

1 **Optimal stomatal behaviour around the world: synthesis of a global**  
2 **stomatal conductance database**

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4 Yan-Shih Lin<sup>1</sup>, Belinda E. Medlyn<sup>1</sup>, Remko A. Duursma<sup>2</sup>, I. Colin Prentice<sup>1,3</sup>, Owen K.  
5 Atkin<sup>4</sup>, Craig V.M. Barton<sup>2</sup>, Jonathan Bennie<sup>5</sup>, Alexandre Bosc<sup>6,7</sup>, Mark S.J.  
6 Broadmeadow<sup>8</sup>, Lucas A. Cernusak<sup>9</sup>, Paolo De Angelis<sup>10</sup>, John E. Drake<sup>2</sup>, Derek Eamus<sup>11</sup>,  
7 David S. Ellsworth<sup>2</sup>, Michael Freeman<sup>12</sup>, Oula Ghannoum<sup>2</sup>, Teresa E. Gimeno<sup>2</sup>, Qingmin  
8 Han<sup>13</sup>, Kouki Hikosaka<sup>14</sup>, Lindsay B. Hutley<sup>15</sup>, Jeff W. Kelly<sup>1</sup>, Kihachiro Kikuzawa<sup>16</sup>, Pasi  
9 Kolari<sup>17</sup>, Kohei Koyama<sup>16,18</sup>, Jean-Marc Limousin<sup>19</sup>, Maj-Lena Linderson<sup>20</sup>, Markus Löw<sup>21</sup>,  
10 Cate Macinins-Ng<sup>22</sup>, Nicolas K. Martin-StPaul<sup>23</sup>, Patrick Meir<sup>24</sup>, Teis N. Mikkelsen<sup>25</sup>,  
11 Patrick Mitchell<sup>26</sup>, Jesse B. Nippert<sup>27</sup>, Yusuke Onoda<sup>28</sup>, Maarten Op de Beeck<sup>29</sup>, Victor  
12 Resco de Dios<sup>30</sup>, Ana Rey<sup>31</sup>, Alistair Rogers<sup>32</sup>, Lucy Rowland<sup>24</sup>, Samantha A. Setterfield<sup>15</sup>,  
13 Wei Sun<sup>33</sup>, Lasse Tarvainen<sup>34</sup>, Sabine Tausz-Posch<sup>21</sup>, David T. Tissue<sup>2</sup>, Johan Uddling<sup>35</sup>,  
14 Göran Wallin<sup>35</sup>, Jeff M. Warren<sup>36</sup>, Lisa Wingate<sup>6</sup>, Joana Zaragoza-Castells<sup>24</sup>

15

16 <sup>1</sup>: Department of Biological Sciences, Macquarie University, North Ryde, NSW 2109,  
17 Australia

18 <sup>2</sup>: Hawkesbury Institute for the Environment, University of Western Sydney, Penrith, New  
19 South Wales 2751, Australia

20 <sup>3</sup>: Grantham Institute and Division of Ecology and Evolution, Imperial College, Silwood  
21 Park Campus, Ascot SL5 7PY, United Kingdom

22 <sup>4</sup>: Division of Plant Sciences, Research School of Biology, The Australian National  
23 University, Canberra, Australian Capital Territory 0200, Australia

24 <sup>5</sup>: Environment and Sustainability Institute, University of Exeter, Penryn, United Kingdom

25 <sup>6</sup>: Institut National de la Recherche Agronomique, Villenave d'Ornon F-33140, France

- 26 <sup>7</sup>: Bordeaux Sciences Agro, UMR 1391 ISPA, Gradignan F-33170, France
- 27 <sup>8</sup>: Climate Change Forest Services, Forestry Commission England, United Kingdom
- 28 <sup>9</sup>: James Cook University, Cairns, Queensland 4879, Australia
- 29 <sup>10</sup>: Department for Innovation in Biological, Agro-food and Forest systems, University of  
30 Tuscia, Via San Camillo de Lellis, Viterbo 01100, Italy
- 31 <sup>11</sup>: School of Life Sciences , University of Technology, Sydney, New South Wales 2007,  
32 Australia
- 33 <sup>12</sup>: Department of Ecology, Swedish University of Agricultural Sciences, UPPSALA 75007,  
34 Sweden
- 35 <sup>13</sup>: Hokkaido Research Center, Forestry and Forest Products Research Institute (FFPRI),  
36 Toyohira, Sapporo, Hokkaido 062-8516, Japan
- 37 <sup>14</sup>: Graduate School of Life Sciences, Tohoku University, Aoba, Sendai 980-8578, Japan
- 38 <sup>15</sup>: Research Institute for Environment and Livelihoods, Charles Darwin University,  
39 Casuarina, Northern Territory 0810, Australia
- 40 <sup>16</sup>: Department of Environmental Science, Faculty of Bioresources and Environmental  
41 Sciences, Ishikawa Prefectural University, Ishikawa 921-8836, Japan
- 42 <sup>17</sup>: Department of Physics, University of Helsinki, Finland
- 43 <sup>18</sup>: Department of Life Science and Agriculture, Obihiro University of Agriculture and  
44 Veterinary Medicine, Obihiro, Hokkaido 080-0834, Japan
- 45 <sup>19</sup>: Department of Biology, University of New Mexico, Albuquerque, NM 87131-0001,  
46 United States
- 47 <sup>20</sup>: Department of Physical Geography and Ecosystem Science, Lund University, Sweden
- 48 <sup>21</sup>: Department of Agriculture and Food Systems, University of Melbourne, Creswick,  
49 Victoria 3363, Australia
- 50 <sup>22</sup>: School of Environment, University of Auckland, Auckland 1142, New Zealand

