volcanic islands, cratons). See Figures 2 and 5 for locations. Generally,
341 the coherence is very good, with a clear maximum centred close to 0° misfit. Only the absolute
342 value of that maximum varies between the regions. We attribute this to differences in the observed
343 and predicted delay times, as we will discuss below.

344 Montagner et al. (2002) selected Western United States and Central Asia for closer discussion. For
345 consistency and comparison with that study we will briefly discuss the results of our new
346 coherence study, and also present results for other selected regions and tectonic settings.
347 Additional maps of test regions can be found in the Appendix. This section shall provide an
348 overview on coherences between the two datasets. For detailed interpretation of the anisotropy in
349 the selected regions we kindly refer to the according publications.

350 4.2.1. The Andes

351 Several studies analysed shear-wave splitting in the Andes and adjacent Nazca plate. Polet et al.
352 (2000) argue that most significant contribution to splitting occurs below the slab, with a complex,
353 spatially varying anisotropy pattern. Russo and Silver (1994) and Helffrich et al. (2002) propose
354 that the large-scale Pacific mantle flow pattern is deviated around the South American continent by
355 roll-back of the Nazca slab.

356 The coherence between predicted and interpolated observed splitting is variable in this area, with
357 poles at -70° , $+20^\circ$ and $+60^\circ$ (Figure 7a, Figure A1). This behaviour renders the complex
358 interaction, sometimes at small scale, between subduction of oceanic plate and mountain range

359 formation, both of which may cause different anisotropy orientations (Vauchez and Nicolas, 1991;
360 Barruol et al., 1998; Kneller et al., 2007).

361 4.2.2. The East Pacific Rise

362 The coherence between predicted and interpolated observation of splitting is striking for stations in
363 the vicinity of the East Pacific Rise (Figure 7b; Figure A2). These measurements come from the
364 MELT and GLIMPSE Ocean Bottom Seismometers experiments (Wolfe and Solomon, 1999;
365 Harmon et al., 2004). They proposed Lattice Preferred Orientation (LPO) of anisotropic minerals
366 parallel to mantle flow trending normal to the spreading axis as main cause for splitting, as well as
367 a deeper contribution of an asthenospheric return flow from the South Pacific superswell. This
368 agreement between the fast split directions and the surface wave anisotropy is not restricted to the
369 ridge itself but is extending further West in the French Polynesia domain where Fontaine et al.
370 (2007) evidenced a clear signature of the asthenospheric flow in the SKS splitting observations
371 that also dominates within the surface wave tomographies, both exhibiting dominant fast directions
372 parallel to the plate motion direction. Further south, the EPR region also contains station RPN,
373 located on the Easter Island Hot Spot, for which a multilayer case has been proposed (Fontaine et
374 al., 2007). The SKS anisotropy pattern observed at this station is clearly not the result of the ridge
375 spreading alone and may likely result from the combination of spreading-related mantle flow and
376 hotspot-related mantle upwelling. South and east of station RPN, although both the station
377 coverage and resolution of the surface wave model is too small to confidently relate this behaviour
378 to mantle upwelling, the predicted and interpolated splitting coincide rather well, whereas towards
379 the north, the two models are almost perpendicular. This can be seen in Figure 7b as a smaller
380 peak at -65° .

381 4.2.3. North America

382 The understanding of regional tectonics in North America is continuously improved (e.g.,
383 Humphreys and Coblenz, 2007). Seismic anisotropy beneath North America has been addressed
384 by numerous authors (see references in Walker et al., 2004; Fouch and Rondenay, 2006,
385 Bokelmann and Wüstefeld, 2009). The pertaining mantle flow is mainly controlled by the various

386 tectonic settings ranging from cratons in the north (e.g., Bokermann, 2002a, b), mountain ranges in
387 the east (e.g., Barruol et al., 1997; Fouch et al., 2000), and continental hotspot (e.g., Waite et al.,
388 2005) and subduction in the west that could interfere with strike-slip tectonics to produce a
389 complex toroidal mantle flow pattern (e.g., Xue and Allen, 2007; Zandt and Humphreys, 2008).
390 The splitting dataset presented in this study indicates good correlation with the splitting predicted
391 from surface wave azimuthal anisotropy in North America (Figure 7c, Figure A3). Montagner et
392 al. (2000) observed however a rotation of $+30^\circ$ between observed and predicted splitting in the
393 Western US (Figure 8a). In this region, the coherence of the new dataset has improved (Figure 7d),
394 likely due to the larger amount of splitting data (109 measurements today versus 47 available in
395 1996), but perhaps also due to the more recent tomographic model used in this study that may
396 provide an improved lateral resolution. The resulting misfit is reduced to a slight rotation of -10°
397 for all of North America. In Western North America the angular misfit is precisely 0° . This
398 suggests that surface waves and shear wave splitting experience the same anisotropic structures
399 (Figure 8a) and therefore, that the apparent complexity of the crustal tectonics in this region may
400 be overlying a mantle structure characterized by a simpler pattern at longer wavelength. It thus
401 appears to be consistent to invert the two datasets together as has been done recently by Marone
402 and Romanowicz (2007).

403 4.2.4. Kaapvaal Craton

404 Several studies analysed the Kaapvaal upper mantle anisotropy by using either SKS wave splitting
405 (e.g., Vinnik et al., 1996; Barruol and Ben Ismail, 2001; Silver et al., 2001; Fouch et al., 2004) or
406 the information brought to the surface by kimberlite nodules (e.g., Ben Ismail et al., 2001). Silver
407 et al. (2001) and Gao et al. (2002) point out that the fast orientations do not correlate with plate
408 motion directions of Gripp and Gordon (2002). The fast orientation correlates however very well
409 with regional geologic trends, suggesting lithospheric origins of anisotropy. Furthermore, a high-
410 density array in the Kimberley region found small-scale variations in shear wave splitting
411 parameters, which can only be explained by lithospheric origins of anisotropy (Fouch et al., 2004).

412 In global tomographic models, one of the most intriguing features is the African Superswell (e.g.,
413 Nyblade and Robinson, 1994; Ritsema and van Heijst, 2000; Conrad and Gurnis, 2003), which is
414 an ongoing, large-scale, northward oriented mantle upwelling. This upwelling can provide an
415 explanation for the predicted splitting (Figure 2b, 8b) particularly because of the absence of
416 predicted splitting beneath the Namibia-Botswana border region (Figure 8b), since vertically
417 oriented anisotropy is not included in the methods used here. The presence of two peaks in the
418 regional coherence function (Figure 7e) may indicate that the anisotropy observed by tomographic
419 studies is not only related to the ongoing mantle upwelling, but also related to ancient lithospheric
420 anisotropy, at least in the upper mantle regions.

421 4.2.5. The East African Rift Zone

422 Rifting along the East African Rift Valley (EAR) has been analysed at mantle to crustal scales by
423 various studies (see Kendall et al., 2006 for a review). Collectively, the results support a model for
424 magma assisted rifting in Ethiopia with an increase in melt production towards the Red Sea, which
425 is strongly supported by the prediction of partial melt on the basis of P- and S-wave tomography
426 (Bastow et al., 2005, 2008). In Tanzania and Kenya, fast split shear waves parallel the E and W
427 arms of the EAR that encircle the Tanzanian craton (Gao et al., 1997; Walker et al., 2004).

428 The coherence between observed and predicted splitting is rather strong with a maximum at 0°
429 deviation (Figure 7f, Figure A4). The strong coherence is mainly due to high correlation of both
430 direction and amplitude of splitting between the predicted and interpolated datasets beneath Afar
431 (Figure A4). Kendall et al. (2006) proposed a suite of different causes of anisotropy beneath the
432 East African rift system. The main cause of anisotropy is attributed to thin melt pockets directly
433 beneath the rift zone, oriented parallel to the rift axis. Away from the rift axis, the lithospheric
434 LPO is likely related to pre-existing fabric, while beneath the lithosphere the LPO could be due to
435 viscous coupling between the base of the lithosphere and large-scale mantle upwelling. This model
436 explains the rift-parallel fast splitting orientations in the rift valley. Such explanation leaves the
437 good correlation somewhat surprising, since global surface waves are not expected to resolve that
438 feature. The splitting delay times predicted in this area are relatively low, which may be due to two

439 perpendicular anisotropic orientations (see discussion for Australia). An alternative explanation
440 might be that the mantle upwelling beneath the rift causes vertically oriented fast axis in the
441 mantle. These do not contribute to the observed and the predicted splitting.

442 4.2.6. *Central Asia*

443 In Central Asia (Figure 7g, Figure A5), more than 250 measurements are now available, in
444 comparison with the 33 available before 1997. The new model seems to be less coherent (Figure
445 7g) than the previous one, as discussed in Montagner (2000), and it is characterized by the
446 presence of two peaks in the coherence function at $+15^\circ$ and -70° . Montagner et al. (2000) used a
447 local high-resolution tomographic model (Griot et al., 1998) for calculating the predicted splitting.
448 The two compared datasets seem to be rotated by 20° . The main region of discrepancy is the
449 Tibetan Plateau, while coherence is good for the Tien Shan basin in the North-West and the North
450 China craton, in the North-East of Figure A5). In general, discrepancies between the global
451 (Montagner and Tanimoto, 1991) and local (Griot et al, 1998) tomographic datasets highlight the
452 importance of local high-resolution tomography that may be sensitive to shorter wavelength
453 structures. This regional analysis also suggests that more data do not necessarily imply a better
454 coherence since local studies involving a large number of stations over a limited space may
455 strongly bias the general coherence function at the regional and global scale. They conclude that
456 future approaches should consider the effect of different data density in greater detail. New
457 azimuthal anisotropy tomographic models of Central Asia with an enhanced lateral resolution are
458 presently issuing. Consequently time is ripe for a new quantitative comparison between SKS
459 splitting data and tomographic models, but it is beyond the scope of this paper.

460

461 4.2.7 *Australia*

462 The coherence in Australia is rather good (Figure 7h, A6). Given the complex anisotropy
463 described by other studies of this area, this is somewhat surprising. Debayle et al. (2005) found
464 that Australia is the only continent where azimuthal anisotropy (inferred from surface waves)

465 correlates well with present day absolute plate motion. This correlation is most significant at
466 depths between 150 and 300km. In Australia many stations are observed as isotropic, i.e. Nulls
467 from a broad range of backazimuths. Heintz and Kennett (2005, 2006) point out that this apparent
468 isotropy at these stations is also consistent with two layers of mutually perpendicular anisotropy
469 orientations (Silver and Savage, 1994; Barruol and Hoffmann, 1999).

