

---

# Crustal Stress Pattern in China and Its Adjacent Areas

Xingping Hu<sup>a,b,\*</sup>, Arno Zang<sup>c</sup>, Oliver Heidbach<sup>c</sup>, Xiaofeng Cui<sup>b</sup>, Furen Xie<sup>b</sup>, Jiawei Chen<sup>b</sup>  
*a School of Earth and Space Science, University of Science and Technology of China, 230026 Hefei, China*

*b Key Laboratory of Crustal Dynamics, Institute of Crustal Dynamics, China Earthquake Administration, 100085 Beijing, China*

*c GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany*

*\* Corresponding author. Xingping Hu. School of Earth and Space Science, University of Science and Technology of China, 230026 Hefei, China*

*Telephone: +8601062846726, +8613811111002*

*E-mail address: huxp1987@163.com (Xingping Hu).*

## Abstract

During the update of the World Stress Map (WSM) database, we integrated the China stress database by strictly using the internationally developed quality ranking scheme for each individual stress data record. This effort resulted in a comprehensive and reliable dataset for the crustal stress of China and its adjacent areas **with almost double** the amount of data records from the **WSM database release 2008**, i.e., a total of 8,228 data records with reliable A-C qualities in the region of 45-155° East and 0-60° North. We use this dataset for an analysis of the stress pattern for the orientation of maximum compressive horizontal stress ( $S_{Hmax}$ ). In contrast to earlier findings **that suggested that** the mean  $S_{Hmax}$  orientation **would** be aligned with the **direction** of plate motion, we clearly see **from our results that** the plate boundary forces, as well as topography and faulting, are important control factors for the overall stress pattern. Furthermore, the **smoothing** results indicate that the  $S_{Hmax}$  orientation in China rotates clockwise from **the west to the east**, which results in a fan-shaped crustal stress

---

28 pattern for the continental scale. The plate boundary forces around China, which are  
29 the Indian-Eurasian plate collision in the west and the Pacific plate subduction and the  
30 push from the Philippine plate in the east, can still be seen as the key driving  
31 processes and the first-order controls for the crustal stress pattern. The South-North  
32 seismic zone can be seen as the separation zone for the western and eastern plate  
33 boundary forces. **Topographic** variation and faulting activity, however, provide  
34 second-order changes, **and lead** to local variations and different inhomogeneity scales  
35 for the stress pattern. Due to differences in these factors, Northeast China and the  
36 central part of **the** Tibetan plateau have **notably** homogeneous stress patterns, while  
37 the South-North seismic zone, the Hindu Kush-Pamir region, and the Taiwan region  
38 have extremely inhomogeneous stress patterns. **Furthermore, the different behaviors**  
39 **of stress** orientations around continental and oceanic plate boundaries could imply  
40 that complicated mechanisms exist and **warrant** further and more specific **studies**.

41 **Keywords:** stress data integration; China and its adjacent areas; stress orientation;  
42 inhomogeneity scale; geodynamic interpretation

## 43 **1. Introduction**

44 The crustal stress state is a key parameter for our understanding of geodynamic  
45 processes, seismic hazard assessment and the stability of underground openings (Zang  
46 and Stephansson, 2010; Zoback, 2007; Fuchs and Müller, 2001). There are different  
47 stress indicators regarding the crustal stress state, such as earthquake focal mechanism  
48 solutions, borehole breakouts, hydraulic fracturing tests, overcoring, and geological

---

49 data. However, obtaining complete information for the 3D stress field (i.e., the six  
50 independent components of the stress tensor) remains a challenging task (Schmitt et  
51 al., 2012; Stephansson and Zang, 2010). It is also complicated to display either a full  
52 or partial representation of the stress tensor in an **easily interpretable** manner (Lund  
53 and Townend, 2007). The orientation of the maximum horizontal stress  $S_{Hmax}$   
54 determines the orientation of the 3D stress tensor when assuming that the vertical  
55 stress  $S_V$ , also called lithostatic overburden, is a principal stress. The pattern of the  
56  $S_{Hmax}$  orientation, which is able to reflect the dynamic background (Zoback, 1992;  
57 Townend and Zoback, 2006, 2004), became a feasible representation for a stress field  
58 and was widely used for research in the stress field at a global scale (Heidbach et al.,  
59 2010, 2007; Sperner et al., 2003; Zoback, 1992; Zoback et al., 1989) as well as at  
60 regional and local scales (Rajabi et al., 2016; Xie et al., 2015, 2007; Reiter et al., 2014;  
61 Balfour et al., 2011; Reinecker et al., 2010; Rebaï et al., 2007; Brudy and Kjørholt,  
62 2001; Hillis et al, 1998; Coblenz et al., 1998; Müller et al., 1997, 1992; Bird and Li,  
63 1996; Sbar and Sykes, 1973).

64 The World Stress Map (WSM) project is a global compilation of information on  
65 the crustal stress field **from** a wide range of stress indicators. This systematic work of  
66 WSM began in 1986 as a Task Force of the International Lithosphere Program (ILP)  
67 under the leadership of Mary Lou Zoback, and WSM was a research project at the  
68 Heidelberg Academy of Sciences **then**. The WSM is a collaborative project that  
69 includes the input and expertise of many scientists worldwide, **and it** provides free

---

70 information on its website located at [www.world-stress-map.org](http://www.world-stress-map.org). Since 2009, the  
71 WSM project has been maintained by the Helmholtz Center Potsdam - German  
72 Research Center for Geosciences GFZ. **The amount of data records has increased**  
73 **from ~7700 in the first WSM database release 1992 to 21,750 in the WSM database**  
74 **release 2008 (Heidbach et al., 2010, 2009).**

75 **Complementary** to the ongoing effort of stress data compilation within the WSM  
76 project, the research of stress field and stress data compilation was established in  
77 China (Cui et al., 2005; Xie et al., 2004; Xu et al., 2001, 1989; Wang et al., 1993,  
78 1980; Yan et al., 1979; Deng and Zhang, 1979). Between 2000 and 2002, the Institute  
79 of Crustal Dynamics collected a wide variety of stress data in China, conducted  
80 comprehensive work on the crustal stress field of the Chinese continent, compiled the  
81 China stress map, and built the Fundamental Database of Crustal Stress Environment  
82 in Continental China (hereafter referred to as **the China Stress Database**). The China  
83 Stress Database is the first fundamental database that incorporates various stress data  
84 records (Xie et al., 2007). It has been updated continuously since 2002, and up to now,  
85 the number of data records inputted has exceeded 7000 entries. **Based on these stress**  
86 **data**, the latest version of the Recent Tectonic Stress Map of China and its Adjacent  
87 Areas has been published, which mainly represents the various stress data **and also**  
88 shows the achievements of stress division and stress trajectory for the stress field in  
89 China (Xie et al., 2015).