51 <sup>23</sup>: Université Paris-Sud, Laboratoire Ecologie, Systématique et Evolution, UMR8079,  
52 Orsay F-91405, France

53 <sup>24</sup>: School of Geosciences, The University of Edinburgh, Edinburgh EH8 9XP, United  
54 Kingdom

55 <sup>25</sup>: Center for Ecosystems and Environmental Sustainability, Department of Chemical and  
56 Biochemical engineering, Technical University of Denmark, DK-4000 Roskilde, Denmark

57 <sup>26</sup>: CSIRO Ecosystem Sciences, Sandy Bay, Tasmania 7005, Australia

58 <sup>27</sup>: Division of Biology, Kansas State University, Manhattan, KS 66505, United States

59 <sup>28</sup>: Division of Environmental Science and Technology, Graduate School of Agriculture,  
60 Kyoto University, Oiwake, Kitashirakawa, Kyoto 606-8502, Japan

61 <sup>29</sup>: Research Group Plant and Vegetation Ecology, University of Antwerp, Wilrijk 2610,  
62 Belgium

63 <sup>30</sup>: Producció Vegetal i Ciència Forestal, Universitat de Lleida, Lleida 25198, Spain

64 <sup>31</sup>: Department of Biogeography and Global Change, MNCN-CSIC, Spanish Scientific  
65 Council, Madrid 28006, Spain

66 <sup>32</sup>: Environmental and Climate Sciences Department, Brookhaven National Laboratory,  
67 Upton, NY 11973-5000, United States

68 <sup>33</sup>: Institute of Grassland Science, Northeast Normal University, Key Laboratory of  
69 Vegetation Ecology, Changchun, Jilin 130024, China

70 <sup>34</sup>: Department of Forest Ecology and Management, Swedish University of Agricultural  
71 Sciences, Umeå 90183, Sweden

72 <sup>35</sup>: Department of Biological and Environmental Sciences, University of Gothenburg,  
73 Göteborg 40530, Sweden

74 <sup>36</sup>: Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN,  
75 USA

76 **Main text**

77 Stomatal conductance is a key land surface attribute as it links plant water-use and carbon  
78 uptake. In this study we synthesised a globally distributed database of stomatal  
79 conductance data sets obtained in the field for a wide range of plant functional types (PFTs)  
80 and biomes. We employed a model of optimal stomatal conductance<sup>1</sup> to assess differences  
81 in stomatal behaviour. We estimated the model slope coefficient,  $g_1$ , which is directly  
82 related to the marginal carbon cost of water-use, for each dataset. We then tested how  $g_1$   
83 varies with climatic factors, including temperature and water availability, and across PFTs.  
84 We found that  $g_1$  varied considerably among PFTs, with evergreen savanna trees having  
85 the largest  $g_1$  (least conservative water-use), followed by C<sub>3</sub> grasses and crops, angiosperm  
86 trees, gymnosperm trees, and C<sub>4</sub> grasses. Amongst angiosperm trees, species with larger  
87 wood density had a larger marginal carbon cost of water-use, as predicted by the theory  
88 underpinning the optimal stomatal model. There was an interactive effect between  
89 temperature and moisture availability (on  $g_1$ : for wet environments,  $g_1$  was largest in high  
90 temperature environments, indicated by high mean annual growing degree days above 0°C  
91 (mGDD<sub>0</sub>), but it did not vary with mGDD<sub>0</sub> across dry environments. These findings  
92 provide a robust theoretical framework for understanding and predicting the behaviour of  
93 stomatal conductance across biomes and across PFTs that can be applied to regional,  
94 continental and global-scale modelling of productivity and ecohydrological processes in a  
95 future changing climate.

96

97 Earth System Models (ESMs) integrate biogeochemical and biogeophysical land surface  
98 processes with physical climate models and have been widely used to demonstrate the  
99 importance of land surface processes in determining climate and to highlight the issue of  
100 large uncertainties in quantifying land surface processes<sup>2, 3, 4, 5</sup>. Within the biogeophysical

101 components of land surface processes, stomatal conductance plays a pivotal role because it  
102 is a key feedback route for carbon and water exchange between the atmosphere and  
103 terrestrial vegetation. Stomata are small pores on leaves whose behaviour can be regulated  
104 by the plant in response to multiple abiotic and biotic factors. Stomatal conductance ( $g_s$ ) is  
105 a major determinant of both transpiration rates and rates of photosynthetic C uptake. .  
106 Therefore, our ability to model the global carbon and water cycles under future changing  
107 climate depends on our ability to predict stomatal behaviour globally<sup>1</sup>, an ability that to-  
108 date has remained particularly intractable . Although there have been previous synthesis  
109 studies on plant stomatal conductance and related traits<sup>6,7,8,9</sup>, a global scale database and  
110 associated mechanistic globally applicable model of  $g_s$  that would allow prediction of  
111 stomatal behaviour is lacking.