470 The predicted shear wave splitting contains a few regions of negligible splitting amplitude (central
471 Northern Territory, just south of Western Australia, and in Central New South Wales; see Figure
472 A6). In our approach, the predicted splitting is calculated from 19 layers, each 25 km thick. The
473 correlation between non-Null observations and predicted splitting is very good, indicating that
474 such gradual change in anisotropy orientation with depth mimics the non-Null splitting
475 observations well. This in turn indicates that assuming a two layer case may be an
476 oversimplification.

477 **5. Discussion**

478 Generally, the resolution of global anisotropic surface wave models is thought to not be better than
479 a thousand kilometres. For an increasing number of regions, recent high-resolution regional
480 anisotropic tomographic models are available, and future studies should address their correlation
481 with regional splitting data in more detail. For the global model, the dependence of correlation on
482 search radius in Figure 6b may suggest that resolution capability is somewhat better than the
483 initially thought thousand kilometres. This is true at least for the parts of the Earth that contain the
484 most seismological stations. These areas correspond to the seismically best-resolved portions on
485 Earth, obviously for shear wave splitting but also in surface wave data due to the higher density of
486 crossing ray paths in those areas. The use of Voronoi cells allows the tomographic model of
487 Debayle et al. (2005) to reflect spatially varying resolutions. The drop-off in correlation below 400
488 km is interesting, since we would be able to see that effect only if there is resolution of surface
489 wave data for those best-resolved parts of the Earth down to 400 km length scales, which is
490 considerably better than we expected. Whether or not this is the correct explanation for the decay
491 below 400 km, this resolution study is very encouraging, since it indicates lateral surface wave

492 resolution somewhat below a thousand kilometres for the well-resolved portion of the Earth. The
493 resolution will be considerably weaker in less well-covered regions. A recent study of the
494 Canadian shield (Bokermann and Wüstefeld, 2009) has suggested that surface-wave anisotropy
495 models do not yet have a similar resolution there, which would be required to distinguish inner-
496 cratonic variations of anisotropy.

497 This will probably change somewhat in the next years, with the availability of massive regional
498 datasets. Also methodological developments such as simultaneous inversions of splitting and
499 surface wave data are quite useful (e.g., Marone and Romanowicz, 2007).

500 A limitation of our method is that no Null stations, i.e. apparently isotropic stations, are included.
501 The explanation of such Null stations is not yet completely understood as ever more evidence
502 suggests that at least the upper part of the mantle is anisotropic. This evidence is based on
503 seismological observations as presented in this paper and also on mineralogical studies (e.g., Ben
504 Ismail and Mainprice, 1998; Mainprice et al., 2000; Holtzman et al., 2003). Nulls stations do not
505 necessarily imply pervasive upper mantle isotropy, but may for example be caused by two
506 anisotropic layers with mutually perpendicular fast orientations (e.g., Silver and Savage, 1994;
507 Heintz and Kennett, 2006). Null stations may also not imply large scale upper mantle isotropy. For
508 instance, P-polarization analysis at station PPT in Tahiti Island (Fontaine et al., 2009) clearly
509 demonstrates that the isotropy deduced from SKS splitting, located vertically beneath the station,
510 has a restricted lateral extent, implying that such a short-scale upper mantle structure can hardly be
511 visible in surface wave tomographies.

512 The database contains only a limited amount of multi-layer cases. For the bulk of data, the
513 observed (apparent) splitting parameters reflect the vertical integration of the different layers of the
514 surface wave anisotropic model. Although the model is divided in 19 layers between 40 and 500
515 km depth, the radial correlation length limits the actual number of independent layers to 4 or 5.
516 These layers can in turn display effectively the same azimuth and so the real number of layers with
517 different orientations (in complex areas) may be at the most two or three. However, it is important
518 to note that in many areas these azimuthal variations and this stratification of anisotropy are real

519 and significant, although they cannot directly be inferred from shear wave splitting (Silver and
520 Savage, 1994; Rumpker and Silver, 1998; Saltzer et al., 2000).

521 The predicted delay times are smaller than the observed. Figure 9 shows a scatter-plot, comparing
522 the predicted delay times of the surface wave model with those delay times of the smoothed,
523 observed delay times for smoothing parameters of $R = 600$ km. The majority of the data are
524 located on the right-hand side of the graph, implying that surface wave-predicted delay times are
525 biased to smaller values. This also shows up in relatively low coherence (Figure 4). Our findings
526 of best coherence between the two datasets at approximately 600 km is in agreement with the
527 stochastic model of anisotropy correlation by Becker et al. (2007), which reveals a relatively short
528 correlation length of splitting parameters of $L \sim 550$ km for orogens and volcanic zones.

529 There is only a limited amount of shear-wave splitting measurements in the oceans although future
530 deployments of Ocean Bottom Seismometers will eventually enhance the global splitting coverage
531 (e.g., Suetsugu et al., 2005). This should allow for a separate analysis of continents having mostly
532 thick and old lithosphere, with sometimes ancient anisotropy orientations, and oceans having a
533 much more recent and simpler history (Montagner, 2002; Becker et al., 2003), which will probably
534 include exciting new possibilities such as observing hotspot-induced mantle flow, small-scale
535 convection, plume-ridge interaction etc.

536 The coverage of shear-wave splitting data that are available at this point does not allow accepting
537 or rejecting predominantly East-West mantle flow (e.g., Doglioni, 1994) at global scale as
538 manifested in fast directions. The maximum observed in Figure 3b is clearly an artefact of the
539 spatial sampling and probably includes many observations of fossil lithospheric anisotropy.

540 6. Conclusion

541 In this paper, we have compared shear-wave splitting measurements made around the world with
542 predicted splitting parameters derived from anisotropic surface wave tomography. This allowed us
543 to show that the two measures of anisotropy are indeed correlated, even though they have very
544 different lateral and vertical resolution. This correlation is apparently supported by the fact that

545 both measures are mostly sensitive to the upper mantle (e.g., Sieminski et al., 2007). The quality of
546 the measurements and resulting models allows us to address the limit of lateral resolution of the
547 anisotropic surface wave model. Finally, the agreement of the two different methods highlights the
548 fact that the two techniques are fully complementary since they are sensitive to vertical or lateral
549 variations of upper mantle flow and therefore deserve to be twined together in studies aiming at
550 mapping upper mantle deformation.

551 **Acknowledgements**

552 We would like to thank Derek Schutt and Matt Fouch for their initial work of collecting the
553 splitting parameters and for providing them online. Alexis Rochat helped us entering additional
554 SKS published data. Special thank goes to all colleagues who already entered their results to the
555 database. We are grateful to Birgit Müller and Oliver Heidbach of the University of Karlsruhe for
556 providing the smoothing code. We thank Ian Bastow for discussion on the East African Rift. The
557 reviews by of Matt Fouch and Christine Houser greatly improved our manuscript.
558

559 **References**

- 560 Ando, M., Ishikawa, Y., Wada, H., 1980, S-wave anisotropy in the upper mantle under a volcanic
561 area in Japan, *Nature*, 286, 43–46
- 562 Assumpcao, M., Heintz, M., Vauchez, A., Silva, M. E., 2006, Upper mantle anisotropy in SE and
563 Central Brazil from SKS splitting: Evidence of asthenospheric flow around a cratonic keel,
564 *Earth Planet. Sci. Lett.*, 250(1-2), 224-240.
- 565 Babuska, V., Plomerova, J., and Sileny, J., 1984, Spatial variations of P-residuals and deep-
566 structure of the European lithosphere, *Geophys. J. Roy. Astron. Soc.*, 79(1), 363-383.
- 567 Backus, G. E., 1962, Long-Wave Elastic Anisotropy Produced by Horizontal Layering, *J.*
568 *Geophys. Res.*, 67(11), 4427-4440.
- 569 Barruol, G., Ben Ismail, W., 2001, Upper mantle anisotropy beneath the African IRIS and
570 Geoscope stations, *Geophys. J. Int.*, 146(2), 549-561, doi: 10.1046/j.0956-
571 540x.2001.01481.x
- 572 Barruol, G., Granet, M., 2002, A Tertiary asthenospheric flow beneath the southern French Massif
573 Central indicated by upper mantle seismic anisotropy and related to the west
574 Mediterranean extension, *Earth Planet. Sci. Lett.*, 202, 31-47, doi:10.1016/S0012-
575 821X(02)00752-5.
- 576 Barruol, G., Hoffmann, R., 1999, Upper mantle anisotropy beneath the Geoscope stations, *J.*
577 *Geophys. Res.*, 104(B5), 10757-10773.
- 578 Barruol, G., Souriau, A., Vauchez, A., Diaz, J., Gallart, J., Tubia, J., Cuevas, J. (1998),
579 Lithospheric anisotropy beneath the Pyrenees from shear wave splitting, *J. Geophys. Res.*
580 103(B12), 30039-30053.
- 581 Barruol, G., Silver, P. G., Vauchez, A., 1997, Seismic anisotropy in the eastern US: deep structure
582 of a complex continental plate, *J. Geophys. Res.*, 102, 8329-8348
- 583 Bastow, I. D., Stuart, G. W., Kendall, J.M., Ebinger C. J., 2005, Upper-mantle seismic structure in
584 a region of incipient continental breakup: northern Ethiopian rift. *Geophys. J. Int.*, 162,
585 479-493, [doi: 10.1111/j.1365-246X.2005.02666.x](https://doi.org/10.1111/j.1365-246X.2005.02666.x),
- 586 Bastow, I. D., Nyblade, A. A., Stuart, G. W., Rooney, T., Benoit, M. H., 2008. Upper Mantle

- 587 Seismic Structure Beneath the Ethiopian Hotspot: Rifting at the Edge of the African Low
588 Velocity Anomaly. *Geochem. Geophys. Geosyst.*, 9(12), Q12022,
589 doi:10.1029/2008GC002107
- 590 Becker, T. W., Kellogg, J. B., Ekstrom, G., O'Connell, R. J., 2003, Comparison of azimuthal
591 seismic anisotropy from surface waves and finite strain from global mantle-circulation
592 models, *Geophys. J. Int.*, 155(2), 696-714.
- 593 Becker, T. W., Browaeys, J. T., Jordan, T. H., 2007, Stochastic analysis of shear-wave splitting
594 length scales, *Earth Planet. Sci. Lett.*, 259, 526-540.
- 595 Becker, T. W., Chevrot, S., Schulte-Pelkum, V., Blackman, D. K., 2006, Statistical properties of
596 seismic anisotropy predicted by upper mantle geodynamic models, *J. Geophys. Res.*
597 111(B10), B08309
- 598 Behn, M. D., Conrad, C. P., Silver, P., 2004, Detection of upper mantle flow associated with the
599 African Superplume, *Earth Planet. Sci. Lett.*, 224, 259-274.
- 600 Ben-Ismail, W., Barruol, G., Mainprice, D., 2001, The Kaapvaal craton seismic anisotropy:
601 Petrophysical analyses of upper mantle kimberlite nodules, *Geophys. Res. Lett.*, 28, 2497-
602 2500.
- 603 Ben Ismail, W., Mainprice, D., 1998, An olivine fabric database: an overview of upper mantle
604 fabrics and seismic anisotropy, *Tectonophysics*, 296(1-2), 145-157.
- 605 Bird, P., Li, Y., 1996, Interpolation of principal stress directions by nonparametric statistics:
606 Global maps with confidence limits, *J. Geophys. Res.*, 101, 5435-5444.
- 607 Bokelmann, G. H. R., 1995, P-wave array polarization analysis and effective anisotropy of the
608 brittle crust, *Geophys. J. Int.*, 120(1), 145-162.
- 609 Bokelmann, G. H. R., 2002a, Convection-driven motion of the North American craton: Evidence
610 from P-wave anisotropy, *Geophys. J. Int.*, 248(2), 278-287.
- 611 Bokelmann, G.H.R., 2002b, Which forces drive North America?, *Geology*, 30(11), 1027-1030.
- 612 Bokelmann, G. H. R., Wüstefeld, A., 2009, Comparing crustal and mantle fabric from the
613 North American craton using magnetics and seismic anisotropy, *Earth Planet. Sci. Lett.*,
614 277(3-4), 355-364, [doi:10.1016/j.epsl.2008.10.032](https://doi.org/10.1016/j.epsl.2008.10.032)