90 Both the WSM project and the stress field research in China have accumulated

---

91 an abundance of stress data. However, the WSM database and the China Stress  
92 Database were never well integrated into each other to allow for a higher resolution of  
93 the stress pattern beyond the national borders. Therefore, during the course of the  
94 current global effort to publish the WSM database release 2016 (Heidbach et al, 2016)  
95 for the 30<sup>th</sup> anniversary of the WSM project, the collaboration between China and the  
96 WSM intensified in order to integrate the two databases into each other and conduct  
97 further investigations on the stress pattern in China and its adjacent areas.

98 This paper presents the integration of stress data from the WSM database and the  
99 latest China Stress Database. This effort not only resulted in a significant increase in  
100 the amount of data records but also led to a comprehensive dataset with a higher  
101 reliability and better resolution for the first time in two decades. This paper also  
102 presents an analysis of the stress pattern for the  $S_{Hmax}$  orientation by using two  
103 different smoothing schemes, in order to reveal regional and local variability of the  
104 stress pattern and its relationship with geodynamic processes and/or structural  
105 sources.

## 106 **2. Brief tectonic stress background of China and its adjacent areas**

107 China is located in the southeastern portion of the Eurasian plate, and it is an  
108 important part of the plate. There are four other plates around China: the Indian plate,  
109 the Pacific plate, the Philippine plate, and the North American plate. The influence  
110 from the North American plate is quite marginal for the tectonic deformation of China  
111 (Zhang et al., 2002). Therefore, the main plate boundary forces are from the Indian

---

112 plate, the Pacific plate, and the Philippine plate (Fig. 1). The western force source is  
113 primarily generated by the Indian plate's northwestward collision with the Eurasian  
114 plate, while the eastern force source includes the combined effect of the Pacific plate  
115 subduction and the push from the Philippine plate. Among all the boundary forces, the  
116 influence of Indian-Eurasian collision was determined to be the largest according to  
117 some geodynamic simulations (Zhu et al., 2006; Wang et al., 1996). There are four  
118 key regions for the transmission of plate forces corresponding to the plate boundaries:  
119 the **Himalayan west tectonic** knot, the **Himalayan east tectonic** knot, the deep seismic  
120 area in Northeast China, and the Taiwan region. The former two regions are the  
121 tectonic knots of the Indian-Eurasian collision, and they are located in the Hindu  
122 Kush-Pamir region and the southeast margin of **the** Tibetan plateau, respectively. The  
123 Northeast China and the Taiwan Region are the key regions for the transmission of  
124 plate forces from the Pacific plate and from the Philippine plate. Due to the crucial  
125 tectonic locations, these **four regions** have been **the** focus regions for research of  
126 geodynamic processes as well as the tectonic stress field for several decades, and they  
127 also have a great significance for this study.

128 **Under the control of the surrounding tectonism**, the stress field in China and its  
129 adjacent areas **shows** obvious **divisional** features, which are manifested **as** different  
130 stress orientations, stress regimes, and stress intensities in different regions (Xie et al.,  
131 2015). By using different methods, such as focal mechanism analysis and numerical  
132 simulation, some scholars have investigated the crustal stress field for all of China

---

133 and/or some regions in China. One significant feature that has been commonly found  
134 is that the  $S_{Hmax}$  orientations in China rotate clockwise from the west to the east (Xie  
135 et al., 2015, 2007, 2004; Fan et al., 2012; Cui et al., 2005; Xu et al., 2001, 1989; Wang  
136 et al., 1996, 1993, 1980; Yan et al., 1979; Deng and Zhang, 1979), but more details  
137 with a higher resolution will still contribute to an improved understanding of the  
138 stress field in China.

139 More reliable and various stress data could help to reveal a more comprehensive  
140 and refined stress pattern. Among the analysis methods for stress orientations, the  
141 smoothing algorithm (Heidbach et al., 2010; Zang and Stephansson, 2010; Müller et  
142 al. 2003; Hansen and Mount, 1990; Watson, 1985) provides a means of identifying  
143 significant patterns in sets of oriented data by eliminating local perturbations in the  
144 observations and by predicting patterns of oriented data in places which lack  
145 observations. Consequently, the smoothing algorithm is an effective mathematical  
146 way to analyze stress orientation characteristics. Therefore, a further study with more  
147 reliable stress data and an appropriate smoothing method could better describe the  
148 crustal stress pattern and its inhomogeneity. This would help to reveal more details of  
149 the crustal stress field and improve its geodynamic interpretation in China and its  
150 adjacent areas.

### 151 **3. Integration of stress data in China and its adjacent areas**

152 First, we integrated the latest China Stress Database (Xie et al., 2015) and the  
153 WSM database for more reliable stress data. The China Stress Database provides 6089

---

154 chosen data records with 3983 data records from earthquake focal mechanism  
155 solutions (FMSs), 454 data records from borehole breakouts and drilling induced  
156 tensile fractures, 544 geological fault slip data records, 459 hydraulic fracture data  
157 records and 649 overcoring data records. Some FMSs of small earthquakes and  
158 aftershocks, as well as a few unpublished stress measurement data, were not  
159 integrated. Due to differences in the quality assessment used for the China Stress  
160 Database and the WSM, each data record was referenced again, and the latest WSM  
161 quality ranking scheme from Heidbach et al. (2010) was applied. In these stress data,  
162 most of the overcoring data were stored as single individual measurements, and thus  
163 were not in agreement with the ranking requirements of the WSM. Therefore, we  
164 calculated the mean value for those overcoring measurements with the same location  
165 and from the same original reference, and received 203 overcoring data records at  
166 different locations. In total, 5643 stress data records from the China Stress Database  
167 were finally obtained and integrated into the WSM database release 2016 (Heidbach  
168 et al., 2016).

169 After removing the duplicated stress data, we obtained a comprehensive and  
170 reliable dataset for the crustal stress of China and its adjacent areas. In the region of  
171 45-155° East and 0-60° North, there are 11,255 stress data records (Table 1) with A-E  
172 qualities, of which 8,228 have A-C qualities. Among these A-C quality stress data  
173 records, 1884 FMS data records with the criteria of a Possible Plate Boundary Event  
174 (PBE) were considered as PBEs (Heidbach et al., 2010, 2009, 2008; Townend, 2006).