112

113 For this study, we compiled a unique global database of field measurements of stomatal  
114 conductance and photosynthesis suitable for extracting model parameters. We employed a  
115 model of optimal stomatal conductance<sup>1</sup> to develop hypotheses for how stomatal behaviour  
116 should vary with environmental factors and with plant traits associated with hydraulic  
117 function. In the optimal stomatal model, the slope parameter,  $g_1$ , is proportional to the  
118 marginal carbon cost of water-use<sup>1</sup>, meaning that plants with smaller  $g_1$  values are more  
119 conservative with their water-use and have higher water-use-efficiency (and *vice versa*).  
120 Therefore, we hypothesised that variation in  $g_1$  values among climate zones and PFTs  
121 should reflect differences in the cost of water transport. We proposed that:

122 (1)  $g_1$  values among PFTs should vary according to the cost of stemwood construction,  
123 such that C3 herbaceous species should have the largest  $g_1$  (i.e. least conservative water-  
124 use), followed by angiosperm trees and gymnosperm trees. Since the optimal stomatal

125 theory predicts that, for the same marginal water cost,  $g_1$  should be lower by approximately  
126 one-half<sup>10</sup>. We therefore predicted that C4 plants would have the smallest  $g_1$ .

127 (2) For trees, the cost of water transport should increase with wood density, due to the  
128 higher cost of wood construction<sup>11</sup> and the generally smaller hydraulic conductance of  
129 sapwoods with large density. Therefore within both angiosperms and gymnosperms, trees  
130 with highest wood density should have the smallest  $g_1$ .

131 (3) Moisture stress should increase the cost of water-use to the plant, so plants in dry  
132 environments should have a larger marginal cost of water-use and lower  $g_1$ .

133 (4)  $g_1$  values should increase with temperature for two reasons. First, we previously  
134 showed that  $g_1$  is approximately proportional to a combination term of the carbon cost of  
135 water transport and  $\Gamma^*$  (the CO<sub>2</sub> compensation point in absence of photorespiration)<sup>1</sup>. As  
136  $\Gamma^*$  is exponentially dependent on temperature<sup>1, 12</sup>,  $g_1$  should similarly increase with  
137 temperature. Second, the viscosity of water decreases with increasing temperature, making  
138 it less costly to transport water leading to an increased  $g_1$ <sup>13</sup>.

139

140 To test these hypotheses, we collated a globally distributed database of  $g_s$  and  
141 photosynthesis of 56 field studies, covering a wide range of biomes from Arctic tundra,  
142 boreal and temperate forest to tropical rainforest (Table S1). We estimated the model  
143 coefficient,  $g_1$ , from observations of leaf-level gas exchange ( $g_s$ , rates of transpiration  
144 and net photosynthesis, see Methods) and environmental drivers. We used mean annual  
145 degree days above 0°C (mGDD<sub>0</sub>) and moisture index (MI) derived from observed long-  
146 term meteorological data as proxies to quantify the temperature and water availability that  
147 are relevant to plant physiological functions for each site<sup>14</sup>. The growing degree days  
148 above 0°C is an index of the energy available for completion of the annual life cycle and  
149 quantifies temperature limitations to carbon assimilation and growth<sup>15, 16</sup>. Our database

150 covered a range of  $mGDD_0$  from 2.7 to 29.7 °C and a range of MI from 0.17 to 3.26,  
151 representing the majority of the climatic space for vegetation covered land surfaces (Fig.  
152 1). We then tested how  $g_1$  varies with MI and  $mGDD_0$  across PFTs and biomes?.

153

154 We found a clear pattern of  $g_1$  variation among different PFTs with evergreen savanna  
155 trees having largest  $g_1$ , followed by C<sub>3</sub> grasses and crops, angiosperm trees, gymnosperm  
156 trees, and C<sub>4</sub> grasses (Table S2 and Fig. 2). For angiosperm trees,  $g_1$  was negatively  
157 correlated with wood density, although we did not find any correlation for gymnosperm  
158 species (Fig. 3).  $g_1$  significantly increased with both increasing  $mGDD_0$  and MI across the  
159 entire data set. However, when evaluated as a bivariate relationship (Fig. 2c-d, and Fig. 4a-  
160 b) we observed that there was an interactive effect between temperature and moisture  
161 availability on  $g_1$ : for wet environments,  $g_1$  was largest at sites with high  $mGDD_0$ , but it  
162 varied with  $mGDD_0$  to a much smaller degree across dry environments (Table 1 and Fig.  
163 4).