- 615 Conrad, C. P., Behn, M. D., Silver, P. G., 2007, Global mantle flow and the development of
616 seismic anisotropy: Differences between the oceanic and continental upper mantle, *J.*
617 *Geophys. Res.*, 112, B07317.
- 618 Conrad, C. P., Gurnis, M., 2003, Seismic tomography, surface uplift, and the breakup of
619 Gondwanaland: Integrating mantle convection backwards in time, *Geochemistry,*
620 *Geophysics, Geosystems*, 4(3), 1031.
- 621 Crampin, S., 1984, Effective anisotropic elastic constants for wave propagation through cracked
622 solids, *Geophys. J. R. Astron. Soc.*, 76, 135-145.
- 623 Debayle, E., Kennett, B., Priestley, K., 2005, Global azimuthal seismic anisotropy and the unique
624 plate motion deformation of Australia, *Nature*, 433, 509-512.
- 625 Doglioni, C., 1994, Foredeeps versus subduction zones, *Geology*, 22(3), 271-274.
- 626 Doglioni, C., Carminati, E., Bonatti, E., 2003, Rift asymmetry and continental uplift, *Tectonics*,
627 22(8), 1024
- 628 Evans, M. S., Kendall, J., Willemann, R. J., 2006, Automated SKS splitting and upper-mantle
629 anisotropy beneath Canadian seismic stations, *Geophys. J. Int.*, 165(3), 931-942.
- 630 Flesch, L. M., Holt, W. E., Silver, P. G., Stephenson, M., Wang, C., Chan, W. W., 2005,
631 Constraining the extent of crust-mantle coupling in central Asia using GPS, geologic, and
632 shear wave splitting data, *Earth Planet. Sci. Lett.*, 238, 248-268.
- 633 Fontaine, F. R., G. Barruol, B. L. N. Kenneth, G. H. R. Bokelmann, and D. Reymond (2009),
634 Upper mantle anisotropy beneath Australia and Tahiti from P-wave polarization -
635 Implication for real-time earthquake location, *J. Geophys. Res.*, 114 (B03306),
636 doi:10.1029/2008JB005709.
- 637 Fontaine, F. R., Barruol, G., Tommasi, A., Bokelmann, G. H. R., 2007, Upper-mantle flow
638 beneath French Polynesia from shear wave splitting, *Geophys. J. Int.*, 170, 1262-1288, doi:
639 10.1111/j.1365-246X.2007.03475.x.
- 640 Fontaine, F. R., Hooft, E. E. E., Burkett, P. G., Toomey, D. R., Solomon, S. C., Silver, P. G., 2005,
641 Shear-wave splitting beneath the Galápagos archipelago, *Geophys. Res. Lett.*, 32, L21308,
642 doi:10.1111/j.1365-246X.2007.03475.x
- 643 Forsyth, D. W., 1975, A new method for the analysis of multi-mode surface-wave dispersion:

- 644 Application to Love-wave propagation in the east Pacific, *Bull. Seis. Soc. Am.*, 65(2), 323-
645 342
- 646 Fouch, M. J., Fischer, K. M., Parmentier, E. M., Wysession, M. E., Clarke, T. J., 2000, Shear wave
647 splitting, continental keels, and patterns of mantle flow, *J. Geophys. Res.*, 105(B3), 6255-
648 6275.
- 649 Fouch, M. J., Rondenay, S., 2006, Seismic anisotropy beneath stable continental interiors, *Phys.*
650 *Earth Planet. Int.*, 158(2-4), 292-320.
- 651 Fouch, M. J., Silver, P. G., Bell, D. R., Lee, J. N., 2004, Small-scale variations in seismic
652 anisotropy near Kimberley, South Africa, *Geophys. J. Int.*, 157, 764-774.
- 653 Gao, S., Davis, P. M., Liu, H., Slack, P. D., Rigor, A. W., Zorin, Y. A., Mordvinova, V. V.,
654 Kozhevnikov, V. M., Logatchev, N. A., 1997, SKS splitting beneath continental rift zones,
655 *J. Geophys. Res.*, 102(B10), 2281-22798.
- 656 Gao, S. S., Silver, P. G., Liu, K. H., 2002, Mantle discontinuities beneath Southern Africa,
657 *Geophys. Res. Lett.*, 29(10), 1491, doi:10.1029/2001GL013834
- 658 Griot, D., Montagner, J., Tapponnier, P., 1998, Phase velocity structure from Rayleigh and Love
659 waves in Tibet and its neighbouring regions, *J. Geophys. Res.*, 103, 21215-21232.
- 660 Gripp, A. E., Gordon, R. G., 2002, Young tracks of hotspots and current plate velocities,
661 *Geophys. J. Int.*, 150(2), 321-361, doi: 10.1046/j.1365-246X.2002.01627.x
- 662 Harmon, N., D. W. Forsyth, K. M. Fischer, and S. C. Webb , 2004, Variations in shear-wave
663 splitting in young Pacific seafloor, *Geophys. Res. Lett.*, 31, L15609, doi: 10.1029/2004GL020495.
- 664 Helffrich, G., Wiens, D. A., Vera, E., Barrientos, S., Shore, P., Robertson, S., Adaros, R., 2002, A
665 teleseismic shear-wave splitting study to investigate mantle flow around South America
666 and implications for plate-driving forces, *Geophys. J. Int.*, 149(1), F1-F7, doi:
667 10.1046/j.1365-246X.2002.01636.x
- 668 Heintz, M., Kennett, B. L. N., 2005, Continental scale shear wave splitting analysis: Investigation
669 of seismic anisotropy underneath the Australian continent, *Earth Planet. Sci. Lett.*, 236(1-
670 2), 106-119.
- 671 Heintz, M., Kennett, B. L. N., 2006, The apparently isotropic Australian upper mantle, *Geophys.*
672 *Res. Lett.*, 33, L15319. doi:10.1029/2006GL026401

- 673 Hess, H. H., 1964, Seismic Anisotropy of the Uppermost Mantle under Oceans, *Nature*, 203, 629-
674 631.
- 675 Holtzman, B. K., Kohlstedt, D. L., Zimmerman, M. E., Heidelbach, F., Hiraga, T.; Hustoft, J.,
676 2003, Melt Segregation and Strain Partitioning: Implications for Seismic Anisotropy and
677 Mantle Flow, *Science*, 29(301), 1227 – 1230, doi: 10.1126/science.1087132
- 678 Humphreys, E. D., Coblenz, D. D., 2007, North American dynamics and western U.S. tectonics,
679 *Rev. Geophys.*, 45, RG3001, doi:10.1029/2005RG000181
- 680 Kendall, J. M., Pilidou, S., Keir, D., Bastow, I., Stuart, G., Ayele, A., 2006, Mantle upwellings,
681 melt migration and magma assisted rifting in Africa: Insights from seismic anisotropy. In:
682 G. Yirgu; C. J. Ebinger, P. K. H. Maguire (Editors), Structure and evolution of the rift
683 systems within the Afar volcanic province, Northeast Africa, pp. 57-74.
- 684 Kendall, J. M., Stuart, G., Ebinger, C., Bastow, I., Keir, D., 2005, Magma-assisted rifting in
685 Ethiopia, *Nature*, 433, 146-148.
- 686 Kendall, J. M., 1994, Teleseismic arrivals at a mid-ocean ridge: Effect of mantle melt and
687 anisotropy, *Geophys. Res. Lett.*, 21, 301-304.
- 688 Kneller, E. A., van Keken, P. E., Katayama, I., Karato, S., 2007, Stress, strain, and B-type olivine
689 fabric in the fore-arc mantle: Sensitivity tests using high-resolution steady-state
690 subduction zone models, *J. Geophys. Res.*, 112(B4), B04406. doi:10.1029/2006JB0
- 691 Larmat, C., Montagner, J.-P., Fink, M., Capdeville, Y., Tourin, A., Clévéde E., 2006, Time-
692 reversal imaging of seismic sources and application to the great Sumatra earthquake
693 *Geophys. Res. Lett.*, 33, L19312, doi:10.1029/2006GL026336.
- 694 Levin, V., Droznin, D., Park, J., Gordeev, E., 2004, Detailed mapping of seismic anisotropy with
695 local shear waves in southeastern Kamchatka, *Geophys. J. Int.*, 158(3), 1009-1023.
- 696 Lucente, F. P., Margheriti, L., Piromallo, C., Barruol, G., 2006, Seismic anisotropy reveals the
697 long route of the slab through the western-central Mediterranean mantle, *Earth Planet. Sci.*
698 *Lett.*, 241, 517-529, doi:10.1016/j.epsl.2005.10.1041.
- 699 Maggi, A., Debayle, E., Priestley, K., Barruol, G., 2006, Azimuthal anisotropy of the Pacific
700 region, *Earth Planet. Sci. Lett.*, 250, 53-71, doi: 10.1016/j.epsl.2006.07.010.
- 701 Mainprice, D., Barruol, G., Ben Ismail, W., 2000. The seismic anisotropy of the Earth's mantle:

- 702 from single crystal to polycrystal. In: S.I. Karato, A. Forte, R.C. Liebermann, G. Masters
703 and L. Stixrude (Editors) Earths deep interior: Mineral Physics and Tomography from the
704 atomic to the global scale. Geophysical Monograph. AGU, Washington, D.C., vol 117, pp.
705 237-264.
- 706 Mainprice, D., Silver, P. G., 1993, Interpretation of SKS-waves using samples from the
707 subcontinental lithosphere, *Phys. Earth Planet. Int.*, 78, 257-280.
- 708 Margheriti, L., Lucente, F. P., Pondrelli, S., 2003, SKS splitting measurements in the Apenninic-
709 Tyrrhenian domain (Italy) and their relation with lithospheric subduction and mantle
710 convection, *J. Geophys. Res.*, 108, B2218, doi:10.1029/2002JB001793.
- 711 Marone, F., Romanowicz, B., 2007, The depth distribution of azimuthal anisotropy in the
712 continental upper mantle, *Nature*, 447(7141), 198-201.
- 713 Montagner, J.-P., Marty, B., Stutzmann, E., Sicilia, D., Cara, M., Pik, R., Lévêque, J.-J., Rault, G.,
714 Beucler, E., Debayle, E., 2007, Mantle upwellings and convective instabilities revealed by
715 seismic tomography and helium isotope geochemistry beneath eastern Africa, *Geophys.*
716 *Res. Lett.*, 34, L21303, doi:10.1029/2007GL031098.
- 717 Montagner, J.-P., 1994, Can seismology tell us anything about convection in the mantle?, *Rev.*
718 *Geophys.*, 32(2), 115-137
- 719 Montagner, J.-P., 2002, Upper mantle low anisotropy channels below the Pacific Plate, *Earth*
720 *Planet. Sci. Lett.*, 202, 263-274.
- 721 Montagner, J.-P., 1986, Dimensional structure of the Indian Ocean inferred from long period
722 surface waves, *Geophys. Res. Lett.*, 13, 315-318.
- 723 Montagner, J.-P., Griot-Pommeroy, D., Lavé, J., 2000, How to relate body wave and surface wave
724 anisotropy?, *J. Geophys. Res.*, 105, 19015-19028.
- 725 Montagner, J.-P., Tanimoto, T., 1991, Global Upper Mantle Tomography of Seismic Velocities
726 and Anisotropies, *J. Geophys. Res.*, 96(B12), 20,337–20,351
- 727 Müller, B., Wehrle, V., Hettel, S., Sperner, B., Fuchs, K., 2003, A new method for smoothing
728 oriented data and its application to stress data, In: M. Ameen (Editor). Fracture and in-situ
729 stress characterisation of hydrocarbon reservoirs, Geol. Soc. Lond. Spec. Publ., pp. 107-
730 126.

- 731 Nakajima, J., Hasegawa, A., 2004, Shear-wave polarization anisotropy and subduction-induced
732 flow in the mantle wedge of northeastern Japan, *Earth Planet. Sci. Lett.*, 225, 365-377.
- 733 Nicolas, A., Christensen, N. I., 1987, Formation of anisotropy in upper mantle peridotites - A
734 review, In: K. Fuchs, C. Froideveaux (Editors). Composition structure and dynamics of the
735 lithosphere asthenosphere system, AGU, Washington D.C., pp. 111-123.
- 736 Nishimura, C. E., Forsyth, D. W., 1988, Rayleigh wave phase velocities in the Pacific with
737 implications for azimuthal anisotropy and lateral heterogeneities, *Geophys. J. Int.*, 94, 479-
738 501.
- 739 Nyblade, A. A., Robinson, S. W., 1994, The African superswell, *Geophys. Res. Lett.*, 21, 765-768.
- 740 Polet, J., Silver, P.G., Beck, S., Wallace, T., Zandt, G., Ruppert, S., Kind, R., Rudloff, A., 2000,
741 Shear wave anisotropy beneath the Andes from the BANJO, SEDA, and PISCO
742 experiments, *J. Geophys. Res.*, 105(B3), 6287-6304
- 743 Ritsema, J., van Heijst, H., 2000, New seismic model of the upper mantle beneath Africa,
744 *Geology*; 28(1), 63-66;
- 745 Rümpker, G., Silver, P. G., 1998, Apparent shear-wave splitting parameters in the presence of
746 vertically varying anisotropy, *Geophys. J. Int.*, 135(3), 790-800.
- 747 Russo, R.M. and Silver, P.G., 1994. Trench-parallel flow beneath the Nazca plate from seismic
748 anisotropy, *Science*, 263, 1105-1111.
- 749 Saltzer, R. L., Gaherty, J. B., Jordan, T. H., 2000, How are vertical shear wave splitting
750 measurements affected by variations in the orientation of azimuthal anisotropy with
751 depth?, *Geophys. J. Int.*, 141, 374-390.
- 752 Savage, M. K., 1999, Seismic anisotropy and mantle deformation: what have we learned from
753 shear wave splitting, *Rev. Geophys.*, 37, 69-106. Schulte-Pelkum, V., Blackman, D. K.,
754 2003, A synthesis of seismic P and S anisotropy, *Geophys. J. Int.*, 154, 166-178.
- 755 Schulte-Pelkum, V., Masters, G., Shearer, P. M., 2001, Upper mantle anisotropy from long-period
756 P polarization, *J. Geophys. Res.*, 106, 21917-21934.
- 757 Sebai, A., Stutzmann, E., Montagner, J.-P., Sicilia, D., Beucler, Eric, 2006) Anisotropic structure
758 of the African upper mantle from Rayleigh and Love wave tomography, *Phys. Earth
759 Planet. Int.*, 155(1-2), 48-62

- 760 Sieminski, A., Liu, Q., Trampert, J., Tromp, J., 2007, Finite-frequency sensitivity of body waves to
761 anisotropy based upon adjoint methods, *Geophys. J. Int.*, 171(1), 368-389,
762 doi:10.1111/j.1365-246X.2007.03528.x
- 763 Silver, P. G., 1996, Seismic Anisotropy Beneath the Continents: Probing the Depths of Geology,
764 *Annu. Rev. Earth Planet. Sci.*, 24, 385-432.
- 765 Silver, P. G., Chan, W. W., 1991, Shear Wave Splitting and Subcontinental Mantle Deformation,
766 *J. Geophys. Res.*, 96(B10), 16429-16454.
- 767 Silver, P. G., Savage, M., 1994, The interpretation of shear-wave splitting parameters in the
768 presence of two anisotropic layers, *Geophys. J. Int.*, 119, 949-963.
- 769 Silver, P. G., Gao, S. S., Liu, K. H., 2001, Mantle deformation beneath southern Africa, *Geophys.*
770 *Res. Lett.*, 28(13), 2493-2496.
- 771 Simons, F. J., van der Hilst, R. D., 2003, Seismic and mechanical anisotropy and the past and
772 present deformation of the Australian lithosphere, *Earth Planet. Sci. Lett.*, 211(3-4), 271-
773 286 doi:10.1016/S0012-821X(03)00198-5
- 774 Smith, D. B., Ritzwoller, M. H., Shapiro, N. M., 2004, Stratification of anisotropy in the Pacific
775 upper mantle, *J. Geophys. Res.*, 109(B18), B11309.
- 776 Steinberger, B., O'Connell, R. J., 1998, Advection of plumes in mantle flow: implications for
777 hotspot motion, mantle viscosity and plume distribution, *Geophys. J. Int.* 132(2), 412-
778 434. Suetsugu, D., Isse, T., Tanaka, S., Obayashi, M., Shiobara, H., Sugioka, H.,
779 Kanazawa, T., Fukao, Y., Barruol, G., Reymond, D., 2005, Probing South Pacific mantle
780 plumes with Broadband OBS. *Eos*, 86(44): 429-435.
- 781 Trampert, J., Woodhouse, J. H., 2003, Global anisotropic phase velocity maps for fundamental
782 mode surface waves between 40 and 150 s, *Geophys. J. Int.*, 154, 154-165.
- 783 Vauchez, A., Nicolas, A., 1991, Mountain building: strike parallel motion and mantle anisotropy,
784 *Tectonophysics*, 185, 183-201.
- 785 Vinnik, L. P., Farra, V., Romaniwicz, B., 1989, Azimuthal anisotropy in the earth from
786 observations of SKS at GEOSCOPE and NARS broadband stations, *Bull. Seis. Soc. Am.*,
787 79(5), 1542-1558.
- 788 Vinnik, L. P., Green, R. W. E., Nicolaysen, L. O., 1996, Seismic constraints on dynamics of the

- 789 mantle of the Kaapvaal craton, *Phys. Earth Planet. Int.*, 95, 139-151.
- 790 Vinnik, L. P., Kosarev, G. L., Makeyeva, L. I., 1984, Anisotropiya litosfery po nablyudeniya
791 voln SKS and SKKS, *Dokl. Akad. Nauk USSR*, 278, 1335-1339.
- 792 Waite, G. P., Schutt, D. L., Smith, R. B., 2005, Models of lithosphere and asthenosphere
793 anisotropic structure of the Yellowstone hot spot from shear wave splitting, *J. Geophys.*
794 *Res.*, 110, B11304, doi:10.1029/2004JB003501
- 795 Walker, K. T., Bokelmann, G. H. R., Klemperer, S. L., 2001, Shear-wave splitting to test mantle
796 deformation models around Hawaii, *Geophys. Res. Lett.*, 28, 4319-4322.
- 797 Walker, K. T., Bokelmann, G.H.R., Klemperer, S.L., 2004, Shear-wave splitting beneath the
798 Snake River Plain suggests a mantle upwelling beneath eastern Nevada, USA, *Earth.*
799 *Planet. Sci. Let.*, 222, 529-542.
- 800 Walker, K. T., Bokelmann, G. H. R., Klemperer, S. L., Bock, G., 2005, Shear-wave splitting
801 around the Eifel hotspot: evidence for a mantle upwelling, *Geophys. J. Int.*, 163(3), 962-
802 980.
- 803 Walker, K. T., Nyblade, A. A., Klemperer, S. L., Bokelmann, G. H. R., Owens, T. J., 2004, On the
804 relationship between extension and anisotropy: Constraints from shear wave splitting
805 across the East African Plateau, *J. Geophys. Res.*, 109(B18), B08302.
- 806 Watson, G. S., 1985, Interpolation and smoothing of directed and undirected line data, in P. R.
807 Krishnajah, ed., *Multivariate Analysis-VI*, Elsevier Science, New York, , pp. 613-625.
- 808 Wehrle, V., 1998, Analytische Untersuchung intralithosphärischer Deformationen und Numerische
809 Methoden zur Bestimmung krustaler Spannungsdomänen, PhD thesis (in german), Univ.
810 Karlsruhe, <http://digbib.ubka.uni-karlsruhe.de/volltexte/12098>
- 811 Wolfe, C. J., Silver, P. G., 1998, Seismic anisotropy of oceanic upper mantle: Shear wave splitting
812 methodologies and observations, *J. Geophys. Res.*, 103(B1), 749-771.
- 813 Wolfe, C. J., Solomon, S. C., Shear-Wave Splitting and Implications for Mantle Flow Beneath the
814 MELT Region of the East Pacific Rise, *Science*, 280, 1230-1232, doi:
815 10.1126/science.280.5367.1230
- 816 Wüstefeld, A., Bokelmann, G. H. R., 2007, Null Detection in Shear-Wave Splitting Measurements,
817 *Bull. Seism. Soc. Am.*, 97(4), 1204-1211, doi:10.1785/0120060190.