---

175 This means that these FMS data have a larger potential for a large offset between the  
176 P-, B-, and T-axes and the principal stress orientations. Therefore, these 1884 FMS  
177 data records were removed, and the remaining 6344 stress data records (Fig. 2) were  
178 used to analyze the stress field in China and its adjacent areas for this study.

179 **Through** the data check and quality reassignment, the stress data qualities were  
180 evaluated and **verified**, and the A-C quality stress data records could be considered  
181 reliable for the analysis of the stress pattern and the interpretation of geodynamic  
182 processes. **Compared** with the previous **WSM database release 2008** (Fig. 3a), **the**  
183 **amount of the** stress data **has** increased significantly (Fig. 3b) all over the region,  
184 which provides a good basis for further investigating the stress pattern in China and  
185 its adjacent areas.

186 According to the distribution of stress data in China and its adjacent areas as  
187 depicted in Fig. 2, it is evident that the stress data cover the majority of China, but  
188 with an inhomogeneous data distribution. Quite **many** data points **assemble** in some  
189 places, such as the east margin of **the** Tibetan plateau and the Hindu Kush-Pamir  
190 region, while only **few** data points **distribute** in some other parts, such as the Ordos  
191 basin, the Tarim basin, and the South China. The  $S_{Hmax}$  orientations have good  
192 consistency in some places, such as in Northeast China and the central part of **the**  
193 Tibetan Plateau, but the orientations scatter in some other places, such as in the east  
194 margin of **the** Tibetan Plateau. Another phenomenon that **should be considered in the**  
195 **stress field analysis, is that** some disperse orientation data points cluster in a very

---

196 small place, or even at almost the same place, such as **those** in North China,.

197       The 6344 stress data records presented by different methods cover a wide depth  
198 in range. Geological and overcoring data provide the near surface information.  
199 Borehole breakouts and hydraulic fracturing provide stress indicators down to a depth  
200 of 6 km. Focal mechanisms provide stress information throughout the brittle crust  
201 down to a depth of 40 km. The tectonic stress regime (Zoback, 1992) could be  
202 assigned for 77% of the 6344 A-C quality data records (Table 2), and it is clear that  
203 each stress regime constitutes a comparable proportion. This indicates that there is no  
204 dominant tectonism of a certain stress regime that could control the stress regime for  
205 the majority of China, and **thus** represents the diversity and complexity of the stress  
206 field in China and its adjacent areas to some extent.

#### 207 **4. Continental scale stress pattern**

208       The WSM has revealed that the continental scale stress pattern exists in many  
209 plates, and it is controlled primarily by the plate boundary forces. Knowledge  
210 regarding **the continental scale stress** pattern in China and its adjacent area is quite  
211 helpful for the analysis of the geodynamic background and how it controls the stress  
212 field. Additionally, it is also a prerequisite to identify and investigate the local  
213 anomalies or perturbations of the stress field.

214       Since the FSR-smoothing-method described by Müller et al. (2003) is suitable  
215 for identifying a major feature on a certain scale, we adopted this method with a  
216 constant search radius of 500 km for the analysis of the continental scale stress pattern.

---

217 The smoothing parameter  $\lambda$  was set at 2, and different weight factors were given to  
218 different data qualities, namely, 1 for A, 0.75 for B, and 0.5 for C quality. The distance  
219 weight was calculated using a tri-cube weight function, and finally determined  
220 through the normalization of the weight function by the number of neighbors,  $n_n$ ,  
221 within the search radius (Müller et al., 2003; Wehrle, 1998).

222 By applying the smoothing method with the parameters mentioned above to the  
223 6344 stress data points with the A-C qualities, we obtained the continental scale  
224 variation of the  $S_{Hmax}$  orientation for China and its adjacent areas (Fig. 4). The  
225 smoothing result clearly reveals that the stress field has a fan-shaped pattern. The  
226  $S_{Hmax}$  orientation in China has a clockwise rotation around the boundary of the  
227 Indian-Eurasian plate collision, which varies from northwest in the Hindu Kush-Pamir  
228 region, to north-south, northeast, east-west, and finally **southeast** in South China. This  
229 feature of stress field rotation is especially obvious at the two tectonic knots of **the**  
230 Indian-Eurasian collision, which are the **Himalayan** west **tectonic** knot and the  
231 **Himalayan** east **tectonic** knot.

232 By combining Figures 2 and 4, we identified some interesting phenomena for the  
233  $S_{Hmax}$  orientations around **the** different plate boundaries. Around the continental plate  
234 boundaries, including the Indian-Eurasian plate collision boundary and the North  
235 American plate boundary near Northeast China,  $S_{Hmax}$  orientations are **often** almost  
236 perpendicular to the **strikes** of boundaries, whether from the original stress data or  
237 from the smoothing result. However, around the oceanic boundaries, including the

---

238 Pacific plate boundary and the Philippine plate boundary,  $S_{Hmax}$  orientations appear to  
239 be more **complex**. Some stress data depict the  $S_{Hmax}$  orientations to be almost  
240 perpendicular to the boundary **strikes**, but some other orientations are sub-parallel.  
241 The smoothing result indicates that  $S_{Hmax}$  orientations seem to be sub-parallel to **the**  
242 boundary **strikes** around the section of the Philippine plate boundary from Taiwan to  
243 Japan, **and around** the majority of the Pacific plate boundary, while around the section  
244 of the Philippine plate boundary from Taiwan to the Philippines, the  $S_{Hmax}$  orientations  
245 are almost perpendicular to **the** boundary **strikes**.

246 In the intermediate regions, the **smoothed**  $S_{Hmax}$  orientations **on** the continental  
247 scale **change** gradually **from those around different plate boundaries**. Therefore, it  
248 could be deduced that the continental scale stress pattern in China and its adjacent  
249 areas is mainly controlled by **the surrounding plate boundary forces, which are** the  
250 Indian-Eurasian plate collision in the western part, and the Pacific plate subduction  
251 and the push from the Philippine plate in the eastern part. Since the rotation feature  
252 around the Indian-Eurasian plate collision boundary covers the majority of the  
253 Chinese mainland, it is reasonable to determine that the boundary force of the  
254 Indian-Eurasian plate collision has a larger influence on the continental scale feature  
255 of the stress pattern.