164 Our results largely supported our hypotheses for how  $g_1$  should vary among PFTs  
165 (hypothesis 1) and biomes. The variation in  $g_1$  among PFTs is a result of trade-offs among  
166 plant functions such as growth, defence and reproduction, through different resource  
167 allocation patterns that aim to achieve the optimal cost-to-benefit ratios<sup>8,13</sup> Long life-span  
168 PFTs, such as evergreen gymnosperm and angiosperm trees, must invest more in building  
169 supporting and defence structures relative to short life-span PFTs, such as grasses, so that  
170 they can be sustained over many years of biotic and abiotic stress. Such an investment  
171 preference has to come at the cost of reduced growth rates<sup>17,18</sup>, meaning reduced the rates  
172 of carbon uptake and water loss cost through opening stomata. Therefore we predicted a  
173 more conservative water-use strategy in trees (lower  $g_1$ ) than in C<sub>3</sub> grass (higher  $g_1$ ), and  
174 this was observed in the database. However, evergreen savanna trees formed an exception

175 with a surprisingly large  $g_1$ , relative to expectations based upon trees wood density and  
176 biomes MI. This may result from the fact that these species have several unique hydraulic  
177 functional traits that may offset the carbon cost of water-use which allow them to have a  
178 less conservative water use strategy. These hydraulic functional traits include: deep roots  
179 to access groundwater, large sapwood area for water transport, narrow but long conduits to  
180 reduce the risk of embolism and reduce the cost of conduit wall construction<sup>19, 20</sup> and dry  
181 season declines in LAI to balance increased atmospheric aridity in the dry season . This  
182 special case of evergreen savanna trees is worthy of further investigation.

183

184 We found a significant relationship between  $g_1$  and wood density among angiosperm trees  
185 (Fig. 3; excluding savanna angiosperms) which supported our hypothesis that  $g_1$  is  
186 negatively correlated with wood density (hypothesis 2). A larger wood density is  
187 advantageous for plants that need to avoid hydraulic failure so that they can sustain more  
188 negative sapwood water pressures during drought<sup>18</sup>. However, such an investment is at the  
189 expense of a reduced capacity for stem water storage, reduced sapwood conductivity and  
190 the carbon cost of building wood with higher density<sup>20, 21, 22</sup>, and thus leads to a more  
191 conservative water-use-strategy. However, we did not find such a relationship among  
192 gymnosperm trees. This lack of correlation may be due to the limited variability in wood  
193 density in gymnosperms. There are significant differences in the anatomical structure of  
194 sapwood between angiosperms and gymnosperms. The majority of angiosperm trees have  
195 evolved to separate the water transport structure (i.e. vessels) from the mechanical support  
196 structure, while gymnosperm trees do not have such a functional differentiation, as  
197 tracheids are used for both water transport and mechanical support<sup>18, 23</sup>. Therefore, wood  
198 density is a good proxy for quantifying the trade-offs between transport and support  
199 investments for angiosperm trees but not for gymnosperm trees<sup>23</sup>. The distinct differences



200 in the water-use strategy between angiosperm trees and gymnosperm trees (Fig. 2) is  
201 consistent with a recent observation that angiosperms maintain a much smaller hydraulic  
202 safety margin than gymnosperms<sup>24</sup>, showing that angiosperms allow some loss of  
203 hydraulic conductivity – a risky strategy – while gymnosperms minimise loss. This  
204 evolutionary development confers an advantage to angiosperm trees by allowing them to  
205 use water in a less conservative way, thereby increasing their carbon gain relative to  
206 gymnosperm trees.

207

208 Our results only partially supported our hypotheses for how  $g_1$  should vary with moisture  
209 stress and temperature (hypotheses 3 and 4 as there was an interactive effect between  
210 temperature and moisture stress on  $g_1$ . This interactive response between MI and  $mGDD_0$   
211 demonstrates the complexity of how plants co-ordinate their resource allocation strategies  
212 along two axes of climatic gradient (Fig. 4). Temperature affects the cost of water transport  
213 in such a way that it should be more costly to transport water in a colder environment than  
214 in a warmer one. However, lower temperature also comes with water savings as the  
215 evaporative demand and photorespiratory cost are lower. The interactive relationship  
216 between MI and  $mGDD_0$  suggest that the rate of change in  $g_1$  (i.e. the slope of each  
217 exponential curve; Fig. S3) along temperature or water availability gradient is much higher  
218 in the wet and warm environments than in dry and cold environments.

219

220 Our study demonstrated the first mechanistically robust framework that can be applied to  
221 various scales for understanding and predicting the behaviour of stomatal conductance  
222 across biomes and across PFTs. We analysed a global stomatal behaviour data set along  
223 two major climatic axes, providing an analytic framework for understanding how  
224 stomatal behaviour adapts to the environment. Our findings will allow the ESM

225 community to move on from using empirical stomatal models (ref ref) with tuned  
226 parameters to using a more robust, theory-derived optimal stomatal model with meaningful  
227 parameters. In addition, we provide a valuable stomatal behaviour database that can be  
228 used to parameterise  $g_s$  among PFTs and which can be applied directly within ESMs for  
229 modelling productivity and ecohydrological processes in a future changing climate across  
230 regional, continental and global scales.