- 818 Wüstefeld, A., Bokermann, G. H. R., Barruol, G., 2009, Lithospheric anisotropy and deformation
819 beneath the East European Craton, *Tectonophysics*, in press,
820 doi:10.1016/j.tecto.2009.01.010
- 821 Xue, M., Allen, R. M., 2007, The Fate of the Juan de Fuca Plate: Implications for a Yellowstone
822 Plume Head, *Earth Planet. Sci. Lett.*, 264, 266-276, doi:10.1016/j.epsl.2007.09.047
- 823 Zandt, G. and Humphreys, E., 2008, Toroidal mantle flow through the western U.S. slab window,
824 *Geology*, 36(4), 295-298, doi:10.1130/G24611A.1
- 825

826 **Figure Captions**

827 Figure 1: Paths and spatial resolution associated with teleseismic (SKS) shear waves and surface
828 waves. Surface waves propagate along the surface of the Earth, while wave paths of
829 teleseismic shear waves are nearly vertical. For the latter, there is a progressive time delay
830 between the two (split) shear-waves on the path toward the station at the Earth's surface.

831

832 Figure 2: Global comparison of shear-wave splitting parameters: a) measured b) predicted. a)
833 World-wide shear-wave splitting observations contained in the splitting database. b):
834 predicted splitting values calculated using the method of Montagner et al. (2000) for the
835 $1^\circ \times 1^\circ$ anisotropic tomography model of Debayle et al. (2005) at depths between 50 and
836 500km. Values are displayed on a $3^\circ \times 3^\circ$ grid. The regions which are analysed in further
837 detail in the text are marked (a-h)

838

839 Figure 3: Statistical distribution of 2286 globally distributed shear-wave splitting measurements
840 contained in the current SKS splitting database. a) shows the distribution of delay times, b)
841 that of fast split directions. The statistical distributions of predicted splitting parameters,
842 calculated from surface wave anisotropy (Debayle et al., 2005) are presented separately
843 for continents (c, d) and oceans (e, f). See text for discussion.

844

845 Figure 4: Coherence of the SKS splitting parameters with the predicted splitting values integrating
846 anisotropy between 50 to 500 km depth, for “correlation lengths” D_{corr} of 5, 10, and 20
847 degrees. Several combinations of datasets are tested, such as the effect of a 1° and 10° grid
848 of predicted values and a limited set of data (e and f): studies published before 1997,
849 corresponding to dataset of Silver (1996)). See text for discussion.

850

851 Figure 5: Smoothed version of shear-wave splitting observations. Smoothing parameters are
852 chosen as $R = 600$ km and $\lambda = 5$ (cf. Figure 7). Calculation was for a $1^\circ \times 1^\circ$ grid, displayed
853 on a $3^\circ \times 3^\circ$ grid

854

855 Figure 6: a) Coherence function using the smoothed splitting data of Figure 5. Three different
856 values for R are used (100, 600, 1000 km), as well as a smoothing value $\lambda = 5$. b)
857 Coherence value as a function of search smoothing parameter λ at 0° misfit. c) and d)
858 show the same as a) and b) respectively, but for a randomised distribution of splitting
859 parameters to test for inherent correlation of the two models. Note the much lower
860 amplitude of correlation in c) and the random variation in d).

861

862 Figure 7: Correlation of the smoothed splitting parameters (similar to Figure 4), for individual
863 regions shown in Figure 5.

864

865 Figure 8: Map of the predicted (blue), observed (red, with circle marker) and smoothed (magenta
866 with small arrow head) shear wave splitting data in a) Western US and b) Kaapvaal Craton
867 where the tomographic model (i.e., predicted splitting) seems to be dominated by the
868 African Super Swell. Differences in coherence magnitude (Figure 7) are caused by
869 different delay time due to damping effects in the tomography.

870

871 Figure 9: Scatter-plot of predicted splitting delay versus observed splitting delay. The predicted
872 delay times are generally smaller, indicating a bias from the tomography, probably due to

873 damping effects.

874

875 Figure A1: Map of the predicted (blue), observed (red, with circle marker) and smoothed (magenta
876 with small arrow head) shear wave splitting data in the Andes.

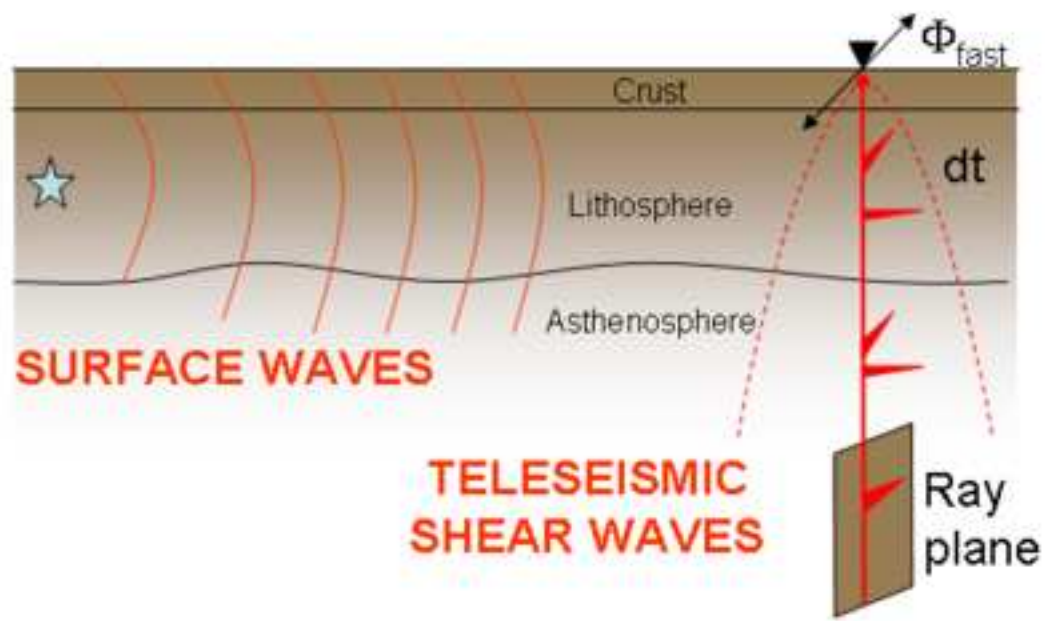
877 Figure A2: Map of the predicted (blue), observed (red, with circle marker) and smoothed (magenta
878 with small arrow head) shear wave splitting data in the East Pacific.

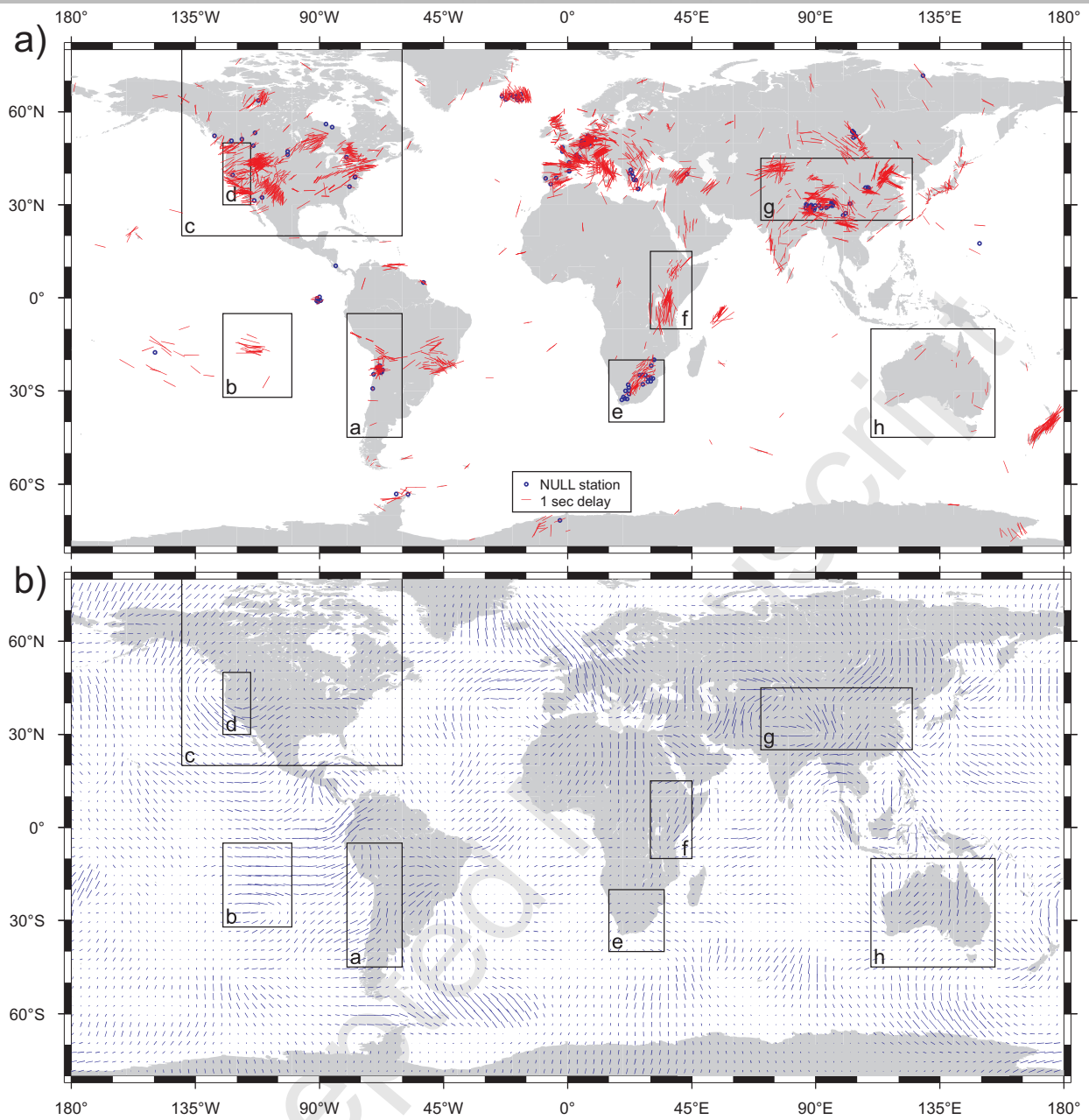
879 Figure A3: Map of the predicted (blue), observed (red, with circle marker) and smoothed (magenta
880 with small arrow head) shear wave splitting data in the North America.