256 This continental scale variation supports the viewpoint that the plate boundary  
257 forces are the main factor that controls the first-order stress pattern (Heidbach et al.,  
258 2010, 2007; Coblenz et al, 1998; Richardson, 1992; Zoback, 1992). The clockwise

---

259 rotation of the  $S_{Hmax}$  orientation in China from the west to the east coincide with the  
260 previous findings (Xie et al., 2015, 2007, 2004; Cui et al., 2005; Xu et al., 2001, 1989;  
261 Wang et al., 1993, 1980; Yan et al., 1979; Deng and Zhang, 1979), but this is more  
262 distinct in our results. The vast extent of the rotation feature around the  
263 Indian-Eurasian plate collision boundary also provides practical stress data evidence  
264 for the inference from geodynamic simulations, which means that the Indian-Eurasian  
265 collision has the most vital role for the stress pattern in China and its adjacent areas  
266 (Zhu et al., 2006; Wang et al., 1996).

## 267 5. Local scale stress variability

268 In addition to the continental scale analysis, a further investigation of local scale  
269 stress anomalies and perturbations was conducted. The research regarding local scale  
270 variation has also been conducted since the initial study of the WSM (Zoback et al.,  
271 1992). A smoothing method with a varying search radius could provide an insight to  
272 the inhomogeneity scale of stress orientations (Heidbach et al. 2010) by judging the  
273 orientation data spreading within the search radius. This smoothing method has been  
274 adopted in the analysis work of the global stress field (Heidbach et al., 2010) and of  
275 the stress field in Canada (Reiter et al., 2014). In this method, the mean  $S_{Hmax}$   
276 orientation is an important indicator that is used to represent the maximum  
277 compressive direction, while the stress wavelength is also a valuable parameter which  
278 could partly reflect the spatial inhomogeneity scale of the stress field in a region. This  
279 makes the method effective for investigating local stress inhomogeneity. In this study,

---

280 we use this smoothing method with some adjustments to analyze the inhomogeneity  
281 on the local scale of the  $S_{Hmax}$  orientation in China and its adjacent areas.

## 282 **5.1 Adjusted smoothing algorithm**

283 Similar to the method of Heibach et al. (2010), the distance weight was also  
284 taken into account in this study. However, it is considered only in the mean  $S_{Hmax}$   
285 orientation, but not in the standard deviation (**SD**) for inhomogeneity scale judgement.  
286 The inhomogeneity scale in this study has a specific meaning of describing the  
287 **horizontal** scale of inhomogeneity for the regional stress pattern, and it is not exactly  
288 the same as the stress wavelength described by Heibach et al (2010). In this  
289 **horizontal** scale around one point, the  $S_{Hmax}$  orientations could be considered  
290 homogeneous, or in other words, the mean  $S_{Hmax}$  orientation could represent the  
291 regional  $S_{Hmax}$  orientations. Conversely, out of this scale, the mean  $S_{Hmax}$  orientation is  
292 incapable of representing the regional  $S_{Hmax}$  orientations. This inhomogeneity scale is  
293 determined by the **SD** of the stress orientations. In case the orientations far from one  
294 point are quite different from the uniform orientations in the central region, the stress  
295 pattern **should** not be considered homogeneous for this whole region. However, if the  
296 distance weight is still used in the **SD** calculation, the contribution to **SD** from these  
297 far and disparate orientations would be negligible, and the **SD** would still be quite  
298 small. In this case, the stress pattern of the vast region probably would be indicated as  
299 homogeneous by the small value of **SD**, and the inhomogeneity scale would be a  
300 larger value than what it truly represents. Thus, we removed the distance weight factor

---

301 from the **SD** calculation when judging inhomogeneity scale.

302 In addition, data density weight was introduced for the practical stress data  
303 distribution. There are a few places where a quantity of disperse orientation data  
304 points cluster in a very small region or even at almost the same location (see Figure 2).  
305 In this case, no matter how consistent other orientations are, the **SD** around the  
306 disperse cluster would result in a larger scatter, owing to the excessive influence of  
307 this cluster in the **SD** calculation. This **SD** result comprises a large portion from the  
308 uncertainty of the cluster point, which could come from a variation with depth,  
309 measurement outliers or other reasons. However, as for the **horizontal** inhomogeneity,  
310 it is the difference among different locations, but not the uncertainty at one location,  
311 should be emphasized. Therefore, this **SD** result cannot reflect the inhomogeneity of  
312 the orientation data. To reduce **the influence of this** factor, we adjusted the weight of  
313 the stress data in a cluster by dividing each data entry by the number of neighboring  
314 data points within a small distance (assumed to be 1 km in this study). This distance  
315 value is equal to 1/50 of the minimum search radius; hence the orientations within this  
316 distance can be seen as attached to the same location.

317 The quality weights were set as 1 for A, 0.75 for B, and 0.5 for C quality, which  
318 also **match** the continental smoothing above. Other settings are the same **as those** in  
319 Heidbach et al.(2010). Distance weighting  $w_D = 1/D$  ( $D = 25$  km when  $D < 25$  km) is  
320 applied, where  $D$  is the distance from the measured location to the grid point. The  
321 criterion **for consistency** is also the standard deviation of orientations  $SD \leq 25^\circ$ . The

---

322 lower limit of the data records is  $n \geq 5$ , where  $n$  is the number of reliable data records  
323 within the search radius. Starting with a search radius of 50 km around each grid point,  
324 the radius is increased stepwise by 50 km up to 200 km, then stepwise by 100 km up  
325 to 1000 km. The inhomogeneity scale equals the largest radius ( $r_{\max}$ ), which fulfils all  
326 criteria ( $SD \leq 25^\circ$ ,  $n \geq 5$ ), and all the data points within  $r_{\max}$  around the grid point are  
327 used to calculate the mean  $S_{H\max}$  orientation (Reiter et al., 2014; Heidbach et al.,  
328 2010). The mean  $S_{H\max}$  orientations are plotted based on the  $0.5^\circ$  grid, and  
329 inhomogeneity scales are color coded based on a  $0.5 \times 0.5^\circ$  grid in order to display  
330 the inhomogeneity of the  $S_{H\max}$  orientation in China and its adjacent areas.

## 331 **5.2 Mean stress orientations and inhomogeneity scales**

332 By applying the adjusted smoothing method with a varying search radius to the  
333 6344 stress data points with A-C qualities, we obtained the mean  $S_{H\max}$  orientations  
334 and inhomogeneity scales for China and its adjacent areas (Fig. 5). Even though there  
335 are some places where the stress data are insufficient to obtain reliable results, as  
336 shown in the gray areas in Fig. 5, it is still evident that the stress pattern in China and  
337 its adjacent areas seems quite inhomogeneous. Compared to the continental scale  
338 smoothing map in Fig. 4, the  $S_{H\max}$  orientations in Fig. 5 show the same trend of  
339 clockwise rotation from the west to the east, and they also have different behaviors  
340 around continental and oceanic boundaries.