231

232

## 233 **Methods**

### 234 *Source of data*

235 We synthesised published and unpublished leaf gas exchange data sets for a wide range of  
236 PFTs and biomes (Table S1). Our database covers 314 species from 56 experiment sites  
237 around the world with 17 sites from Australasia, 15 sites from Europe, 14 sites from North  
238 America, six sites from Asia, three sites from South America and one site from Africa. Site  
239 latitudes range from 42.9°S to 72.3°N although the majority of the sites are within the  
240 temperate zone (n=35; latitude range between 23.5° to 55° and between -23.5° and -55°),  
241 followed by tropical zone (n=14; latitude range between -23.5° and 23.5°), boreal zone  
242 (n=6; latitude range between 55° and 66.5°) and Arctic zone (n=1; latitude range above  
243 66.5°). We used MI and mGDD<sub>0</sub> derived from Climate Research Unit data (CRU TS3.1)<sup>25</sup>  
244 from 1991 to 2010 using a modified version of the STASH model<sup>26</sup> at a grid resolution of  
245 0.5°. In this derivation, mGDD<sub>0</sub> was calculated as the ratio of the annual sum of  
246 temperatures above 0°C (growing degree days) to the length of the period with  
247 temperatures above 0°C; MI was calculated as the ratio of mean annual precipitation to the  
248 equilibrium evapo-transpiration (E<sub>eq</sub>). We estimated E<sub>eq</sub> from temperature and net radiation  
249 (calculated from monthly mean percentage of cloud cover) based on the Priestley-Taylor  
250 equation<sup>26</sup>. The Sea-WiFS fAPAR (fraction absorbed photosynthetically active radiation)  
251 product was used to determine areas with green vegetation cover at a grid resolution of 0.5°.  
252 The wood density data were obtained from the Global Wood Density Database<sup>23, 27</sup>.

253

### 254 *Data analysis*

255 We used data points measured at a photosynthetic photon flux density (PPFD) > 0 μmol  
256 m<sup>-2</sup> s<sup>-1</sup>, and only data collected from the top third of the canopy (what would happen if you  
257 used data for PAR > 250 μmol m<sup>-2</sup> s<sup>-1</sup> rather than > 0? . Data points with negative

258 photosynthesis rates were excluded. In all cases, species were grown under ambient  
259 environmental conditions and were not subjected to any treatments, such as elevated CO<sub>2</sub>,  
260 temperature, or drought treatments. We employed an optimal stomatal model<sup>1</sup> as:

$$g_s = g_0 + 1.6 \times \left(1 + \frac{g_1}{\sqrt{D}}\right) \frac{A}{C_a}$$

261 where  $D$  is vapour pressure deficit,  $A$  is net photosynthesis rate,  $C_a$  is CO<sub>2</sub> concentration at  
262 leaf surface, and  $g_0$ ,  $g_1$  are model coefficients for intercept and slope. We used a non-linear  
263 mixed-effect model to estimate the model slope coefficient,  $g_1$ , for each group separately  
264 for various classification schemes as shown in Fig. 2. In all  $g_1$  estimations, we assumed the  
265 intercept coefficient,  $g_0$ , to be zero to avoid strong correlation between  $g_0$  and  $g_1$  which  
266 would mask any interesting variation in  $g_1$ . In this model, individual species were assumed  
267 to be the random effect to account for the differences in the  $g_1$  slope among species within  
268 the same group. To test how  $g_1$  varies with climatic variables (i.e. MI and mGDD<sub>0</sub>), we  
269 first estimated  $g_1$  for each species using non-linear regression. We then used a linear  
270 mixed-effect model to test the relationship between  $g_1$ , MI and mGDD<sub>0</sub>. We fitted the  
271 model as:

$$\log(g_1) \sim \text{MI} + \text{mGDD}_0 + \text{MI} \times \text{mGDD}_0$$

272 assuming PFTs as the random effect to account for the differences in intercept among PFTs.  
273 To evaluate the goodness of fit for linear mix-effect model, we calculated both the  
274 marginal R<sup>2</sup> to quantify the proportion of variance explained by the fixed factors alone and  
275 the conditional R<sup>2</sup> to quantify the proportion of variance explained by both the fixed and  
276 random factors as described in Nakagawa and Holger Schielzeth (2013)<sup>28</sup>. The relationship  
277 between  $g_1$  and wood density were tested with a simple linear regression model. All model  
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381 **Acknowledgements**

382 This research was supported by the Australian Research Council (ARC MIA Discovery  
383 Project 1433500-2012-14). A.R. was financially supported in part by The Next-Generation  
384 Ecosystem Experiments (NGEE-Arctic) project that is supported by the Office of  
385 Biological and Environmental Research in the Department of Energy, Office of Science,  
386 and through the United States Department of Energy contract No. DE-AC02-98CH10886  
387 to Brookhaven National Laboratory. M.O.d.B. acknowledges that the Brassica data were  
388 obtained within a research project financed by the Belgian Science Policy (OFFQ, contract  
389 number SD/AF/02) and coordinated by Dr Karine Vandermeiren at the Open-Top  
390 Chamber research facilities of CODA-CERVA (Tervuren, Belgium).