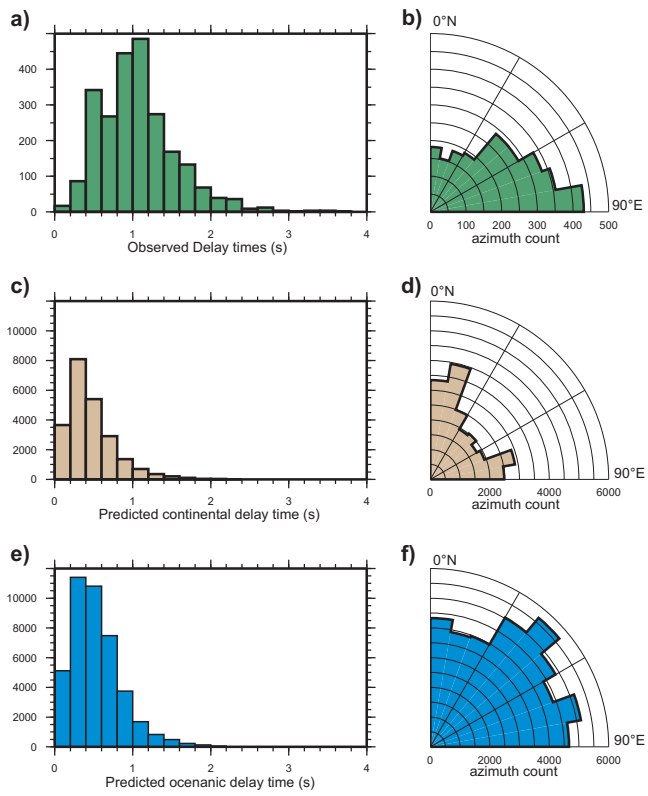
881 Figure A4: Map of the predicted (blue), observed (red, with circle marker) and smoothed (magenta
882 with small arrow head) shear wave splitting data in East Africa.

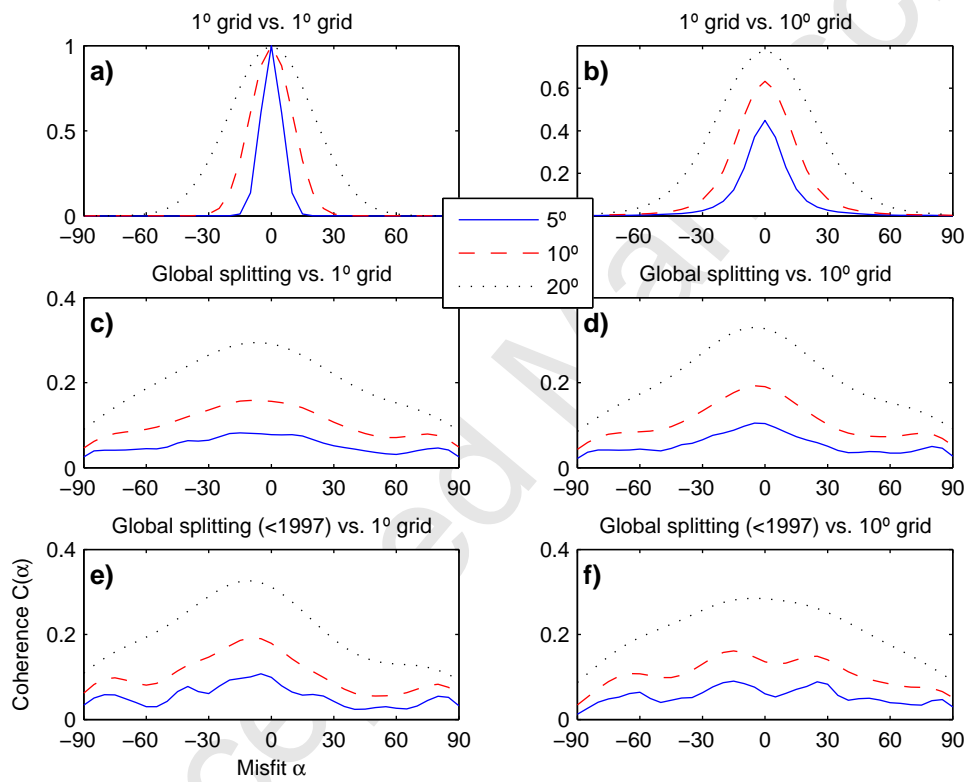
883 Figure A5: Map of the predicted (blue), observed (red, with circle marker) and smoothed (magenta
884 with small arrow head) shear wave splitting data in Central Asia.

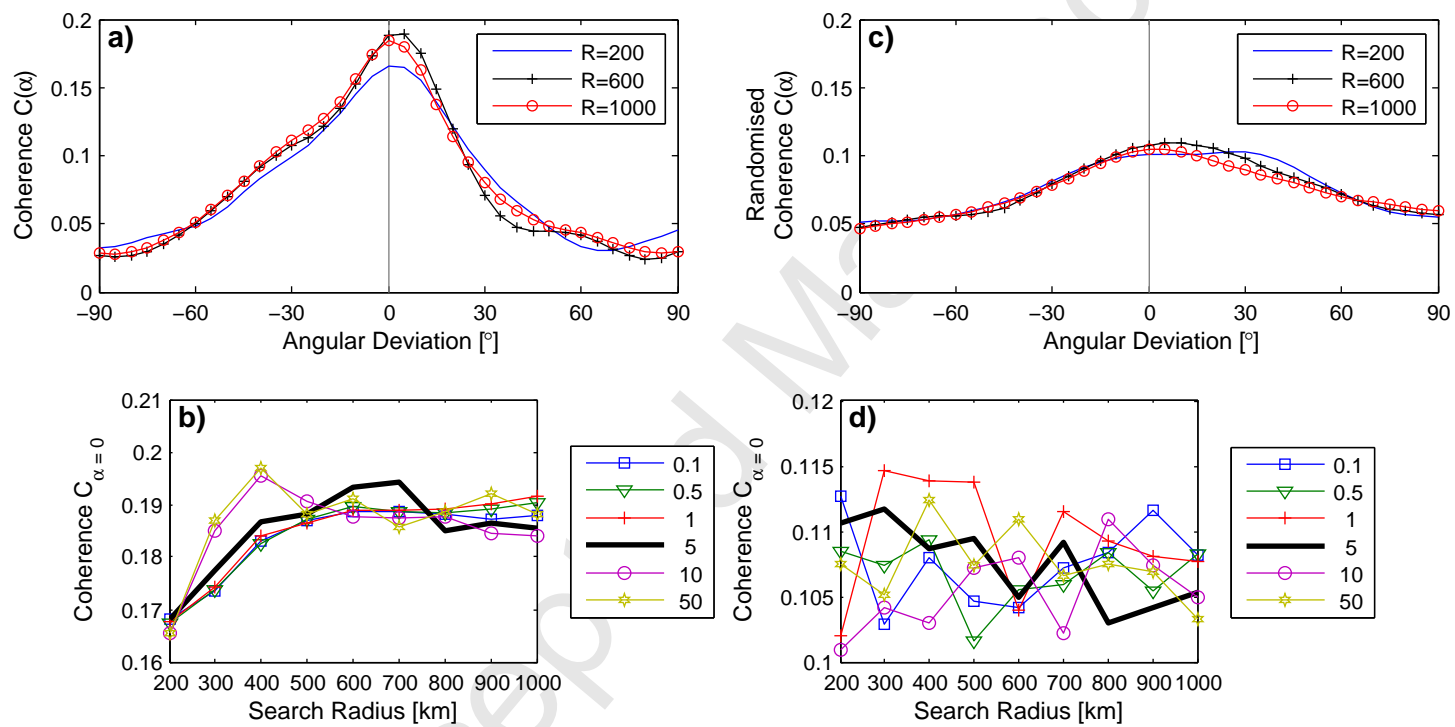
885 Figure A6: Map of the predicted (blue), observed (red, with circle marker) and smoothed (magenta
886 with small arrow head) shear wave splitting data in Australia