341 Other than the similar features, Fig. 5 exhibits more details and the  
342 inhomogeneity scale distribution of  $S_{H\max}$  orientations. In some regions, including



---

343 regions I, II and III, the  $S_{Hmax}$  orientations show more **complex** variations on local  
344 scales than the continental scale orientations. The small inhomogeneity scales in  
345 regions I, II and III indicate the strong inhomogeneity for the stress pattern, while  
346 regions IV and V have quite large inhomogeneity scales, which indicate the relative  
347 homogeneity of their stress patterns.

348       Regions I and II are located around the two tectonic knots of the Indian-Eurasian  
349 collision, and region III can be identified as the tectonic knot of **the** Philippine plate  
350 subduction. Due to the tectonic knot effect, these three regions have extremely  
351 inhomogeneous stress fields. Furthermore, this strong inhomogeneity of the stress  
352 field results in an intense **topographic** variation and a **complex** active **fault** system (Fig.  
353 1), and makes them the three regions with strongest tectonic movement and seismicity  
354 in China and its adjacent areas, namely, the Hindu Kush-Pamir region, South-North  
355 seismic zone, and the Taiwan region. The intense **topographic** variation in concert  
356 with the **complex** active **fault** system, in turn, enhances the inhomogeneity of the  
357 stress pattern to some extent.

358       In contrast, region IV is located in Northeast China and is separated by part of  
359 the North American plate. Region IV is considerably far from the force source of the  
360 Pacific plate subduction. The tectonic effect from the North American plate is  
361 marginal, and both the North American plate boundary and the Pacific plate boundary  
362 near Northeast China are quite flat. These factors from the plate boundary forces  
363 make region IV liable to have a more homogeneous stress pattern on the first order. In

---

364 addition, region IV has very gentle topography and weak faulting, and this could be  
365 seen as the second-order mechanism for the homogeneous stress pattern in this region.

366 Region V is located in the central part of **the** Tibetan plateau. It is not very far  
367 from the Indian-Eurasian collision boundary – although, since the boundary line  
368 nearby is quite flat, the plate boundary forces **are still relatively simple** here. Similar  
369 to Northeast China, the central part of **the** Tibetan plateau also has gentle topography  
370 and relatively weak faulting, and these two factors, together with the simple plate  
371 boundary forces, make region V another region with a **relatively** homogenous stress  
372 pattern.

373 The plate boundary forces, as the first-order mechanism, control the macro  
374 features of the stress pattern in China and its adjacent areas. Different intensities of  
375 the **topographic** variation and faulting were considered to be the second **or** third-order  
376 mechanisms (Heidbach et al., 2010, 2007; Coblenz et al, 1998; Richardson, 1992;  
377 Zoback, 1992), **resulting** in local variations that cause different inhomogeneity scales  
378 of the stress pattern in China and its adjacent areas.

### 379 **5.3 Further Comparison between regions with inhomogeneous stress patterns**

380 Regions I, II and III seem to have a similar geodynamic interpretation for the  
381 strong inhomogeneity of stress pattern, including the effects of the tectonic knot,  
382 intense **topographic** variation and strong faulting activity. When examining these three  
383 regions more closely, **however**, we find some differences. Taiwan (region III) lies  
384 right on the tectonic knot of **the** Philippine plate, the Hindu Kush-Pamir region

---

385 (region II) extends approximately 500 kilometers from the **Himalayan west tectonic**  
386 knot, while the South-North seismic zone (region I) extends a quite long distance  
387 (over 1500 km) from the **Himalayan east tectonic** knot. Due to the significant  
388 increasing in the distance from tectonic knot, it is reasonable to suggest that the  
389 influence of the tectonic knot effect on stress inhomogeneity decreases successively  
390 from regions III to region II to region I. This vast inhomogeneity in region I could not  
391 be mostly explained by the tectonic knot effect. As revealed above and in previous  
392 findings, the stress pattern in and around China is mainly influenced by the  
393 Indian-Eurasian collision in the west and by the Pacific plate subduction and the push  
394 from the Philippine plate in the east. In this condition, this vast inhomogeneity  
395 suggests that the South-North seismic zone (region I) is the separation zone for the  
396 western and eastern parts. The effects **on** different directions from the western and  
397 eastern plate boundary forces are comparable, which makes the stress orientation  
398 labile here. This interaction between the western and eastern boundary forces is  
399 possibly the correct geodynamic interpretation for the vast inhomogeneity of the  
400 stress pattern from the point of plate boundary force in this region.

## 401 **6. Discussion**

402 Both the smoothing results on the continental and local scales have stress  
403 orientations with **different behaviors** around various types of plate boundaries.  
404 Generally,  $S_{Hmax}$  orientations are almost perpendicular to the **strikes** around the  
405 continental plate boundaries, but they are more **complex** around the oceanic plate

---

406 boundaries. Stress data with perpendicular or sub-parallel orientations co-exist, and  
407 the smoothing results can also vary around different oceanic plate boundaries. **This**  
408 **complexity** of stress orientations around oceanic plate boundaries is possibly **due** to  
409 the different tectonic **positions** in the complex subduction system, such as island arcs,  
410 trenches and back-arc basins. More specific studies on the stress environment around  
411 subduction zones could help reveal and interpret these complicating factors. One  
412 possible and incomplete cause for the continental and oceanic difference is the  
413 different mechanical strength of the structure (Tingay et al., 2006). Tingay et al. (2006)  
414 suggested that the  $S_{Hmax}$  orientation would be generally deflected sub-parallel to  
415 mechanically ‘weak’ structures, but then could be deflected perpendicular to  
416 mechanically ‘stiff’ structures. Compared to a continental plate boundary, there could  
417 be more liquid around an oceanic plate boundary to lubricate the boundary and to  
418 make it mechanically ‘weak’. However, since the subduction surface is  
419 three-dimensional, paralleling the **strike** is not the only choice for paralleling the  
420 subduction structure. Therefore, this cause does not totally explain the difference.  
421 More specific and further studies on this difference are worthwhile and they could be  
422 significant for identifying and explaining the **different behaviors** and mechanisms for  
423 the stress pattern between continental and oceanic plate boundaries.

424       The stress data integration provides a decent dataset, but in some regions in  
425 China, there are still few focal mechanism data points and also few stress  
426 measurement data points. Consequently, it is difficult to obtain more details about the

---

427 stress environment in the regions **lacking data**. Adopting seismic data of small  
428 earthquakes as well as carrying out more stress measurements would be useful and  
429 meaningful to contribute to stress orientation data.