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392 **Author contributions**

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396 **Competing financial interests**

397 The author declare no competing financial interests.



398 **Table 1: Analysis of Variance table for  $g_1$  as a function of MI and mGDD<sub>0</sub>.**

399

<b>Model</b>					
<b>Variables</b>	<b>numDF</b>	<b>denDF</b>	<b>F-value</b>	<b>p-value</b>	<b>Marginal R<sup>2</sup></b>
<b>Intercept</b>	1	97	67.08	< 0.001	0.20
<b>MI</b>	1	97	7.50	0.007	<b>Conditional R<sup>2</sup></b>
<b>mGDD<sub>0</sub></b>	1	97	11.15	0.001	
<b>MI*mGDD<sub>0</sub></b>	1	97	1.34	0.250	

400 **Figure legends**

401 **Figure 1: Climatic space covered by the Stomatal Behaviour Synthesis Database, shown**  
402 **as mean annual degree days above 0°C (mGDD<sub>0</sub>; °C) and moisture index (MI).** Coloured  
403 circles represent climatic space for the database, with different colours indicating different  
404 plant functional types. Grey hexagons represent global climatic space for which vegetation is  
405 present. The global climatic space data were binned by every 1 °C for mGDD<sub>0</sub> and every 0.25  
406 for MI.

407  
408 **Figure 2: Mean  $g_1$  values for plant functional types defined by different classification**  
409 **schemes.** Each bar represents mean  $\pm$  SE. Panels (b) (c) and (d) include C<sub>3</sub> species data only.

410  
411 **Figure 3: Relationship between  $g_1$  and wood density for angiosperm and gymnosperm**  
412 **trees.** Savanna tree species (all angiosperms) are indicated separately. Each data point  
413 represents mean  $\pm$ SE of  $g_1$  for individual species fitted with non-linear regression. A linear  
414 regression line was only fitted for angiosperm trees due to limited data for gymnosperm trees.  
415 The fitted linear regression relationship between  $g_1$  and wood density for angiosperm trees is:  
416  $g_1 = -4.77 \cdot \text{WD} + 6.96$  ( $P = 0.0008$ ,  $R^2 = 0.23$ ). Wood density data were obtained from Global  
417 Wood Density Database<sup>23, 27</sup> and are available for 45 species in the Stomatal Behaviour Synthesis  
418 Database.

419 **Figure 4: Estimated and predicted  $g_1$  as a function of mGDD<sub>0</sub> and MI.** Panels (a) (b) show  
420 the relationship between estimated  $g_1$  and (a) mean annual degree days above 0 °C temperature  
421 (mGDD<sub>0</sub>; °C) and (b) moisture index (MI) at experimental sites among species across different  
422 plant functional types (PFTs). Each data point represents mean  $\pm$  SE of  $g_1$  for individual species

423 fitted with a non-linear regression. Classification of plant functional types are shown in Figure  
424 2e. Panels (c) and (d) are the predicted  $g_1$  under different ranges of MI and mGDD<sub>0</sub> presented  
425 as a partial regression plot. Predictions in (c) and (d) are from linear mixed-effects model for  
426  $\log(g_1)$  assuming PFTs as a random effect to account for the differences in intercept among PFTs.  
427 Colour lines represent the predicted  $g_1$  based on fitted model coefficients (Table S3). Colour  
428 dots represent the partial regression predictions at a given fixed MI or mGDD<sub>0</sub> level.

429 **Supplementary Materials**430 **Table S1: List of data source.**

<b>Data contributor</b>	<b>Location</b>	<b>Species</b>	<b>Reference</b>
Alexandre Bosc	Le Bray, France	<i>Pinus pinaster</i>	Bosc, A. (1999) PhD Thesis.
Alistair Rogers	Barrow, AK, USA	Several Arctic species	Unpublished data.
Ana Rey	Glencorse near Edinburgh, Scotland, UK	<i>Betula pendula</i>	Rey & Jarvis (1998) Tree Physiology.
Belinda Medlyn	Tumbarumba flux tower, Snowy Mts, NSW, Australia	<i>Eucalyptus delegatensis</i>	Medlyn et al. (2007) Tree Physiology.
Cate Macinnis-Ng	Arataki Visitor Centre, Auckland, New Zealand	<i>Agathis australis</i>	Unpublished data
Craig Barton	Glencorse near Edinburgh Scotland	<i>Picea sitchensis</i>	Barton & Jarvis (1999) New Phytologist.
David Ellsworth	Duke Forest, Durham, NC, USA	<i>Pinus taeda</i>	Ellsworth DS (1999) Plant, Cell & Environment.
David Ellsworth	Richmond, Sydney, Australia	<i>Eucalyptus saligna</i>	Unpublished data
David Ellsworth	Richmond, Sydney, Australia	Four <i>Eucalyptus</i> species	Héroult et al. (2013) Plant, Cell & Environment.
David Tissue	Big Bend National Park, Texas, USA	<i>Larrea tridentata</i>	Ogle et al. (2012)
Derek Eamus	Palmerston, NT, Australia	A set of six savanna tree species	Thomas & Eamus (2002) Australian Journal of Botany.
Derek Eamus	Western Sydney, Castlereagh, Australia	<i>Angophora bakeri</i> & <i>Eucalyptus parramattensis</i>	Zeppel et al. (2008) Australian journal of botany.
Harvard forest data archive	Prospect Hill Tract, Harvard Forest, USA	A set of four deciduous angiosperm tree species	Bassow & Bazzaz (1997) Oecologia.
Jean-Marc Limousin	Sevilleta NWR, PJ rainfall manipulation, USA	<i>Juniperus monosperma</i> & <i>Pinus edulis</i>	Limousin et al. (2013) Plant, Cell & Environment.
Jeff Kelly	Daintree forest, Cape Tribulation, QLD, Australia	A set of three tropical rainforest species	Unpublished data
Jeff Warren	ORNL FACE, TN, USA	<i>Liquidambar styraciflua</i>	Warren et al. (2011) Ecohydrology.
Jesse Nippert	Konza Prairie, KS, USA	A set of C3 and C4 grassland species	Unpublished data
Joana Zaragoza-Castells, Patrick Meir & Owen Atkin	French Guiana	A set of tropical rainforest species	Unpublished data