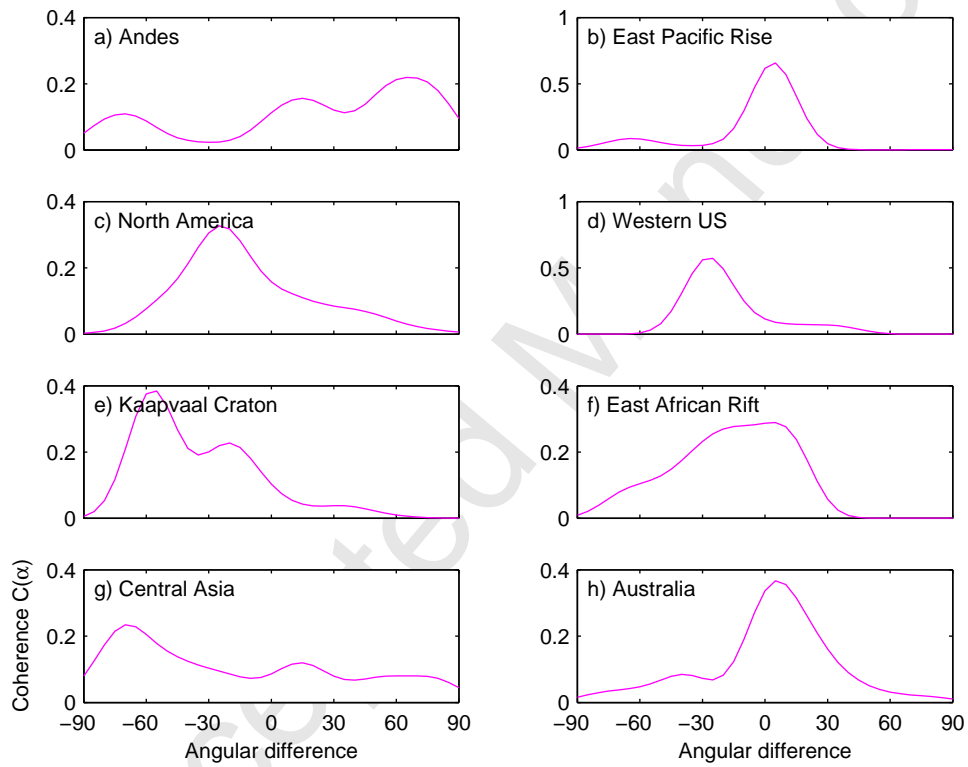


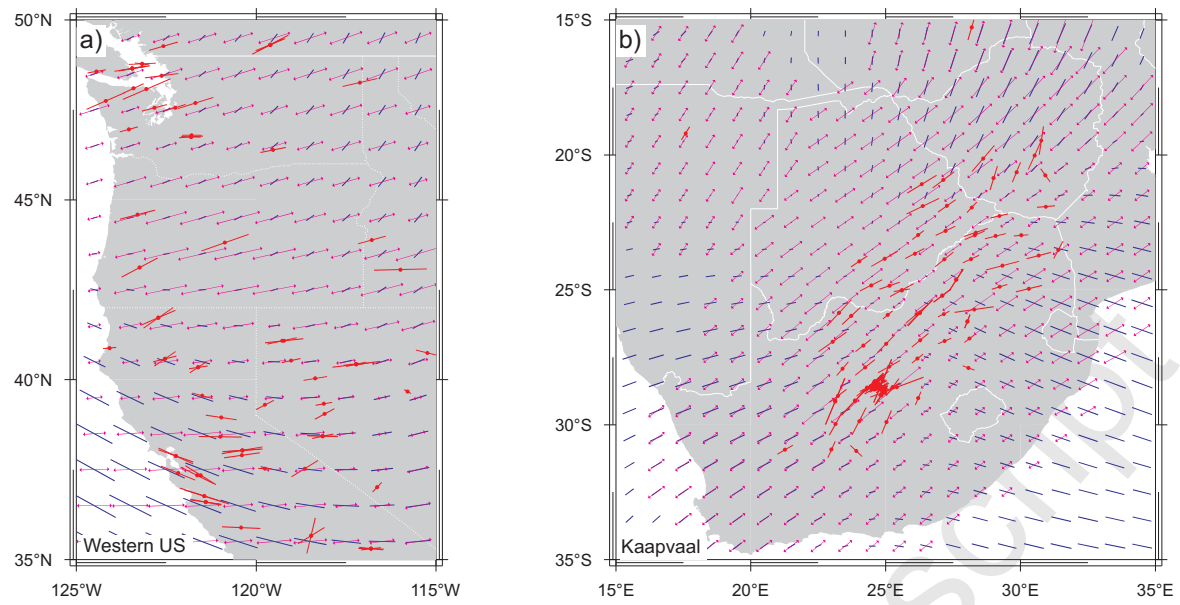


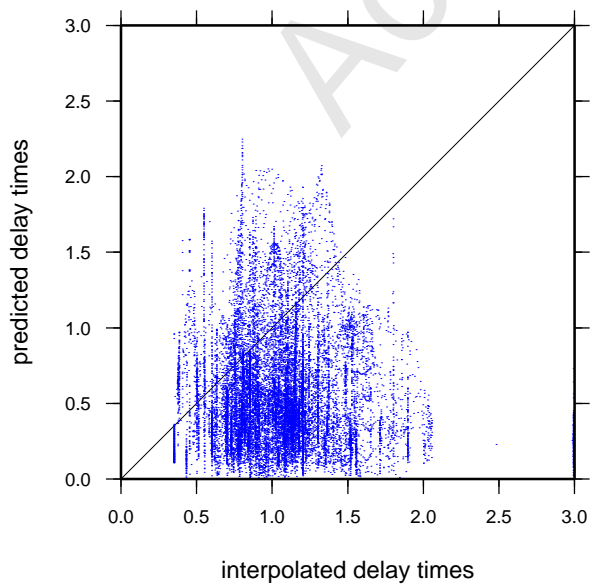


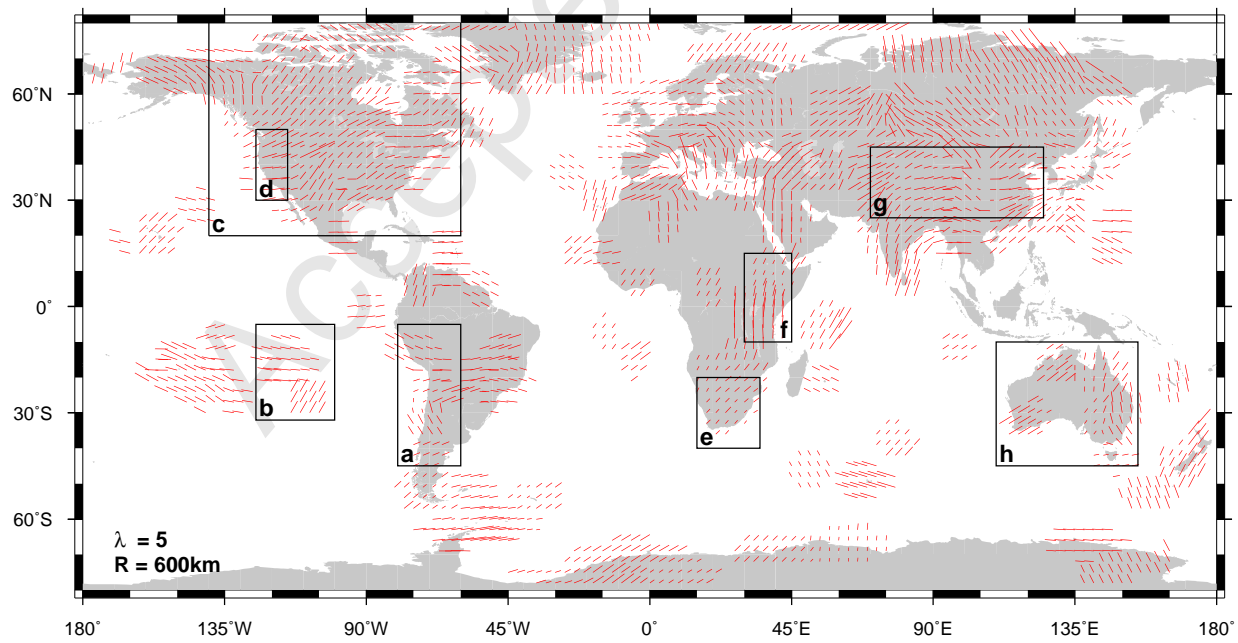


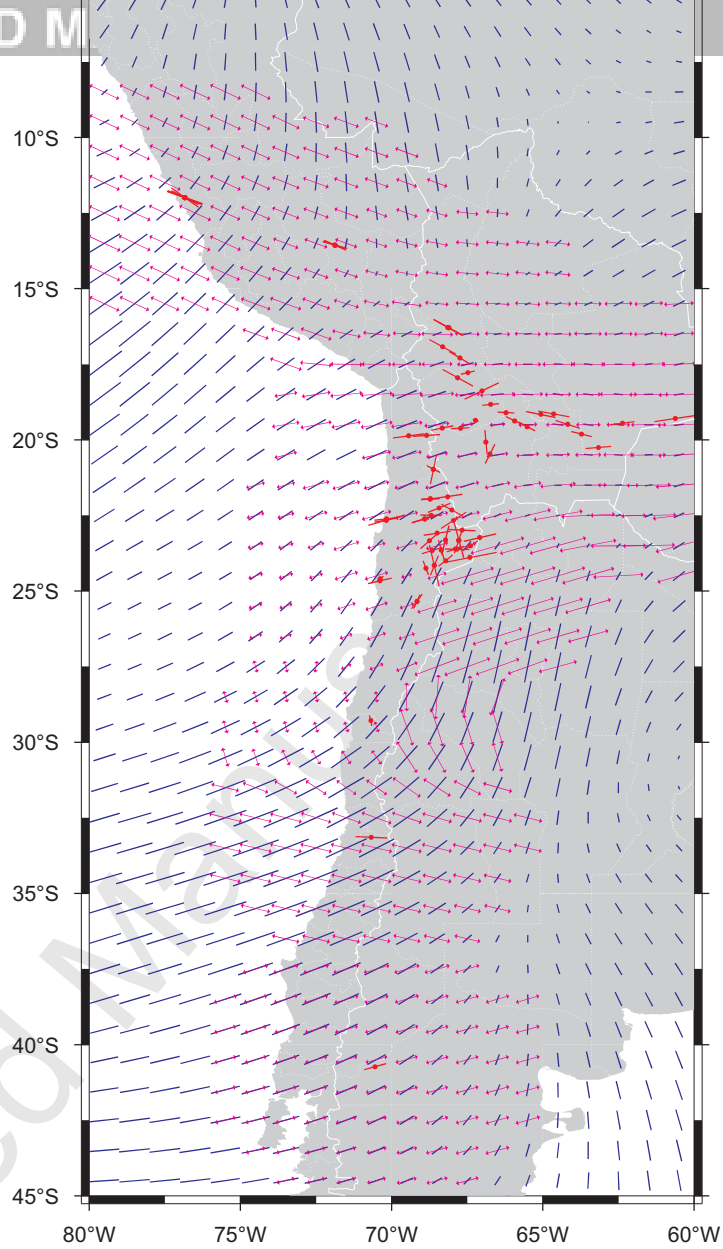