## 430 **7. Conclusions**

431 In this study, we **attempted** to integrate stress data and analyze the crustal stress  
432 patterns for China and its adjacent areas. For the stress data integration, a total of  
433 6089 raw stress data records from the latest China Stress Database were ranked and  
434 standardized according to the latest criteria of the World Stress Map. The resulting  
435 5643 stress data records were integrated into the 2016 WSM release. The enriched  
436 database provides a solid basis for the crustal stress analysis of China and its adjacent  
437 areas.

438 As for the crustal stress pattern analysis, with the 6344 stress data records with  
439 A-C qualities from the integrated dataset (2016 WSM release), the patterns of stress  
440 orientation on the continental and local scales, were analyzed using different  
441 smoothing algorithms. The  $S_{Hmax}$  orientation in China rotates clockwise from **the** west  
442 to **the** east, resulting in a fan-shaped crustal stress pattern on the continental scale. The  
443 inhomogeneity scale distribution indicates that Northeast China and the central part of  
444 **the** Tibetan plateau have large scale stress patterns, while the South-North seismic  
445 zone, the Hindu Kush-Pamir region, and the Taiwan region have small scale stress  
446 patterns in China and its adjacent areas. The results are interpreted from different  
447 orders. The plate boundary forces are the first-order factors, and control the macro

---

448 features of the crustal stress pattern. The second-order mechanism comes from  
449 **topographic** variation and faulting activity, and these factors lead to local variations of  
450 the stress pattern. The vast inhomogeneity of the stress pattern around the  
451 South-North seismic zone supports a separation zone for the western and eastern  
452 boundary forces around China.

### 453 **Acknowledgments**

454 This work was supported jointly by the Institute of Crustal Dynamics, China  
455 Earthquake Administration Research Fund [grant number ZDJ 2014-14 and  
456 ZDJ2015-06], National Science and Technology Support Program [grant number  
457 **WSFD-07**] and SinoProbe-06-04. We thank all the scholars for providing the stress  
458 data records, and we thank R. Yao for the assistance in the stress data collection. The  
459 maps were generated through CASMI (Heidbach et al., 2007) and GMT software  
460 (Wessel et al., 2013). We are also grateful to the reviewers for their constructive  
461 comments and suggestions.

### 462 **References**

- 463 Balfour, N.J., Cassidy, J.F., Dosso, S.E., Mazzotti, S., 2011. Mapping crustal stress  
464 and strain in southwest British Columbia. *Journal of Geophysical Research*, 116  
465 (B3), 428-452
- 466 Bird, P., Li, Y., 1996. Interpolation of principal stress directions by nonparametric  
467 statistics: global maps with confidence limits. *Journal of Geophysical Research*,  
468 101 (B3), 5435-5443.

---

469 Bird, P., Ben-Avraham, Z., Schubert, G., Andreoli, M., Viola, G., 2006. Patterns of  
470 stress and strain-rate in southern Africa. *Journal of Geophysical Research*, 111  
471 (B8), 139-149.

472 Brudy, M., Kjørholt, H., 2001. Stress orientation on the Norwegian continental shelf  
473 derived from borehole failures observed in high-resolution borehole imaging  
474 logs. *Tectonophysics*, 337 (1-2), 65-84.

475 Coblenz, D., Richardson, R.M., 1995. Statistical trends in the intraplate stress field.  
476 *Journal of Geophysical Research*, 100 (B10), 20245-20255.

477 Coblenz, D., Zhou, S., Hillis, R.R., Richardson, R.M., Sandiford, M., 1998.  
478 Topography, boundary forces, and the Indo-Australian intraplate stress field.  
479 *Journal of Geophysical Research*, 103 (B1), 919-931.

480 Camelbeeck, T., de Viron, O., Van Camp, M., Kusters, D., 2013. Local stress sources  
481 in Western Europe lithosphere from geoid anomalies. *Lithosphere*, 5 (3), 235-246.

482 Cui, X. F., Xie, F. R., Zhao, J. T., 2005. The regional characteristics of focal  
483 mechanism solutions in China and its adjacent areas. *Seismology and Geology*,  
484 27 (2), 298-307.

485 Davis, J. C., 1986. *Statistics and Data Analysis in Geology*, 2nd ed., 646 pp. John  
486 Wiley, New York.

487 Deng, Q. D. (Chief Editor), 2007. *Map of Active tectonics in China*. Beijing:  
488 Seismological Press.

489 Deng, Q. D., Zhang, Y. M., 1979. On the tectonic stress field in China and its relation  
490 to plate movement. *Physics of the Earth and Planetary Interiors*, 18(4), 257-273.

---

491 Fan, T. Y., Long, C. X., Yang, Z. Y., Chen, Q. C., Wu, Z. H., Shao, Z. G., Tong, Y. B.,  
492 2012. Comprehensive modeling on the present crustal stress of China mainland  
493 with the viscoelastic spherical shell. *Chinese Journal of Geophysics*, 55(4),  
494 1249-1260.

495 Fuchs, K., Muller, B., 2001. World Stress Map of the Earth: a key to tectonic  
496 processes and technological applications. *Naturwissenschaften*, 88(9), 357-371.

497 Hansen, K.M., Mount, V.S., 1990. Smoothing and extrapolation of crustal stress  
498 orientation measurements. *Journal of Geophysical Research*, 95 (B2), 1155-1165.

499 Hardebeck, J.L., Michael, A., 2004. Stress orientations at intermediate angles to the  
500 San Andreas Fault, California. *Journal of Geophysical Research*, 109 (B11),  
501 285-296.

502 Heidbach, O., Reinecker, J., Tingay, M.R., Müller, B., Sperner, B., Fuchs, K., Wenzel,  
503 F., 2007. Plate boundary forces are not enough: second and third-order stress  
504 patterns highlighted in the world stress map database. *Tectonics*, 26(6), 438-451.

505 Heidbach, O., Höhne, J., 2008. CASMI — A visualization tool for the World Stress  
506 Map database. *Computer and Geosciences*, 34: 783-791

507 Heidbach, O., Tingay, M., Barth, A., Reinecker, J., Kurfeß, D., Müller, B., 2008. The  
508 World Stress Map database release. doi:10.1594/GFZ.WSM.Rel2008.

509 Heidbach, O., Tingay, M., Barth, A., Reinecker, J., Kurfeß, D. and Müller, B., 2009.  
510 The World Stress Map based on the database release 2008, equatorial scale  
511 1:46,000,000, Commission for the Geological Map of the World, Paris.  
512 doi:10.1594/GFZ.WSM. Map2009.