Joana Zaragoza-Castells, Patrick Meir & Owen Atkin	Tambopata, Peru	A set of tropical species	Unpublished data
Johan Uddling	Rhineland, WI, USA	<i>Betula papyrifera &amp; Populus tremuloides</i>	Uddling et al (2009) Tree Physiology
John Drake	Duke Forest, Durham, NC, USA	<i>Pinus taeda</i>	Drake et al. (2011) Global Change Biology
Jonathan Bennie	Agoufou, Hombori, Mali	A set of African savanna tree species	Unpublished data
David Tissue	Narrabri, NSW, Australia	Cotton	Unpublished data
Kohei Koyama & Kihachiro Kikuzawa	Ishikawa, Japan	<i>Fagus crenata</i>	Koyama and Kikuzawa 2012 Ecological Research.
Kouki Hikosaka	Aobayama, Sendai, Japan	A set of nine angiosperm and gymnosperm tree species	Hikosaka and Shigeno (2009) Oecologia.
Kouki Hikosaka	TOEF, Tomakomai, Hokkaido, Japan	<i>Quercus crispula</i>	Hikosaka et al (2007) Tree Physiology.
Lasse Tarvainen & Göran Wallin	Skogaryd, Sweden	<i>Picea abies</i>	Tarvainen et al. (2013) Oecologia.
Lindsay Hutley & Samantha Setterfield	Wildman River, NT, Australia	<i>Alloteropsis semialata &amp; Andropogon gayanus</i>	Unpublished data
Lisa Wingate	Aberfeldy, UK	<i>Picea sitchensis</i>	Wingate et al. (2007) Plant, Cell & Environment.
Lucas Cernusak	Howard Springs, NT, Australia	A set of evergreen savanna tree species	Cernusak et al. (2011) Agriculture & Forest Meteorology.
Lucas Cernusak	Daly River, NT, Australia	A set of evergreen savanna tree species	Cernusak et al. (2011) Agriculture & Forest Meteorology.
Lucas Cernusak	Dry River, NT, Australia	A set of evergreen savanna tree species	Cernusak et al. (2011) Agriculture & Forest Meteorology.
Lucas Cernusak	Adelaide River, NT, Australia	A set of evergreen savanna tree species	Cernusak et al. (2011) Agriculture & Forest Meteorology.
Lucas Cernusak	Sturt Plains, NT, Australia	A set of evergreen savanna tree species	Cernusak et al. (2011) Agriculture & Forest Meteorology.
Lucas Cernusak	Boulija, QLD, Australia	A set of evergreen savanna tree species	Cernusak et al. (2011) Agriculture & Forest Meteorology.
Lucy Rowland & Patrick Meir	Caxiuana, Brazil	<i>Manilkara spp.</i>	Unpublished data
Maj-Lena Linderson & Teis Nørgaard Mikkelsen	Soroe, Denmark	<i>Fagus sylvatica</i>	Linderson et al. (2012) Agriculture & Forest Meteorology

Mark Broadmeadow	Headley S. London, UK	Three <i>Quercus</i> species	Broadmeadow et al. (1999) Water, Air and Soil Pollution.
Markus Löw	Kranzberg forest, Germany	<i>Fagus sylvatica</i>	Op de Beeck et al. (2010) Agriculture & Forest Meteorology.
Michael Freeman	Soroe, Denmark	<i>Fagus sylvatica</i>	Freeman, M. (1998) PhD Thesis.
Nicolas Martin-StPaul	Les Mages, France	<i>Quercus ilex</i>	Martin-StPaul et al. (2012) Functional Plant Biology.
Nicolas Martin-StPaul	Puechabon, France	<i>Quercus ilex</i>	Martin-StPaul et al. (2012) Functional Plant Biology.
Nicolas Martin-StPaul	Vic la Gardiole, France	<i>Quercus ilex</i>	Martin-StPaul et al. (2012) Functional Plant Biology.
Oula Ghannoum	Brian Pastures Res. Stn, Gayndah, QLD, Australia	A set of C4 grasses	Unpublished data
Paolo de Angelis	Montalto di Castro, Italy	<i>Phillyrea angustifolia</i> , <i>Pistacia lentiscus</i> & <i>Quercus ilex</i>	Scarascia-Mugnozza et al. (1996) Plant, Cell & Environment.
Pasi Kolari	Hyytiälä, Finland	<i>Pinus sylvestris</i>	Kolari et al. (2007) Tellus.
Patrick Mitchell	Corrigin Water Reserve, WA, Australia	<i>Eucalyptus capillosa</i> & <i>Eucalyptus salmonophloia</i>	Mitchell et al. (2009) Agriculture & Forest Meteorology.
Qingmin Han	FFPRI, Tsukuba, Ibaraki, Japan	<i>Chamaecyparis obtusa</i>	Han et al. (2009) Journal of forest research.
Qingmin Han	Mt Fuji, Japan	<i>Pinus densiflora</i>	Han et al. (2003) Tree Physiology.
Maarten Op de Beeck	Tervuren, Belgium	<i>Brassica napus</i> & <i>Brassica oleracea</i>	Op de Beeck et al. (2010) Environmental Pollution.
Sabine Tausz-Posch	AGFACE facility, Horsham, VIC, Australia	<i>Triticum aestivum</i> two varieties	Tausz-Posch et al. (2013) Physiologia Plantarum.
Teresa E. Gimeno	Alto Tajo Natural Park, Guadalajara, Spain	<i>Juniperus thurifera</i>	Gimeno et al. (2012) Tree Physiology.
Victor Resco de Dios	Santa Rita Experimental Range, USA	<i>Eragrostis lehmanniana</i> & <i>Heteropogon contortus</i>	VRD et al. (2012) Perspectives in Plant Ecology, Evolution and Systematics.
Wei Sun	Charleston mesquite site, Tombstone, AZ, USA	A set of mesquite C3 and C4 grass species	Sun et al. (2009) Plant, Cell & Environment.
Wei Sun	San Pedro, Sierra Vista, AZ, USA	A set of riparian C3 and C4 grass species	Sun et al. (2010) Oecologia.
Yusuke Onoda	Hakkoda, Aomori, Japan	<i>Fagus crenata</i> , <i>Lindera umbellata</i> & <i>Magnolia salicifolia</i>	Yasumura et al. (2005) & Onoda unpublished.