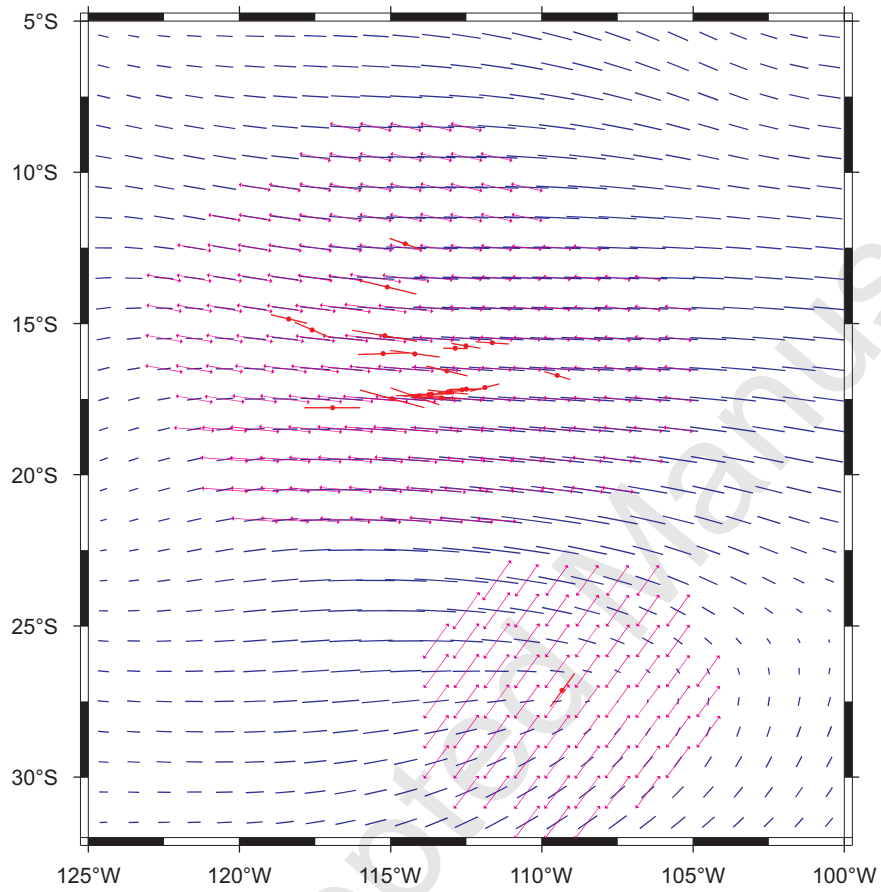


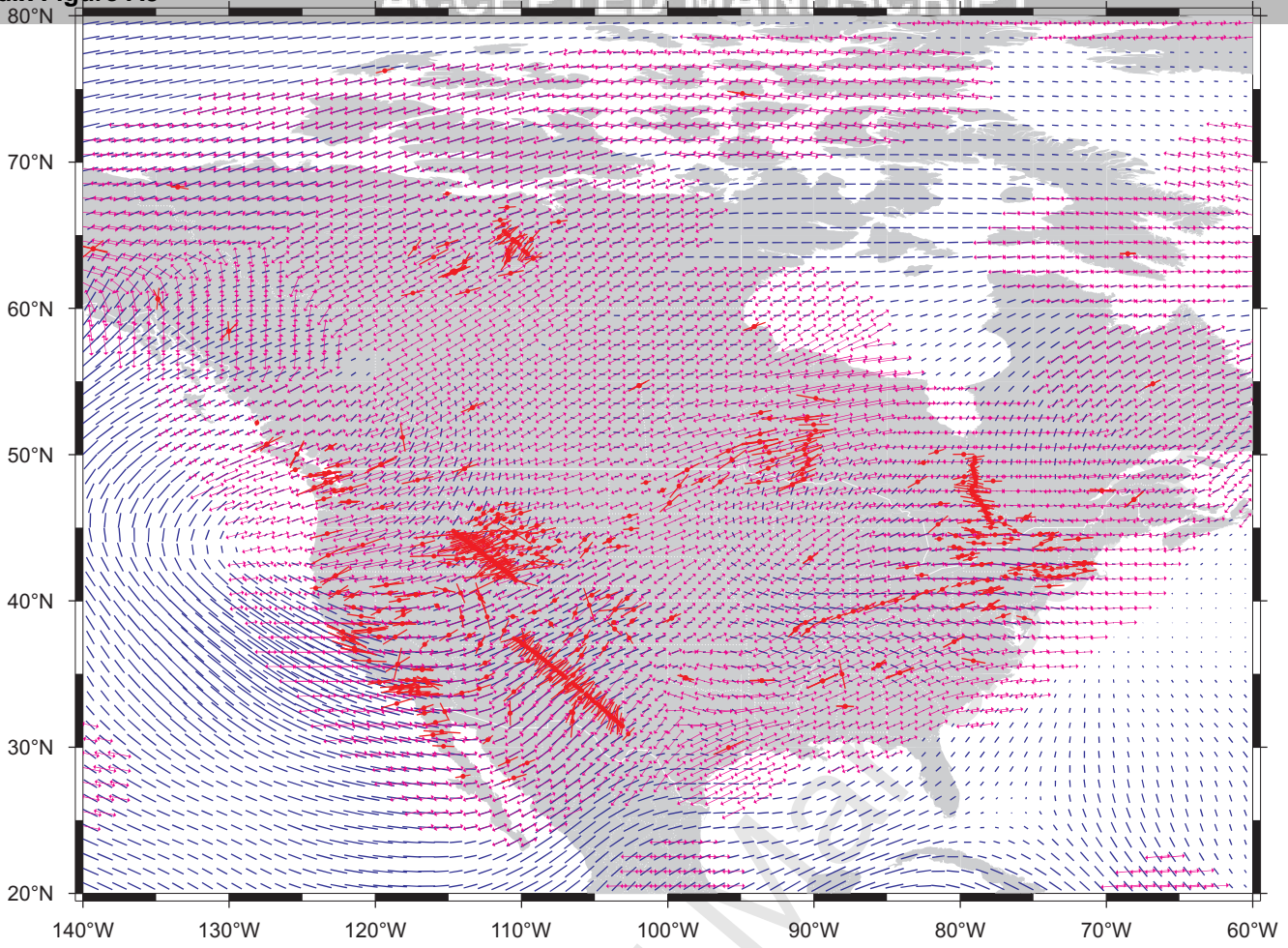




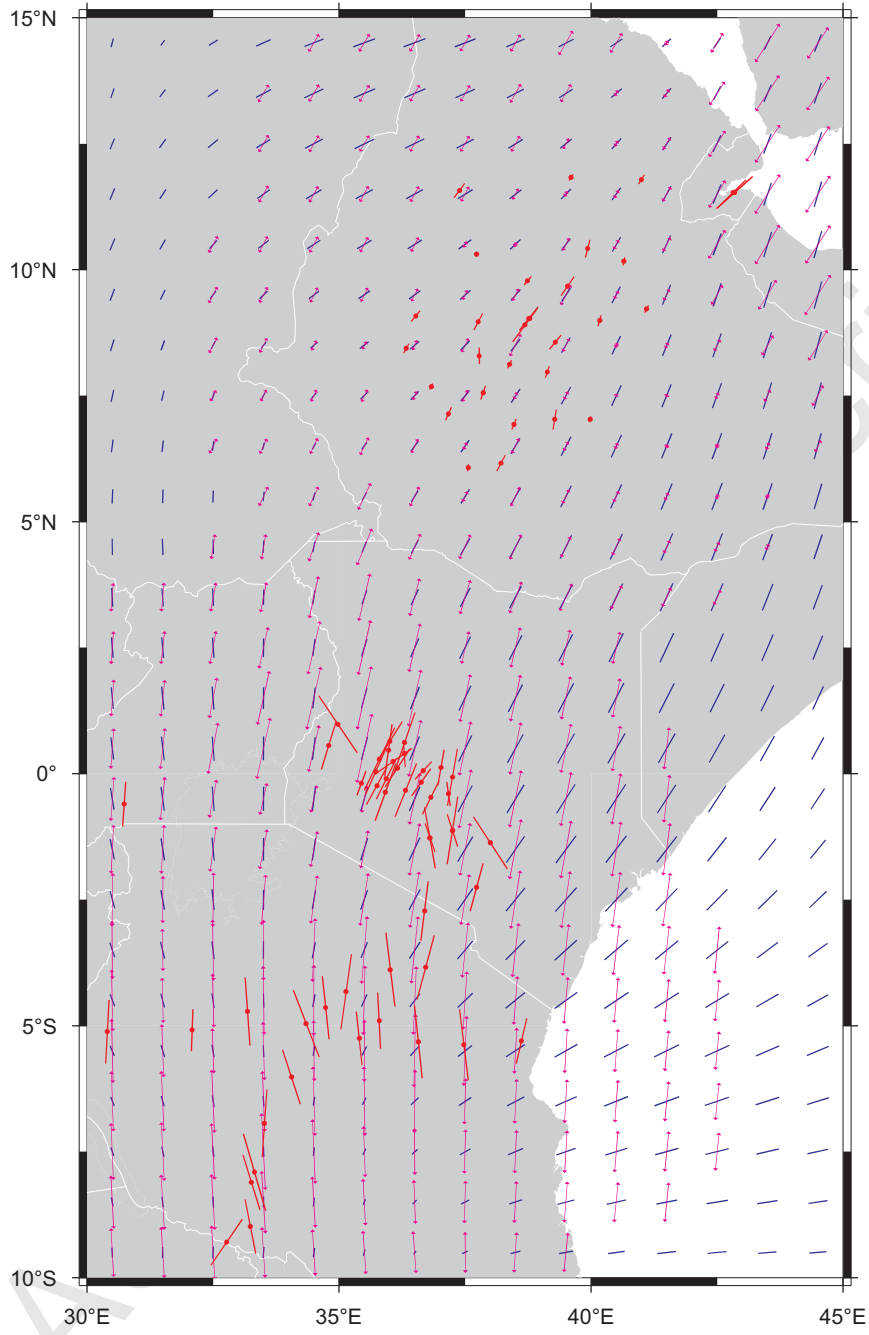


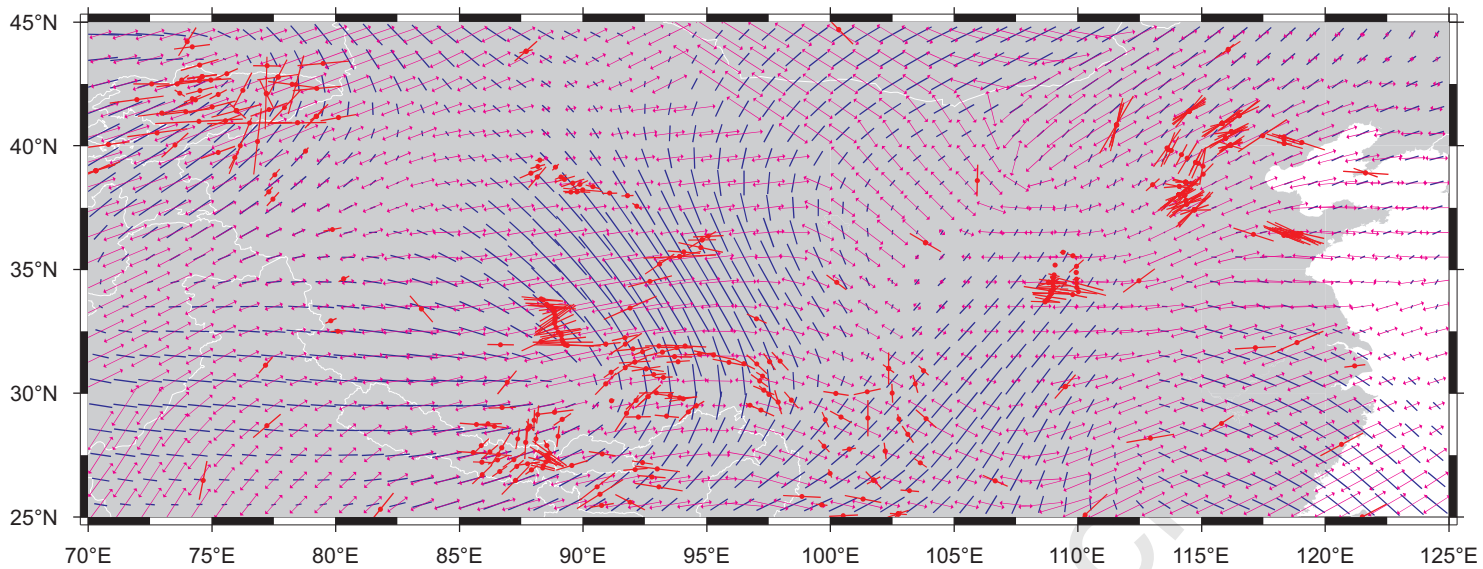
Accepted Manuscript





Accepted Manuscript





Accepted Manuscript