---

513 Heidbach, O., Tingay, M.R.P., Barth, A., Reinecker, J., Kurfeß, D., Müller, B., 2010.  
514 Global crustal stress pattern based on the World Stress Map database release  
515 2008. *Tectonophysics*, 482 (1-4), 3-15.

516 Heidbach, O., Rajabi, M., Reiter, K., Ziegler, M., WSM Team (2016): World Stress  
517 Map Database Release 2016. GFZ Data Services, doi:10.5880/WSM.2016.001.

518 Hillis, R. R., Meyer, J. J., Reynolds, S. D., 1998. The Australian stress map. *Journal of*  
519 *the Geological Society*, 29(4), 420-427.

520 Hodges, J.L., Lehmann, E.L., 1967. On medians and quasi medians. *Journal of the*  
521 *American Statistical Association*, 62 (319), 926-931.

522 Lund, B. and Townend, J., 2007. Calculating horizontal stress orientations with full or  
523 partial knowledge of the tectonic stress tensor. *Geophysical Journal International*,  
524 170, 1328-1335.

525 Mardia, K.V., 1972. *Statistics of Directional Data: Probability and Mathematical*  
526 *Statistics*. Academic Press, London. 357 pp.

527 Müller, B., Zoback, M.L., Fuchs, K., Mastin, L., Gregersen, S., Pavoni, N.,  
528 Stephansson, O., Ljunggren, C., 1992. Regional patterns of tectonic stress in  
529 Europe. *Journal of Geophysical Research*, 971(B8), 11783-11803

530 Müller, B., Wehrle, V., Zeyen, H.J., Fuchs, K., 1997. Short-scale variations of tectonic  
531 regimes in the western European stress province north of the Alps and Pyrenees.  
532 *Tectonophysics*, 275, 199-219.

533 Müller, B., Wehrle, V., Hettel, S., Sperner, B., Fuchs, K., 2003. A new method for  
534 smoothing orientated data and its application to stress data. *Geological Society*

---

535 London Special Publications, 209 (1), 107-126.

536 Ratanaruamkarn, S., Niewiadomska-Bugaj, M., Wang, J.-C., 2009. A new estimator of  
537 a circular median. *Communication in Statistics- Simulation and Computation*, 38  
538 (6), 1269-1291.

539 Rajabi, M., Tingay, M., Heidbach, O., 2016. The present-day stress field of New  
540 South Wales, Australia. *Australian Journal of Earth Sciences*, 63, doi:  
541 10.1080/08120099.0812.2016.01135821, 1-21.

542 Rebaï, S., Philip, H., Taboada, A., 2007. Modern tectonic stress field in the  
543 mediterranean region: evidence for variation in stress directions at different  
544 scales. *Geophysical Journal International*, 110(1), 106-140.

545 Reinecker, J., Tingay, M., Müller, B., Heidbach, O., 2010. Present-day stress  
546 orientation in the molasse Basin. *Tectonophysics*, 482 (1), 129-138.

547 Reiter, K., Heidbach, O., Schmitt, D., Haug, K., Ziegler, M., Moeck, I., 2014. A  
548 revised crustal stress orientation database for Canada. *Tectonophysics*, 636,  
549 111-124.

550 Richardson, R.M., Reding, L.M., 1991. North American plate dynamics. *Journal of*  
551 *Geophysical Research*, 96 (B7), 12201-12223.

552 Richardson, R.M., 1992. Ridge forces, absolute plate motions, and the intraplate stress  
553 field. *Journal of Geophysical Research*, 97, 11739-11748.

554 Sbar, M.L., Sykes, L.R., 1973. Contemporary compressive stress and seismicity in  
555 eastern North America, an example of intraplate tectonics. *Geological Society of*  
556 *America Bulletin*, 84, 1861-1881.

---

557 Schmitt, D.R., Currie, C.A., Zhang, L., 2012. Crustal stress determination from  
558 boreholes and rock cores: Fundamental principles. *Tectonophysics*, 580, 1-26.

559 Sperner, B., Müller, B., Heidbach, O., Delvaux, D., Reinecker, J., Fuchs, K., 2003.  
560 Tectonic stress in the earth's crust: advances in the world stress map project.  
561 Geological Society London Special Publications, 212(1), 101-116.

562 Stephansson, O., Zang, A. (2012): ISRM suggested methods for rock stress estimation  
563 - Part 5: Establishing a model for the in-situ stress at a given site. *Rock*  
564 *Mechanics and Rock Engineering*, 45(6), 955-969.

565 Tingay, M., Muller, B., Reinecker, J., Heidbach, O., 2006. State and origin of the  
566 present-day stress field in sedimentary basins: New results from the World Stress  
567 Map Project. In *The 41st U.S. Symposium on Rock Mechanics (USRMS)*.  
568 Golden, CO: American Rock Mechanics Association.

569 Townend, J., Zoback, M.D., 2004. Regional tectonic stress near the San Andreas fault  
570 in central and southern California, *Geophysical Research Letters*, 31, L15S11,  
571 doi:10.1029/2003GL018918.

572 Townend, J. 2006. What do Faults Feel? Observational Constraints on the Stresses  
573 Acting on Seismogenic Faults, *Earthquakes: Radiated Energy and the Physics of*  
574 *Faulting*, *Geophysical Monograph Series* 170, 313-327.

575 Townend, J., Zoback, M.D., 2006. Stress, strain, and mountain building in central  
576 Japan, *Journal of Geophysical Research*, 111, B03411,  
577 doi:10.1029/2005JB003759.

578 Wang, S. Y., Chen, P. S., 1980. A numerical simulation of the present tectonic stress

---

579 field of china and its vicinity. Chinese Journal of Geophysics, 23(1), 35-45.

580 Wang, S. Y., Gao, A. J., Xu, Z. H., 1993. The characteristics of focal mechanism  
581 solution in China and its adjacent areas. China earthquake zoning corpus.  
582 Earthquake Defense Department, China Earthquake Administration, Beijing:  
583 Seismological Press, 10-26.

584 Wang, S. Y., Xu, Z. H., Yu, Y. X., 1996. Inversion for the plate driving forces acting at  
585 the boundaries of China and its surroundings. Chinese Journal of Geophysics,  
586 39(6), 764-771.

587 Watson, G. S., 1985. Interpolation and smoothing of directed and undirected line data.  
588 In: Krishnajah, P. R. (Editor), Multivariate Analysis-VI. Elsevier Science, New  
589 York, pp. 613-625.