432 **Table S2: Estimates of  $g_1$  by different classification schemes.**

Classification scheme	Class	$g_1$ mean	$g_1$ SE	Number of data points	Number of species
a_Pathway	C4	1.62	0.03	1161	38
	C3	4.16	0.01	14001	276
b_Platform	Gymno. tree	2.35	0.02	4732	13
	shrub	3.32	0.05	689	15
	Angio. tree	3.97	0.02	6265	203
	Grass	5.25	0.13	304	20
	Savanna tree	5.76	0.22	339	20
	Crop	5.79	0.04	1672	5
	c_T region	Arctic	2.22	0.07	162
	Boreal	2.19	0.02	917	5
	Temperate	4.31	0.02	11934	75
	Tropical	4.43	0.08	988	189
d_W region	MI < 0.5	3.77	0.03	3328	17
	0.5 < MI < 1.0	4.69	0.04	1673	45
	1.0 < MI < 1.5	3.87	0.03	4313	29
	MI < 1.5	4.02	0.02	4687	186
e_PFTs	C4 grass	1.62	0.03	1161	38
	Ever. gymno. tree	2.35	0.02	4732	13
	Deci. savanna tree	2.98	0.39	30	2
	Shrub	3.32	0.05	689	15
	Ever. angio. tree	3.37	0.03	2828	17
	Trop. Rainforest tree	3.77	0.06	549	167
	Deci. angio. tree	4.64	0.04	2888	19
	C3 grass	5.25	0.13	304	20
	C3 crop	5.79	0.04	1672	5
	Ever. savanna tree	7.18	0.25	309	18

433

434 **Table S3: Model coefficients for  $g_1$  as a function of MI and mGDD<sub>0</sub>.** The model was fitted  
435 with a linear mixed-effects model as  $\log(g_1) \sim \text{MI} + \text{mGDD}_0 + \text{MI} * \text{mGDD}_0$  using different PFTs  
436 as the random effects to account for the differences in intercept among PFTs.

<b>Model</b>				
<b>Variables</b>	<b>mean</b>	<b>SE</b>	<b>DF</b>	
<b>Intercept</b>	0.449	0.289	97	
<b>MI</b>	0.033	0.013	97	
<b>mGDD<sub>0</sub></b>	0.027	0.192	97	
<b>MI*mGDD<sub>0</sub></b>	0.014	0.012	97	

437

438



439 **Supplementary Figure legends**

440 **Fig. S1: Climatic space covered by the Stomatal Behaviour Synthesis Database.** Shown as  
441 a combination of mean annual temperature (MAT; °C ), mean annual precipitation (MAP; mm),  
442 mean annual degree days above 0°C (mGDD<sub>0</sub>; °C) and moisture index (MI).

443

444 **Fig. S2. Residual plot by PFTs for the model:  $\log(g_1) \sim \text{MI} + \text{mGDD}_0 + \text{MI} * \text{mGDD}_0$ .** The  
445 model was fitted using linear mix-effects model with PFTs as the random effect to account for  
446 the differences in intercept among PFTs.

447

448 **Fig. S3. predicted  $\log(g_1)$  as a function of mGDD<sub>0</sub> and MI.** (a) the predicted  $\log(g_1)$  under  
449 different ranges of MI and mGDD<sub>0</sub> presented as partial regression plot. Predictions are from  
450 linear mixed-effects model for  $\log(g_1)$  assuming PFTs as a random effect to account for the  
451 differences in intercept among PFTs. Colour lines represent the predicted  $g_1$  based on fitted  
452 model coefficients (Table S3). Colour dots represent the partial regression predictions at a  
453 given fixed MI or mGDD<sub>0</sub> level.