590 Wehrle, V., 1998. Analytische Untersuchung intralithosphärischer Deformationen und  
591 Numerische Bestimmung krustaler Spannungsdomänen, TH Karlsruhe,  
592 Karlsruhe, 167 pp.

593 Wessel, P., Smith, W.H.F., Scharroo, R., Luis, J., Wobbe, F., 2013. Generic mapping  
594 tools: improved version released. Eos Transactions American Geophysical Union,  
595 94(45), 409-410.

596 Xie, F. R., Cui, X. F., Zhao, J. T., Chen, Q. C., Li, H., 2004. Regional division of the  
597 recent tectonic stress field in china and adjacent areas. Chinese Journal of  
598 Geophysics, 47(4), 745-754.

599 Xie, F. R., Chen, Q. C., Cui, X. F., Li, H., Yang, S. X., Guo, Q. L., Chen, L. W., Xu, Z.  
600 H., Zhang, Y. S., Dou, S. Q., Zhao, J. T., Zhang, Z. S., Liu, C. Y., Wang, G. J.,

---

601 2007. Fundamental database of crustal stress environment in continental China.  
602 Progress in Geophysics, 22 (1), 131-136.

603 Xie, F. R. (Chief Editor), 2015. Recent tectonic stress map of China and its adjacent  
604 areas. Jiangsu: Sinomaps Press.

605 Xu, Z. H., Wang, S. Y., Huang, Y. R., Gao, A. J., 1989. The tectonic stress field of  
606 Chinese continent deduced from a great number of earthquake. Chinese Journal  
607 of Geophysics, 32(6), 636-647.

608 Xu, Z. H., 2001. A present-day tectonic stress map for eastern Asia region. Acta  
609 Seismologica Sinica, 14(5), 524-533.

610 Yan, J. Q., Shi, Z. L., Wang, S. Y., Huan, W. L., 1979. Some Features of the recent  
611 tectonic stress field of China and Environs. Acta Seismologica Sinica, 1 (1),  
612 9-24.

613 Zang, A., Stephansson, O., 2010. Stress Field of the Earth's Crust. Springer,  
614 Netherlands, Dordrecht.

615 Zhang, P. Z., Wang, Q., Ma, Z. J., 2002. GPS velocity field and active crustal blocks  
616 of contemporary tectonic deformation in continental China. Earth Science  
617 Frontiers, 9 (2), 430-441

618 Zhu, S. B., Shi, Y. L., 2006. Study the controls of the tectonic stress of China  
619 mainland. Science in China Series D: Earth Sciences, 36(12), 1077-1083

620 Zoback, M.L., Zoback, M.D., Adams, J., Assumpção, M., Bell, S., Bergman, E.A.,  
621 Blümling, P., Brereton, N.R., Denham, D., Ding, J., Fuchs, K., Gay, N.,  
622 Gregersen, S., Gupta, H.K., Gvishiani, A., Jacob, K., Klein, R., Knoll,

---

623 P., Magee, M., Mercier, J.L., Müller, B.C., Paquin, C., Rajendran, K., Stephansson,  
624 O., Suarez, G., Suter, M., Udías, A., Xu, Z.H., Zhizhin, M., 1989. Global patterns  
625 of tectonic stress. *Nature*, 341, 291-298.

626 Zoback, M.L., 1992. First and second order patterns of stress in the lithosphere: the  
627 World Stress Map project. *Journal of Geophysical Research*, 97, 11703-11728.

628

---

629 Fig. 1. The tectonic background of China and its adjacent areas. The topography  
630 (SRTM15 PLUS) is color coded. The gray lines are the active faults (Deng, 2007).  
631 The blue fault lines indicate the main plate boundaries around China (Xie et al., 2015).  
632 The red arrows indicate the plate motion direction relative to the Eurasian Plate (Xie  
633 et al., 2015).

634 **Table 1.** *Type and quality of the  $S_{Hmax}$  orientation data in China and its adjacent areas*  
635 *(latitude 0-60°N, longitude 45°-155°E).*

636 Fig. 2 Stress map in China and its adjacent areas of the 6,344 stress data records with  
637 A–C qualities excluding Possible Plate Boundary Events (PBEs). The bars represent  
638 the orientations of maximum horizontal compressional stress  $S_{Hmax}$ , and the bar length  
639 is proportional to quality. The colors indicate the stress regimes with red representing  
640 normal faulting (NF), green representing strike-slip faulting (SS), blue representing  
641 thrust faulting (TF), and black representing an unknown regime (U).

642 Fig. 3 Comparison between the **WSM database release 2008 and 2016** in China and its  
643 adjacent areas. Fig. 3a) Stress data with A-C qualities excluding PBEs in WSM  
644 **database release 2008**; Fig. 3b) Only new stress data with A-C qualities excluding  
645 PBEs in WSM **database release 2016**. The symbols are the same as in Fig. 2.

646 **Table 2.** *Statistics of stress regime for 6344 A-C quality stress data in China and its*  
647 *adjacent areas*

---

648 Fig. 4 Smoothed  $S_{Hmax}$  orientations on the continental scale and indicators of stress  
649 field rotation in China and its adjacent areas. The thin red bars indicate the smoothed  
650  $S_{Hmax}$  orientations on the continental scale using a quality- and distance-weighted  
651 algorithm (Müller et al., 2003). The search radius is  $r = 500$  km, a minimum number  
652 of neighbors  $n_{min} = 5$ , a minimum value of the sum of quality weight factors of the  
653 nearest neighbors  $s_q = 5$ , and a minimum for the sum of the weight terms of the  
654 nearest neighbors  $s_w = 1$ , within the search radius is requested for calculating the  
655 mean stress orientation at a grid point. The solid red dotted bars represent the macro  
656 feature of the smoothing result of the  $S_{Hmax}$  orientation in China. The blue fault lines  
657 indicate the main plate boundary around China (Xie et al., 2015).

658 Fig. 5 Mean  $S_{Hmax}$  orientations and inhomogeneity scales in China and its adjacent  
659 areas. The mean  $S_{Hmax}$  orientations are displayed through the black bars, indicating the  
660  $S_{Hmax}$  orientations on a  $0.5 \times 0.5^\circ$  grid. The inhomogeneity scales equal to the  
661 largest radii  $r_{max}$ , which fulfils the confidence criterion ( $SD \leq 25^\circ$ ) and the data  
662 record criterion ( $n \geq 5$ ) are color coded. The gray areas are the areas without  
663 reliable results. The blue fault lines indicate the main plate boundary around China  
664 (Xie et al., 2015). I~V and white rectangles indicate distinctive regions.